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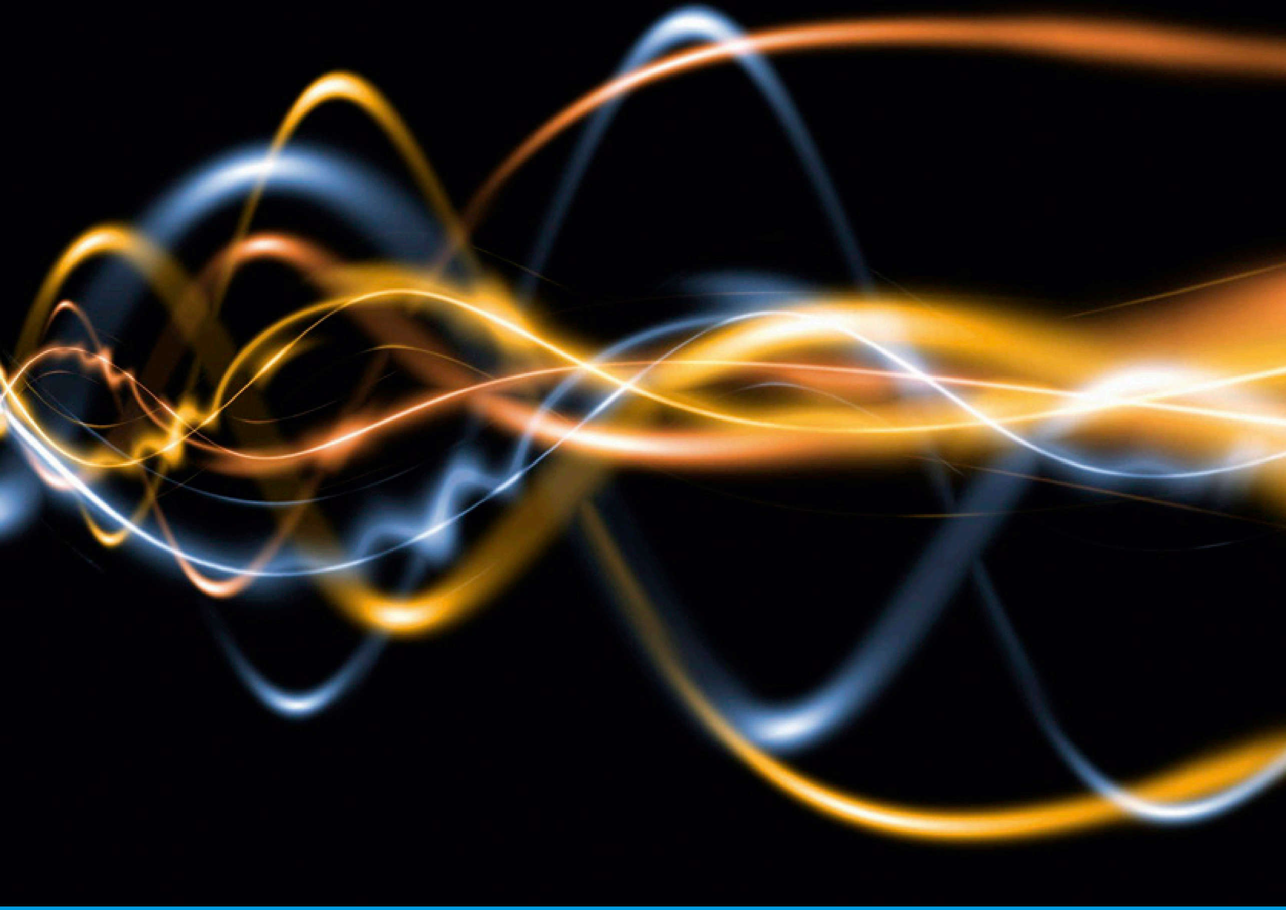

Radio spectrum management: from government to governance

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Peter Anker

Radio spectrum management: from government to governance

Analysis of the role of government in the management of radio spectrum

Proefschrift

ter verkrijging van de graad van doctor

aan de Technische Universiteit Delft,

op gezag van de Rector Magnificus prof.dr.ir T.H.J.J. van der Hagen,

voorzitter van het College voor Promoties,

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Preface

The idea of performing PhD research already arose in 1988 when I graduated as an electrical engineer in the field of avionics at the Technical University in Delft. My supervisors, prof. Goldbohm and prof. Haber tried to convince me to continue doing research after my graduation. I decided to follow their advice, but not as a PhD student but as a researcher at PTT Research Neher Laboratories. With that decision I made a shift from avionics to radiocommunications, a field of expertise that has always fascinated me and it still does.

As a researcher I came to the conclusion that technology in itself is for me not an objective, technology is for me a means to accomplish something else. When I realized that, I decided to make another shift, first to education and later to the ministry of Transport as a policy advisor on mobile communications and frequency management. In 2003, the department on Telecommunications and Post was transferred to the ministry of Economic Affairs and I transferred with it.

I have been working in this field ever since. As being one of the few electrical engineers at the ministry, I became a specialist at the cutting edge of technology and regulations. In 2005, I was one of the main authors of a new Radio Spectrum Memorandum in which we tried to reformulate radio spectrum policy to cope with a combination of technological developments (i.a. mobile broadband and ultra wide band), market developments (i.a. the rise of mobile internet) and further liberalization. After the publication of that Radio Spectrum Memorandum, a new project started on the implementation of this

“Success is being in charge of your lifestyle and creating something you’re proud of, surrounded by people you love”

Troye Sivan,
Australian Singer/Songwriter, 2017

newly formulated policy. This project involved discussions with the stakeholders.

At one of these occasions I met Wolter Lemstra. His questions on our policy rewoke the researcher in me. In the discussions with him, I said that as a policy maker you are somewhat bounded in your analysis and solutions, and that it would be a good idea to have a more fundamental analysis. I added to that if he wanted to perform such an analysis I was very much willing to participate in that effort.

Wolter then asked me if I could give a presentation on the fundamental problems behind spectrum management to the section Economics of Infrastructure, Faculty Technology, Policy and Management at the TU Delft. The presentation went very well and I was asked if I could convert this presentation into a PhD research proposal. Of course, I accepted and devoted much of 2008 to write a research proposal. One of the main reasons that I could accept that offer was that at that time, my two kids were becoming a bit older, giving me a bit more time for myself which allowed me to do research next to my daily work at the ministry. Another important reason was that I felt at home at the section. John Groenewegen, Rolf Künneke, the heads of the section, and the rest of staff and PhD students were very friendly and created a stimulating environment. I will never forget the Friday morning sessions with a presentation and the round of questions followed by an answering and discussion session. They gave me, in the first years of my research, a unique opportunity to learn more about economics of infrastructure and scientific enquiry. Last but not least, I got support from my work to perform PhD Research. They gave me the opportunity to spend one day per week on research.

I would like to thank Richard, Aad, Jean Francois, Wouter, Delphine, Christine and all the others who were present at these Friday morning sessions for insightful and stimulating discussions. A special thanks goes to Rajan Akalu, with whom I had quite a few discussions on the essence of radio spectrum management and to Daniel Scholten and Marloes, who stimulated me to come to Delft and share a desk to work on my thesis for one day a week and occasionally some longer periods when I could take a leave from my daily work. A very special thanks goes to Vic Hayes, the “father of Wi-Fi”, whom I met at the section.

I would like to thank the ministry of Economic Affairs for supporting me all those years. A special thanks goes to Marjolijn Sonnema, who enabled me to start this project and Heleen Uijt de Haag who was very interested and supportive. She stimulated me to finish it. I also should thank all my colleagues who were very understanding and encouraging.

There are many participants of the Nationaal FrequentiebeleidsOverleg and the CRPlatform whom I thank for their support in the discussions. A special thanks goes to Koen Mioulet, one of the co-founders of the CRPlatform and to Jan Kruys with whom I had the opportunity to work together on the subject of generic regulations for license-exempt spectrum.

I also have to thank many international colleagues, especially those at COST TERRA. They provided me an opportunity to present, discuss and develop my ideas on the regulation on Cognitive Radio. I very much liked the workshops in these open settings. A special word of thanks goes to Arturas Medeisis, Keith Nolan, Oliver Holland, Marja Matinmikko, Simon Deleare, Matthias Barrie and Leo Fulvio Minervini which whom I worked closest together. I especially have to thank Oliver who provided me the opportunity to give a lecture during a summer school on Cognitive Radio at Kings College in London.

I also have to thank Joy Farmer, who provided me the motivation and the energy to take the last steps in this long journey. Finally, I have to thank the ones that are dearest to me, my wife Birgitta, my daughter Eva and my son Bastiaan. Without their love and support I could never have made this journey.

I realize that if you make a summary of all those who supported me in this journey there will always be people that you forget. Therefore, to all those anonymous people: thanks!

The trust and (moral) support I received from everyone I mentioned, but also of everyone I forgot, was a source of inspiration and motivation for me.

This journey was long and sometimes tiresome, but I'm proud that I was able to succeed it. It brought me a lot and I wouldn't want to miss it.

Success is a journey, not a destination. The doing is often more important than the outcome.

(Arthur Ashe, American athlete)

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1
Introduction

This thesis is about the role of government in radio spectrum management. Historical developments have led to a situation in which governments have taken a central role in the management of the radio frequency spectrum, i.e. the allocation of frequency bands to specific kinds of use and the assignment of spectrum usage rights to users. Alternative approaches have been proposed to enhance economic efficient use of the radio spectrum through decentralized coordination in the market. With the introduction of decentralized coordination the role of government should shift from a controller of the radio spectrum management process to a facilitator of decentralized coordination in a multi-actor radio spectrum governance process.

Although parts of these alternative approaches have been introduced in the current spectrum management process, with the introduction of license-exempt spectrum access, auctions and secondary trading, governments retained a dominant and central position in the management of radio spectrum and they are still struggling with the implementation of these alternative approaches with more emphasis on decentralized coordination in radio spectrum management.

In this thesis the role of government is analyzed. It starts from the premise that the role of government in spectrum management is broader than only the realization of (economic) efficient use of the radio spectrum. The government is expected to safeguard public interests associated with the use of the radio spectrum, such as a proper functioning of the market and public safety. Hence, the key question is how this shift from governmental control to a decentralized governance regime of the radio spectrum led by private actors can be best realized

"For an active and developed mind free time is nothing more than the freedom to choose its occupation"

Comtesse Diane de Beausacq
French author, 1829-1899

while safeguarding public interests. To address and resolve this question, this thesis provides a contribution to the spectrum management debate from the perspective of the roles of government, a perspective that has been largely neglected in the contemporary debate on radio spectrum management.

1.1 The historical role of government

The radio frequency spectrum[1], which started as an abstract mathematical idea postulated by Maxwell, has now become a resource that is used for the delivery of a broad range of services and applications, for instance, mobile telephony, radio and television broadcasting, maritime radio, research into the (birth of) the universe, radio location and navigation, and even heating food in a microwave oven.
The radio spectrum has become an indispensable resource for the functioning of modern society. All kind of communication and broadcasting services, as part of the economic system, as well as all kind of vital services for society, such as national defense, public safety, disaster warning, weather forecasts and air-traffic control, depend on the use of radio frequencies.

However, the use of this resource is not without limitations. The use of radio waves at a particular frequency by one user will influence simultaneous use of the same, and nearby frequencies by other users in the same geographical area, as radio receivers will have difficulty to distinguish the intended signal from all other signals it receives. This phenomenon is called interference. To manage the problems associated with interference, coordination is needed in the use of radio waves between the various users of the radio spectrum.[2] Historical developments have led to a situation in which the government has taken a pivotal role in the coordination on the use of radio spectrum, by setting up an institutional environment with regard to radio spectrum usage, shortly after exploitation of this resource was made technically possible.

Exploitation of the radio spectrum started around the year 1900 when Marconi, and other private entrepreneurs, took the first steps in the commercial use of spectrum, mainly for ship-to-shore and ship-to-ship radiotelegraphy. Soon after these first private initiatives, a need for coordination on the use of the radio spectrum arose to address monopolization of radio spectrum use and to safeguard safety of life at sea, as can be illustrated with the following summary of the case of the early days of radio.[3]

At the time of Marconi, the radio spectrum was an open and untouched pasture. Marconi was the first to enter this pasture to exploit this common resource. In 1900, he started a business to provide wireless ship-to-ship and ship-to-shore radiotelegraphy as a service. For that purpose he trained his own radio telegraphists and placed them on all ships he equipped with a wireless radio station. These radio telegraphists, or marconists as they were called, were only allowed to communicate with Marconi wireless stations both land based and onboard of other ships (ITU, 1965). By doing so, he created a, very successful, private business using radio waves of a common resource - the radio frequency spectrum.

This monopolistic behavior of the Marconi Company led to governmental involvement in the use of radio

[1] The radio frequency spectrum is the part of the electromagnetic spectrum used for radio transmissions. Currently the radio frequency spectrum is considered to encompass all frequencies up to 3000 GHz, although only the frequency range from 9 kHz up to 275 GHz is internationally allocated to radio services. In the remainder of this text the terms radio spectrum and spectrum are used interchangeable as a shorthand to refer to the radio frequency spectrum. See Annex I for an explanation of the characteristics of the radio spectrum.

[2] The phenomenon of interference is further explained in Annex I.

[3] This case will be described in more detail in chapter 3.

waves. Kaiser Wilhelm of Germany convened an international conference on the use of radio telegraphy. Representatives of nine countries gathered in 1903 in Berlin for the *Preliminary Conference on Wireless Telegraphy* (Kirby, 1995). Complete agreement was not reached, but the Conference drafted a protocol that served as the basis for a future international agreement on the use of wireless telegraphy. Among the articles of the protocol was the requirement that all coastal stations should exchange messages with all ships without distinction as to the system of radio being used (Robinson, 1985).

This preliminary Conference was followed in 1906 by the *first Radio Telegraph Conference of Berlin*. Twenty nine countries adopted the first *International Radiotelegraph Convention*. Two important provisions of the Convention were (1) a requirement to accept all messages from coastal stations and ships regardless of the system used and (2) priority for distress calls. The annex to this Convention contained the first regulations governing wireless telegraphy. It was decided to use two wavelengths corresponding to 1000 kHz and 500 kHz for public correspondence.

The interconnection among radio operators was considered of public interest to support the safety of life at sea. Continuous availability of the service should be assured at all times. This need for rules of engagement and international coordination was strengthened at the next Radio Telegraph Conference which took place in London, shortly after the Titanic disaster in 1912 (Codding, 1952).

In the following years, the uptake in the use of this common-pool resource led to an increase in interference between the various users and services. The uptake of various kinds of applications (especially broadcasting in the 1920s) led eventually to a tragedy of the commons. To solve this tragedy, government took the role of supreme coordinator of the radio spectrum. In 1927 governments agreed on the basic principles on radio spectrum management on which radio spectrum managements is still based.[4]

These principles were laid down in the Radio Regulations (RR), a binding international treaty between nation states, with a voluminous set of rules, recommendations and procedures for the regulation of radio-communications. The Radio Regulations are based on the avoidance of radio interference through the division of spectrum in bands which are allocated to one or more specific services. Some 40 different radio services are defined in the Radio Regulations.[5]

National radio spectrum management is based on the allocations in the RR. The national Spectrum Management Authority (SMA)[6] allocates portions of the radio spectrum to specific services and applications and assigns licenses to users. Usually a license gives an exclusive right to operate on a specific frequency in a specific location or geographic area and under specific technical conditions (e.g., power level, antenna height, antenna location etc.) and possibly other conditions such as service obligations and (network) build-out requirements. The compliance of radio spectrum users with the license obligations is monitored and enforced.

If the demand for radio spectrum within a particular band is considered to be significantly less than the supply, licenses are usually granted on a first come

4 The early history of international radio regulations which led to these principles as agreed upon in 1927 will be assessed in Chapter 3.

5 These radio services include services such as fixed, mobile, satellite, amateur, radio navigation and radio astronomy. See further chapter 3 and Annex I.

6 The term Spectrum Management Authority (SMA) is used to denote the part of the government that is responsible for the allocation of spectrum and the associated spectrum policy for the authorization of spectrum access. The actual arrangements differ among various countries. It may be a responsibility of a ministry, a regulatory body, or it may be a split responsibility between a ministry and a regulatory body.

first served basis. When spectrum demand exceeds the supply, the SMA has to use another mechanism to award the licenses. Increasingly, SMAs have turned to comparative hearings or "beauty contests" and more recently to spectrum auctions (ITU, 2004).

In the spectrum management regime that emerged and evolved all decisions are made by the SMA. Governments make all the key decisions: (1) for what purpose specific parts of the resource may be used (the allocation); (2) who may use these parts (the assignment); and (3) under which conditions. Therefore, this traditional radio spectrum management regime is commonly referred to as Command & Control. This regime has its weaknesses. The two most eminent are:

- Some of the portions of the assigned spectrum are hardly used, and
- The regime is slow in responding to changes in market and technology.

The first point has been validated through various measurements which clearly show that the average occupancy of the radio spectrum is very low (Patil, Prasad and Skouby, 2011). Although, the qualification when a radio frequency is not used is debatable and the observation that there is "no signal present" does not necessarily mean that the frequencies are potentially available for other use. Nevertheless the measurements clearly show that there is ample room for more efficient use of the radio spectrum.[7]

The second point reflects the fact that the traditional spectrum management regime gives preference to the existing services, as new technologies and new types of usage have to adapt to incumbent usage.

In the past, the inefficiencies in radio spectrum utilization introduced by this regime were acceptable. As demand grew, advancements in technology made it possible that (new) higher frequency bands were made available.[8] Consequently, there was no need to deal with those parts of the radio spectrum that were not efficiently used. More recently, demand has grown very rapidly and technological developments has allowed the delivery of new services and devices to serve that demand. However, the opening up of even higher frequency bands is not going in the same pace and does not always provide a solution as not all frequencies are alike.[9] This means that Spectrum Management Authorities more or less ran out of useable radio spectrum to serve the growing demand and to assign radio spectrum for new services and technologies. Hence, services based on new technologies can only be introduced at the expense of radio spectrum for existing services.

In other words, under slow changing conditions the command and control regime oriented towards technical efficient use sufficed. However, this regime has reached its limits in the current environment of growing market demand and fast paced technological change. The command and

7 There are many reasons why parts of the radio spectrum are unused although rights of use have been issued. This may be related to geographical or time differences in demand or the use of guard bands to prevent interference, but it may also be related to the service for which the band is allocated. There are a number of applications which are hard to detect, or are even not to be detected at all in radio spectrum occupancy measurements. Examples are a satellite downlink, frequencies used for distress and alert signals and radio astronomy. Hence, a careful consideration is needed before "unused" radio spectrum is made available for other use. See also Chapter 6 and Anker (2013b).

8 In 1927 only the frequency range up to 23 MHz was allocated; in 1932 this was extended to 30 MHz, since then the upper limit was extended to 200 MHz in 1938, 10.5 GHz in 1947, 40 GHz in 1959, 275 GHz in 1971 and 1,000 GHz in 2000, although there are no allocations made to specific radio services above 275 GHz.

9 More bandwidth (capacity) is available in the higher frequency range, but higher frequencies have a shorter range, ceteris paribus. E.g. for mobile communications the ideal frequency range is roughly 1-3 GHz. Below this frequency range there is not enough data throughput capacity available and above this range the coverage area of the base stations becomes too small.

control regime is regarded as too slow to react, as (economically) inefficient and as biased towards the status quo and hence towards the vested interest of the incumbent users. Faced with increasing pressures from a growing market demand and rapid technological change, a growing number of countries have started a process of liberalization; replacing the traditional centralized command and control regulatory approach with more market-based approaches in certain parts of the radio spectrum. The key question that remains is to what extend market forces can be relied upon and to what extend there remains a need for governmental involvement to safeguard public interests.

1.2 Alternative radio spectrum management approaches

The weaknesses of the current radio spectrum management regime combined with the growing demand and the trend towards liberalization have triggered a debate on the best alternative approach for spectrum governance in which coordination activities are left to private initiatives to overcome the problems associated with the old regime based on command and control. The focus of these approaches is on improvement of economic efficient use of the radio spectrum. These alternatives are based on one of two principle alternative approaches: (1) spectrum management based on property rights; and (2) spectrum management based on a spectrum commons.

1.2.1 *A radio spectrum management approach based on property rights*

The traditional radio spectrum management regime was first challenged by Leo Herzel in 1951.[10] In a comment about standards for color television he wrote (Herzel, 1951):[11]

The most important function of radio regulation is the allocation of a scarce factor of production-frequency channels. The FCC has to determine who will get the limited number of channels available at any one time. This is essentially an economic decision, not a policing decision.

Later, Herzel suggested that the channels should be leased to the highest bidder (Coase, 1959). This idea was worked out and explained in more detail by Ronald Coase in 1959. He posed that the allocation and assignment of radio spectrum should be determined by the forces of the market rather than being a result of government decisions. Radio licenses should be bought and sold like any other scarce resource in our economy, such as land or labor. Rights should be assigned to individual users via an auction with the provision that these rights can subsequently be traded in an open market. The market should not only decide who will have the license, but also what services should be provided. If a business model would fail, the rights to the use of the radio spectrum could be bought by another operator with a different, more successful model or by a new entrant. The problem of interference could be solved by a clear initial definition of these rights in terms of the amount of interference the owner is allowed to make. The specification of the rights should not only come from strict regulations but it should also be possible

10 There were already others who deliberated a property rights system in spectrum. One of the first deliberations is made by Rogers (1924), but the idea of introducing property rights in spectrum is generally attributed to Leo Herzel. This idea was further expanded by Coase in his article of 1959.

11 The Federal Communications Commission (FCC) is the independent U.S. government agency responsible for the regulation of interstate and international communications.

to change those rights as a result of transactions in the market. This allows the owner to make arrangements with his neighbors about the level of interference they are willing to tolerate and for what price (Coase, 1959).[12]

Coase's idea was at first not taken seriously by the FCC. According to Hazlett (2001: v):
In 1959 the Federal Communications Commission invited economist Ronald Coase to testify about his proposal for market allocation of radio spectrum rights. The FCC's first question: 'Is this all a big joke?'.

Nonetheless, since then the idea of an approach based on property rights has been discussed among economists[13], but a property rights approach was only considered seriously by SMAs in the early 1990s.[14] At that time there was a broad consensus in politic thinking towards deregulation; the introduction of market forces was considered in a number of infrastructures that had been heavily regulated in the past, including mobile telephony (Hazlett, 2001). Various countries chose to auction the spectrum rights for mobile telephony (Cave, Doyle and Webb, 2007).

This market-based property rights approach is characterized by three interlinked elements, (adapted from Baumol and Robyn, 2006):

- Well-defined exclusive rights to the use of radio spectrum;
- A market-type mechanism such as an auction for an initial allocation of spectrum rights;
- A secondary market in which these rights can be sold or leased.

Tradability of the property rights will ensure that the radio spectrum is used economically efficient, as trading is expected to take place if the rights can be used more profitably by another user (Baumol and Robyn, 2006).

The creation of the market requires careful attention to the details. Especially, the definition of the rights, or to put it more precisely, defining the amount of interference that may be caused to neighboring users under these rights is a challenging task (Cave, Doyle and Webb, 2007; Crocioni, 2009). Other aspects that have to be addressed in the definition of the rights are the frequency range, the power level, the location, time and possibly use restrictions as to the type of service that can be provided (Kwerel and Williams, 2002; Faulhaber, 2005).

This approach entails an institutional solution to the coordination problem. Decentralized coordination among participants takes place in a market created by government.

1.2.2 A radio spectrum management approach based on unlicensed access

In the 1980s a regulatory novelty was introduced. A few specific frequency bands were assigned for specific types of communication equipment without the need for an individual license. This equipment can be used as long as it complies with some specific rules (e.g. maximum power level and usage restrictions). Among the first types of equipment that could be used without a license were cordless telephones in the mid-1980s. These unlicensed bands have attracted new types of applications where the communications is generally short range and the devices are numerous. Probably the best known and most successful example is Wi-Fi (Anker and Lemstra, 2011).

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[12] Coase generalized this treatment of interference to other fields where externalities are involved in his seminal article "The Problem of Social Cost" (1960). One of the articles for which Coase eventually would be awarded the Nobel Prize.

[13] See note 6 of Baumol and Robyn for an overview of references (2006).

[14] New Zealand was probably the first country that experimented with the definition of long-term tradable property rights to radio channels, and the first country to auction these rights to the highest bidder (Mueller, 1993).

Inspired by the success and popularity of systems operating in the unlicensed bands an approach where much more spectrum is made license-exempt was advocated. The proponents of a so-called spectrum commons[15] argue that technology can solve the interference problem without the need for exclusivity (Noam, 1998; Benkler, 2002; Buck, 2002). Usually, they build their case on some existing interference mitigation techniques as well as some new techniques and protocols to make more efficient use of the radio spectrum.

The commons proposals generally have the following characteristics:

- Smart radios are used with built-in techniques and rules (etiquettes) to reduce interference;[16]
- Everybody can use the radio spectrum as long as the etiquettes are followed.

In this approach, technology is used to solve the coordination problem associated with interference. The necessary coordination on the technical rules of engagement takes place in the standardization of wireless equipment, with the creation of a market for equipment as a result.

1.2.3 The merits of both approaches and the remaining issue

Both camps realized that their proposed solution was not the complete answer to the issue. The advocates of the spectrum commons realize that the technologies needed to make full advantage of the commons are not fully developed and that property rights can be a solution for the short term. On the other hand, the proponents of a property rights approach acknowledge that a spectrum commons approach might also work. However, they claim that this is only the case as long as radio spectrum is not scarce. The demand growth will eventually lead to scarcity and the necessity of a property rights regime (Hazlett, 2001; Faulhaber and Farber, 2003). In their view, the solution to this resource allocation problem is institutional, rather than technical. Hence, Benkler suggested to carry out a ten year experiment to make clear which solution is superior (Benkler, 2002).

Although there is disagreement about the best solution, there is agreement on both sides about a number of items:

- The inefficiency of the traditional command and control regime;
- (Economically) efficient use of the radio spectrum should be promoted;
- Both a commons (unlicensed use) and exclusive licensing will have a role to play and will co-exist;
- Innovation should be encouraged;
- The new regime should be able to accommodate changes in demand and technology.

The main disagreement is on the cause of the problem within the command and control regime. The property rights advocates belief that regulation is the problem whereas commons advocates think that exclusive licenses are the problem (Faulhaber, 2005, 2006). Since both camps recognize the need to impose some rules on the use of radio spectrum to deal with interference, it can also be regarded as a question of who sets the rules to mitigate interference: Are the rules to be drawn by the SMA, the licensee or a non-governmental body that is open to anybody (Benkler, 1998, 2002; Buck, 2002; Faulhaber, 2005)?

15 In the spectrum management debate, the term spectrum commons and unlicensed access are more or less used interchangeably. However, the first term “commons” only refers to a resource that is shared by a group of users whereby the sharing faces two typical problems: difficulty of exclusion and rivalry between the users. Therefore, I prefer to use the term unlicensed access which refers to a regime to manage the shared use of the resource though general restrictions on the type of use or users. The difference between a common pool resource and a regime to regulate a common pool will be further explained in chapter 2.

16 These techniques include the reduction of power level to just the level needed, listen-before-talk, selection of a free channel and the use of modulation types that are robust to interference.

The debate on the overarching regime is still ongoing. Most of this debate is on a fairly high level of abstraction. The supporting empirical evidence is scarce and mostly anecdotal (Ting, Wildman and Bauer, 2005; Cave, Doyle and Webb, 2007). Most of the contributions come to the conclusion that it is a matter of the right combination. Both a commons (unlicensed use) and exclusive licensing will have a role to play and will co-exist (Bauer, 2002; Cave, Doyle and Webb, 2007; Pogorel, 2007). Various authors also refer to a combination in which a spectrum commons can be implemented in a regime based on property rights in the form of *non-interfering easements* in which all property right owners must accept the use of their radio spectrum by anyone who does not interfere with the use of the rightful owner (Faulhaber and Farber, 2003).

That there is no definitive outcome of the debate can be seen in the approach taken by SMAs. On the one hand there is a trend towards flexibility in the form of the use of spectrum auctions and the introduction of tradable rights (ITU, 2004; ERO, 2006). On the other hand, there is a number of countries which reduce the number of licenses in favor of license-exempt use. At the moment there are at least two different types of spectrum commons used (Wellenius and Neto 2007):

- The *license-exempt* approach in which anybody can use a designated band without individual authorization. The authorization of use of the band is accompanied by some technical limitations and/or restrictions on the kind of usage, to prevent interference among license-exempt users and to protect other users of the band. The best known example of this type of spectrum commons is the 2.4 GHz band, which can be used for a number of applications, including Wi-Fi, cordless telephones, baby monitors and wireless headsets.
- The *restricted commons* approach. In which only qualified users have access to the band, which they share. Examples are amateur radio and maritime radio where many individual authorized users share designated bands, without individual licenses.[17]

In the debate on the overarching regime, it should be realized that the three approaches, private property rights, unlicensed access and command-and-control, should be seen as complementary, each with its own unique strengths and weaknesses. Each will have a role to play in a multi-actor spectrum governance structure. The question is how this structure can best be realized, how the right balance of the approaches is made within this structure and if and how adaptive efficiency can be realized, i.e. how the governance structure can facilitate changes in market needs and technology.[18]

However, the current debate focusses on the coordination needed to realize economic efficient use of the radio spectrum. Coordination to determine who (or what device) is allowed to access spectrum is either based on a market for private property rights or on the use of smart technology. They provide an institutional solution (private property rights) or a technical solution (smart technology) to determine who (or what device) is allowed to access spectrum to realize economic efficient use of the radio spectrum. Notwithstanding the need for governments to assure economic efficient use of the radio spectrum, the current debate ignores other roles the government has in this context, i.e. its responsibility to assure the

17 Wellenius and Neto use the term private commons. I changed this term because a private commons may also refer to a commons under a private property regime.

18 North (1990) makes a distinction between two types of competitive efficiency. Allocative efficiency ensures the maximization of possible wealth through the allocation of given resources and constraints. Adaptive efficiency allows a society to develop new and better ways of doing things and to respond to new conditions and new knowledge.

proper working of the market and the safeguarding of public interests.

To tackle the coordination problem related to spectrum management, there is a need to take a step back and take a closer look at the core of the problem at hand. It appears that at the center of the coordination problem is the necessity for coordination to deal with interference between various users of the radio spectrum while safeguarding the public interests.

The coordination can be left to the government as has been done in the command & control regime. Coordination can also be left to the market, based on property rights. In that case, an institutional approach is taken to address the coordination problem by creating a market for spectrum access. In this case, there seems to be a perfect fit for situations in which frequencies are an input function to deliver infrastructure-based services, such as mobile telephony. A third possibility is to take an technological approach to deal with the coordination problem. In this approach a spectrum commons is used to create a market for equipment. A perfect example of this approach can be found in the standardization of Wi-Fi. The development and standardization of Wi-Fi took place based on a private initiative largely outside the scope of control of governments.

The three axis of coordination - governments, market and technology - are shown in Figure 1-1. In this figure it is assumed that the amount of coordination required is independent of the approach taken.

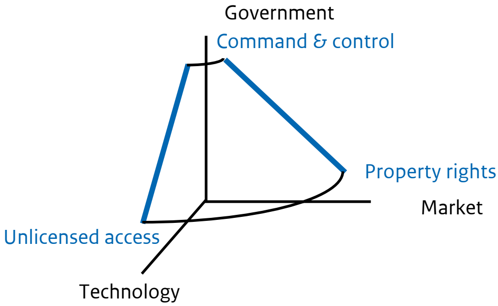

Figure 1-1 The three dimensions of coordination.[19]

In positioning the case in this way the major challenge is becoming apparent: Will private actors assume the necessary coordination efforts if governments reduce their coordinating efforts? Will the resulting coordination lead to economic efficient use of the radio spectrum? How can the public interest be safeguarded if private actors coordinate the use of the radio spectrum? What type of coordination can be left to the market or other private initiatives, and what roles will remain for governments with respect to these coordination activities?

1.3 Emerging technology as an additional challenge

Radio spectrum management is made even more difficult because there are a number of new disruptive technologies emerging that do not fit very well in the current regime of spectrum management. A technology of particular interest in that respect is cognitive radio (CR). A cognitive radio is a smart device that can change its transmission parameters based on information of its radio spectrum environment. Cognitive radios have the ability to recognize unused parts of the radio spectrum that are assigned to conventional users and adapt their communication strategy to use

[19] All figures are from the author, unless stated otherwise.

these unused parts while minimizing the interference that is caused to the conventional users.[20]

Cognitive radio has been closely linked to the spectrum commons. Advocates of the commons see cognitive radio as a technological enabler to realize a spectrum commons (Faulhaber, 2005). However, technologies such as cognitive radio do not favor one radio spectrum management approach over another. Cognitive radio can be used in both radio spectrum management approaches, as it can also be used to facilitate an efficient market-based approach (Anker, 2010b).

At the moment, the possibilities for sharing radio spectrum between various users or applications are based on a static analysis and decision by the spectrum management authority. CR technology provides the possibility to shift these decisions to the technology and/or the users of spectrum (Brito, 2007; Anker, 2010b). It enables the possibility to (dynamically) adapt access to radio spectrum to changes in demand. This will make more dynamic and flexible use of the spectrum possible. An important consequence is that cognitive radio can play a role in a paradigm shift from static radio spectrum management to dynamic spectrum access (DSA) and management (Nekovee, 2006; Olafsson, Glover and Nekovee, 2007; Anker, 2010b).

1.4 Research question

Historical developments have led to a situation in which government has taken a central role in the management of the radio frequency spectrum. Government is in total control over who uses the radio spectrum, for what purpose and under which conditions. The regime is based on the separation of the various radio services to avoid interference and hence based on technical efficient use of the resource. This traditional spectrum management regime has two weaknesses: (1) significant parts of the spectrum are hardly used; and (2) the regime is slow in responding to a changing environment, in terms of technological and market developments. The current regime for spectrum management has reached its limits in dealing with the still growing demand for spectrum.

In the current debate, radio spectrum management is treated as an issue of coordination to mitigate interference for which different solutions are possible. Two alternative approaches have been proposed to replace or to be applied next to governmental control to improve the management of spectrum: (1) property rights; and (2) a spectrum commons, with restrictions on the type of use or users. Although elements of both alternative approaches have been implemented, governments are still struggling with the proper implementation of these approaches and they have retained a dominant role in spectrum management.

The resulting mixed regime, combining command-and-control with property rights and commons approaches, is still a top down process with many rigidities and a government in control which could be improved upon (Anker, 2010b; Freyens and Alexander, 2015). A clear example can be found in the regulation on unlicensed access in Europe. The European regulations are very application specific, favors one type of applications above the other, resulting in an unnecessary barrier for new and innovative applications (Kruys, Anker and Schiphorst, 2016).

Although both alternative approaches proposed are quite different in their solution, they are characterized by a single denominator, deregulation. Both alternatives propose to shift responsibilities for the use of the spectrum from government to

[20] These unused parts are often called white spots. An example of white spots are the empty spaces between the TV channels. The actual size and frequency range of the white spot will vary with the geographical location.

private actors, i.e. a shift from governmental control of the radio spectrum to governance of the radio spectrum.

Governments are in a process of further deregulation with the introduction of more flexible use of the spectrum and applying technology neutrality. As an example, this shift towards further liberalization is clearly shown in the policy objectives of the Dutch government as stated in 2005:[21]

The future radio spectrum policy should provide for the further liberalisation of spectrum use and adapt more rapidly to changing market conditions and technological developments; this can be achieved by more flexibility. (p.5)

...

The radio spectrum policy should contribute to economic growth, market-based conditions and innovation, without ignoring other, non-economic interests (p.5);

...

This Government ... maintains the principle of effective frequency use. This means that frequencies must be allocated, assigned and used effectively. This involves both efficiency – not using more frequencies than is necessary for a specific application – and effectiveness – having sufficient frequencies to achieve the intended economic, social and cultural ambitions. (p.8)

...

This Government is also of the opinion that the users themselves may be given the responsibility to coordinate frequency use to a far greater extent than in the current situation, as this may give quite a boost to innovation and flexibility. The latter could relate to licence-exempt as well as licensed use of frequencies. (p.12)

(Ministry of Economic Affairs, 2006)

The same emphasis on further liberalization of radio spectrum use can be found in other European countries and is also part of the regulatory framework for electronic communications in the European Union.[22] In the preamble to the regulation is stated (EC, 2009: 39, preamble 24):[23]
"Radio frequencies should be considered a scarce public resource that has an important public and market value. It is in the public interest that spectrum is managed as efficiently and effectively as possible from an economic, social and environmental perspective, taking account of the important role of radio spectrum for electronic communications, of the objectives of cultural diversity and media pluralism, and of social and territorial cohesion. Obstacles to its efficient use should therefore be gradually withdrawn."

Deregulation changed the primary objective of governments with regard to radio spectrum management. The primary objective changed from technical efficient use to economic efficient use. The two alternative approaches of spectrum management, property rights and the spectrum commons are both intended to realize this objective of economic efficient use by shifting the coordination from a top-down process centered around the separation of services with the government in control towards decentralized coordination in the market. Decentralized

[21] This shift was made with the publication of the Spectrum Policy Memorandum in 2005 (in Dutch). The cited official translation was published in 2006. In 2016, a new Spectrum Policy Memorandum was published. Although this new Memorandum made some changes in the objectives of radio spectrum policy, this objective of liberalization was not fundamentally changed.

[22] DIRECTIVE 2009/140/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 November 2009 amending Directives 2002/21/EC on a common regulatory framework for electronic communications networks and services, 2002/19/EC on access to, and interconnection of, electronic communications networks and associated facilities, and 2002/20/EC on the authorisation of electronic communications networks and services.

[23] The regulatory framework is in a process of revision. The European Commission proposes to replace the framework by a European Electronic Communications Code (COM (2016) 590 final/2). In this EECC, the term public interest is no longer used, but replaced by the term general interest, and made explicit as *democratic, social, linguistic and cultural interests related to the use of frequencies* (p 57, recital 101).

coordination in the market is supposed to direct the resource to its economically most efficient use.

This focus on (economic) efficient use can also be found in the key purpose of spectrum management as defined by Cave, Doyle and Webb (2007: 3): *"The key purpose of spectrum management is to maximize the value that society gains from the radio spectrum by allowing as many efficient users as possible while ensuring that the interference between different users remains manageable."*

The current debate on the best way forward in radio spectrum management is centered around solutions to control interference with the primary objective to realize (economic) efficient use. However, the current debate on the alternative approaches disregards the fact that a government may also have other public objectives to be realized by spectrum management. This is illustrated by the historic example of the introduction of radio communications by Marconi, in section 1.1. This can also be observed in the objective of the Dutch government on spectrum management as quoted above. Radio spectrum should not only be used (economically) efficient, its use should also be effective "*to achieve the intended economic, social or cultural ambitions"* (Ministry of Economic Affairs, 2006: 8).[24] The need for efficient and effective use can also be found in the text from the legal framework within the European Union quoted above.

This thesis is intended to provide a contribution to the debate on radio spectrum management by taking account of this role of government in radio spectrum management. It is a role of government that is largely neglected in the current discourse on the way forward for radio spectrum management. When this role is taken into account, governments face a dilemma in the implementation of these alternative approaches, i.e., if governments relax their control over the use of the radio spectrum to realize economic efficient use. On the one hand prevailing policy suggests a shift in control to enable (economic) efficient use of the spectrum as a scarce shared resource available to the society at large and on the other hand they are uncertain whether private actors will develop the necessary degree of self-organization required to meet the objective of efficient and effective use of the radio spectrum. Hence, the key question becomes how alternative approaches aimed at economic efficient use of the radio spectrum can be realized while safeguarding the public interest.

Although the term public interest is commonly used, its meaning is non-trivial. The literature shows at least five different approaches to understanding the public interest (Pal, Maxwell and Lussier, 2004: iv):

- *Process: The public interest arises from, and is served by, fair, inclusive, and transparent decision-making procedures.*
- *Majority Opinion: The public interest is defined by what a reasonably significant majority of the population thinks about an issue.*
- *Utilitarian: The public interest is a balance or compromise of different interests involved in an issue.*
- *Common Interest: The public interest is a set of pragmatic interests we all have in common such as clean air, water, defense and security, public safety, a strong economy.*
- *Shared Value: The public interest is a set of shared values or normative principles*

In the context of this research, the public interest is best described by the substantive common interest as stated above.

Bozeman (2007: 12) defines the public interest as *"the outcomes best serving the long-run survival and well-being of a social collective construed as a "public"*. He sees the public interest as a general encompassing term focused on outcomes not on policies, intentions or specific action. It is an ideal concept that can be used to motivate specific policy

24 The Radio Spectrum Policy of the Netherlands has been revised in 2016. However, the primary objective of both efficient and effective use of spectrum remained (Ministerie van Economische Zaken, 2016).

or action. The public interest is closely related to "public values" which have a specific identifiable content. He defines "public values" as (p. 13):
"A society's 'public values' are those providing normative consensus about (a) the rights, benefits, and prerogatives to which citizens should (and should not) be entitled; (b) the obligations of citizens to society, the state and to one another; and (c) the principles on which governments and policies should be based.

Public values are often used in the context of sectors in which the role of government has been reduced. The question then is whether public values are safe in private hands. Jørgensen and Bozeman (2002: 65), for example, argue that *"privatization and contracting out often have the effect of eroding public values"*. Public values are thereby seen as those values government seeks to secure in liberalized and privatized sectors. The central idea is that the government is responsible, either directly or indirectly, to safeguard substantive public values such as universal services, continuity of supply, quality of service, affordability, privacy and consumer protection (Bruijn and Dicke, 2006).

In the context of the research question we will use the more encompassing term "public interest" for the following reasons. First, radio spectrum management is not only about preserving public values in the privatized utility sectors, such as mobile communication services and broadcasting services. Radio spectrum management also has to deal with the use of radio spectrum of what is seen as a public task, such as defense and air traffic control. Secondly, that the government is responsible, does not mean that there is always specific action required by the government. It can be regarded as an outcome that the government is striving for. Whether there is a need for specific action to ensure the public interest remains to be seen.
Given the fact that governments are striving for (economic) efficient use of spectrum, the question is to what extend public interests are at stake in the coordination activities with regard to the management of radio spectrum and whether there is a role of government to safeguard these interest if an approach is chosen of economic efficient use with decentralized coordination.

This leads us to the following research question and related sub questions:

How can economic efficient radio spectrum usage be realized, while safeguarding the public interest?

1. What are the coordination activities that have to take place in the governance of radio spectrum?
2. What is the role of government in these coordination activities?

In answering this research question, this thesis starts from the premise that radio spectrum can be regarded as a common pool resource. This is a resource that is shared by a group of users, whereby the sharing faces two dilemmas: (1) it is difficult to exclude anybody; and (2) the use of the resource by one individual affects the use by another individual. In the case of spectrum, the latter characteristic of the resource refers to interference. The use of radio waves at a particular frequency by one user will influence the use of the same and nearby frequencies by other users at the same time, as radio receivers will have difficulty to distinguish the intended signal from all other signals it receives.[25]

Hardin (1968) explained that a common pool resource faces the risk of the "tragedy of the commons", as will be discussed further in chapter 2. Shared use of the resource may lead to over-consumption, i.e., the appropriation of the resource exceeds its ability to be provisioned or

[25] The area over which a transmission can disturb reception of other transmission depends on i.a. the frequency range and the transmit power. This area can be quite large for high power high tower broadcasting stations. See further Annex I.

replenished. Hardin recognized two solutions to overcome this "tragedy of the commons". Firstly, government can constrain consumption of the shared resource by directly managing or regulating its use. Alternatively, government can establish a system of private property rights delineating ownership of the resource.

Ostrom devoted most of her career to show that there is a rich variety of property rights regimes possible for shared resources to overcome this tragedy of the commons without the need for governmental involvement. Key to her findings is that the tragedy of the commons presupposes that decisions by the users of the shared resource are made independently. Other solutions are possible if users coordinate their action. Sustainable governance of the resource requires cooperation and coordination among the members of the group that share the resource. Hence, to answer the research questions a closer look to the necessary coordination activities is required, to investigate under which circumstances coordination activities can be performed through market forces or can be left to private initiatives.

Historic case studies will be used to analyze the coordination activities required in radio spectrum management. These case studies will be used to answer the two sub questions. An analytical framework will be used to organize this investigation by specifying the general sets of variables of interest and their relationships. It provides a coherent structure to the analysis of the historic cases (Rapoport, 1985; Ostrom, 2005b). The analytical framework used is the "institutional analysis and development framework" (IAD) as developed by Elinor Ostrom and others. The IAD framework has been developed to enable systematic analysis and design of 'institutional arrangements' and to compare alternatives (Ostrom, 2007b). This will be further explained in chapter 2.

This thesis is divided in three parts. The first part describes the problem and the analytical tools to tackle the problem. The second part applies these analytical tools to analyze selected historic cases in the governance of spectrum. This part ends with intermediate conclusions, which allow answering the two sub questions. The third and final part will use the outcome of the second part to provide an answer to the main research question. This part of the thesis will provide conclusions and recommendations for the governance of the radio spectrum. The structure of this thesis will be further explained at the end of chapter 2.

2

Theoretical framework: Not only institutions matter

The focus of this thesis is the proposed shift in responsibilities from government to private actors. If such a shift is made, government will no longer be in full control of the coordination activities that have to take place. Therefore governance problems associated with collective actions to steer, regulate or organize economic activity will have to be addressed. As Chhotray and Stoker put it *"Governance is about the rules of collective decision–making in settings where there are a plurality of actors or organizations and where no formal control system can dictate the terms of the relationship between these actors and organizations* (2009: 3).[26] In this definition, there is a clear differentiation between the term governance and government, while in the past the two words were more or less used as synonyms. The possibility of a lack of formal control

[26] In economics the term governance can have many different other meanings (Rhodes, 1996). Most notably is the use of the word governance to refer to how firms and corporations are steered and organized. This is commonly known as corporate governance.

"Most modern economic theory describes a world presided over by a government ... like the US Cavalry in a good Western, the government stands ready to rush to the rescue whenever the market "fails"... Private individuals, in contrast, are credited with little or no ability to solve collective problems among themselves. This makes for a distorted view of some important economic and political issues."

Sugden, 1986

by government has become a crucial aspect of the governance concept (Rosenau, 1992; Rhodes, 1996).

The role of private actors is becoming more important in the governance of the radio spectrum. In this collective decision-making private actors will pursue their own goal. Their goal is not necessary in line with the goal of the government, being efficient and effective use of the radio spectrum. Hence, because of this overarching goal, governments will continue to play a role in radio spectrum governance, although their role will be shifting. In this thesis the incentives and triggers for coordination by public and private actors are explored to assess the new role of government in the governance of radio spectrum. It is acknowledged that a variety of successful institutions exist to guide private actors in the governance of spectrum or any other common pool resource.

In chapters 3 and 4 of this thesis a deeper analysis of various institutional arrangements and their impact on collective action in the governance of the radio spectrum will be provided. This chapter provides the theoretical framework for that analysis. The starting point for this theoretical framework can be found in institutional economics. Economics is the study about the principles that govern the allocation of scarce resources;[27] i.e. the efficient or optimal production and distribution of these scarce resources.[28] Institutional economics is the part of economics that deals with the analysis of the role of institutions within the economic system.

This chapter starts with a brief introduction into the role of institutions in the economic system and of institutional economics. From there on it will be explained what is meant by institutions in the context of this thesis, what other factors are of importance to explain coordination activities between actors in a common pool resource, such as the radio frequency spectrum, and how these coordination activities can be analyzed. This is followed by an explanation of the role of case studies in the analysis of the required coordination activities in the exploitation of the radio spectrum. The chapter ends with a more detailed explanation of the structure of this thesis.

2.1 Institutions matter

For any resource, including the radio spectrum, the primary economic objective is to maximize the net benefits to society that can be generated from that resource. This is what economists refer to as an economically efficient distribution of the resource. There are various definitions of what is meant by an efficient distribution. Often the concept of Pareto efficiency is used. A distribution of resources is defined as Pareto efficient or Pareto optimal when

[27] There are numerous definitions of what economics is, but a common element in them is the management of scarce resources. See Backhouse and Medema (2009) for an introduction in this matter and Blaug (1997) for a comprehensive explanation of various perspectives of what economic theory is about and how the perspective has changed over time.

[28] Allocation has a slightly different meaning in economics than in spectrum management. In spectrum management allocation of spectrum is only about the distribution of the various radio services to the frequency bands and not about the distribution to the users themselves. The distribution of spectrum usage rights (for a specific radio service to which the band is allocated) over the users is called assignment. To avoid confusion, the term distribution will be used to refer to the term allocation as used in economics. The term allocation will be used in its meaning of an allocation to a radio service as used in spectrum management (see also chapter 3 and Annex I for the difference between allocation and assignment in radio spectrum management).

any (additional) change in the distribution of the resource to make any consumer or firm better off is impossible without making another consumer or firm worse off. Pareto efficiency has three components: (1) Productive or technical efficiency: goods and services are produced in such a way that resources are used efficiently; (2) allocative efficiency: an optimal distribution of goods and services which takes consumer's preferences into account; (3) dynamic efficiency: production processes and products are innovated over time to reduce costs and to take account of changes in consumer's preferences (Sandler, 2001; Cave, Doyle and Webb, 2007).

In this definition efficiency is related to the preferences of consumers for the goods and services provided. Standard neoclassical economics is built on the assumption that consumers act fully rational, that consumers make their decisions based on complete and relevant information, that firms that produce and distribute these goods and services exist only to maximize profit, and that governments act flawless in the interest of their inhabitants and transactions are costless and instantaneous (Sandler, 2001; Ménard and Shirley, 2005).
In such a world, there is no need for governmental involvement to come to an optimal distribution of property rights. Trading of these rights in the market will occur if the distribution is not optimal, i.e. market forces will realize an optimal distribution. In such a simplistic view of the world predictions can be made about the optimal production and distribution of goods and services. It will offer insights into economies of scale and scope. However, neoclassical economics doesn't shed any light on questions such as why firms exist, how they are shaped, and what the role of the government is.

This started to change in 1937. In that year Ronald Coase published his seminal article "The Nature of the Firm". In that article, Coase showed that basic neoclassical economic theory was incomplete, because it neglected the costs of entering into the market, executing contracts and managing organizations. Such costs are commonly referred to as transaction costs. He posed that it was the avoidance of the costs of carrying out transactions through the market that could explain the existence of the firm, i.e. firms are an alternative form of coordination next to the market. Firms will for instance have to decide to buy intermediate goods (on the market) or make these goods by themselves. He argued that an optimal amount of coordination is performed within the firm. A firm can only continue to exist if it performs internal coordination at a lower cost than the transaction in the market would incur. In an efficient economic system there are not only markets but also firms of the appropriate size. With that he introduced a new form of efficiency for the firm as part of the firm's objectives next to lowest production costs per unit, achievement of the lowest transaction cost (Coase, 1937; 2005).

In 1960, Coase published another seminal article "The Problem of Social Cost" (Coase, 1960). In that article Coase tackled the prevailing thought that some sort of government action is needed whenever a negative externality is involved; which means that someone's action has a negative effect on someone else's costs and benefits which is not compensated for. A good example of a negative externality is interference.[29] Due to interference, the use of the radio spectrum by one user can have a negative effect on the use of the radio spectrum by other users.[30] Coase showed that if the transaction costs

29 Other examples are pollution of air and water by manufacturing plants. The pollution will give rise to costs on others which will not be reflected in the prize of the goods produced by the manufacturing plant.

30 Interestingly, this article is based on a study Coase did on the governance of spectrum. In his article "The Federal Communications Commission" (1959) he posed that the allocation of spectrum should be determined by the forces of the market rather than as a result of governmental decisions.

are zero, the necessary arrangements to compensate for a negative externality can be negotiated between the concerned actors themselves and registered in a change of the property rights involved. In that case there is no need for government involvement, other than the initial definition of property rights and the arbitration of disputes (Coase, 1959). In other words, in a world of zero transaction costs, an optimal distribution of property rights to fully internalize the externality can be arranged by the market itself. However, in a world with positive transaction costs, an optimal distribution of property rights will not come about because transaction costs will prohibit full internalization of the externality. This will have an effect on the efficient use of the resource and therefore on the efficiency with which the economic system operates.

Coase argued that governments should provide a legal system in which property rights are clearly defined and enforced. These rights should be assigned to those who can use them most productively with incentives that lead them to do so. In order to discover and maintain such a distribution of rights, the costs of their transfer should be kept as low as possible, through clarity in the law and by making the legal requirements for such transfers as effortless as possible. As a result, the legal system will have a profound effect on the efficient use of a resource and therefore on the performance of the economic system (Coase, 1960; 2005). Coase (1960) showed not only a relationship between economics and legislation but he also gave a fundamental reason for governmental involvement, being the lowering of transaction costs.

In summary, in a world with (non-zero) transaction costs, governance structures matter for efficiency outcomes (Coase, 1937) and legal rules matter for efficiency outcomes (Coase, 1960). Coase therefore came to the conclusion that the institutions of a country, such as its legal system, its political system and its social system, determine its economic performance. With this conclusion, Coase brought the importance of institutions and the embeddedness of the economic system in a broader societal system to the attention of mainstream economists.[31]

2.2 Institutional Economics

Ronald Coase received the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel in 1991 for his discovery and clarification of the significance of transaction costs and property rights for the institutional structure and functioning of the economy. These insights also formed the basis for a new direction in economics: institutional economics. This new direction considers the cost of transactions as a vital element to explain the institutional structure of the economy, including the existence of firms, the many different forms of contracts and the existence and importance of many legal rules including property rights. Analysis of modes of coordination inside the economic system, should take account of the embeddedness of the economic system in the other subsystems of society. And according to Coase (1998) the efficiency with which the economic system operates depends on the political, legal and other institutions of a country. “*In effect, it is the institutions that govern the performance of an economy, and it is this that gives the ´new institutional economics´ its importance for economists*” (Coase, 1998: 73).

This embeddedness of the economic system in the other subsystems of society that Coase mentioned is depicted in Figure 2-1.

The economic system can be regarded as a structure of social rules that coordinates economic interactions between actors and that influences or directs the behavior of the individual actors. Coordination between the economic actors is

31 Coase is especially regarded as a central figure in the development of the interdisciplinary field of law and economics.

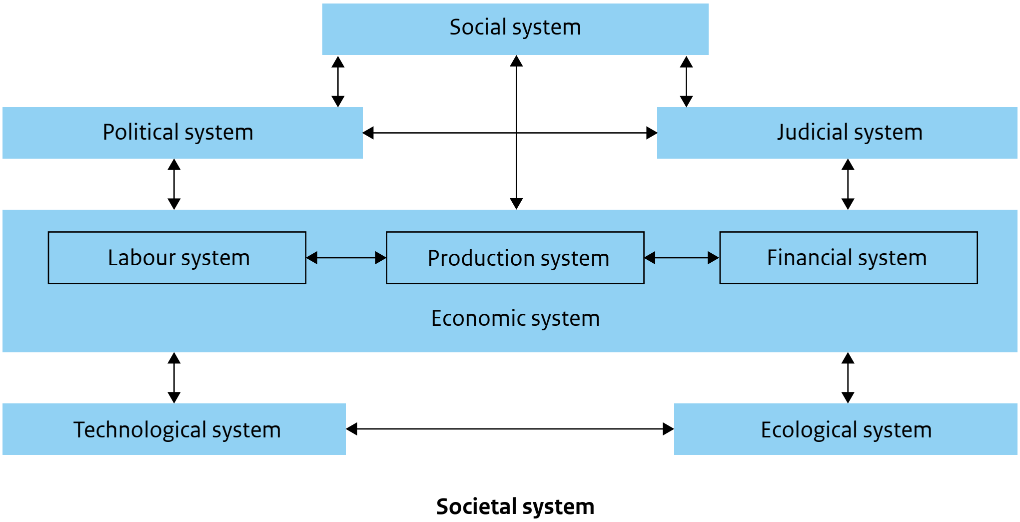

Figure 2-1 The economic system embedded in the societal system (Lemstra and Groenewegen, 2012: 2).

largely determined by the judicial system. This system consists of all the legal rules and regulations that structure behavior of actors in society. Competition law, contract and corporate law, laws on the quality of products and services, and the rules on property rights are important examples of the judicial system that structure behavior of actors within the economic system with respect to the production, distribution and consumption of goods and services.

Both the judicial system and the economic system are influenced by the political system. This system concerns the institutions that coordinate the political process of public organizations such as the government, the parliament and public agencies. The social system is about the values, norms and conventions of society that influence the behavior of actors in all the other parts of the societal system. Behavior of actors in the economic system is further influenced by the technological system, with its technological paradigms and trajectories; and by the ecological system with its natural resources (Groenewegen, Spithoven and Berg, 2010; Lemstra and Groenewegen, 2012).

When we analyze efficient use of the radio spectrum, we are dealing with an issue that is situated in the economic system. However, in answering the research question we have to take account of the embeddedness of the economic system within the societal system and its relations with the other parts of the societal system. Coase already mentioned the connection between the economic system and the judicial system. Institutions are created to lower the cost of transactions, but institutions are not only about the efficiency of transactions in the economic system. Institutions may also have to deal with public interests which are related to the political system and the norms and values in the social system. Hence, there may be public and societal objectives involved in the distribution of frequencies, next to economic objectives. Examples are frequencies that are used for military purposes, by the police, for social alarm systems or for (public) broadcasting. This may lead to a social efficient distribution next to an economic efficient distribution. For the case at hand, the radio spectrum, the relation with the technological sub-system will also be of relevance. Advancements in technology made it for instance possible in the past to expand the resource though the use (new) higher frequencies and to develop new technology that allowed more efficient use of the resource through sharing of radio spectrum between (in the past) incompatible users.[32]

The part of economics that is concerned with the analysis of the role of institutions in the economic system is called institutional economics. Two schools of institutional economics exist which deal with the analysis of how the economic system works or should work: original institutional economics and new institutional economics. Both schools take a very different approach in their analysis.

2.2.1 *New Institutional Economics*

The school of new institutional economics (NIE), which is based on the ideas of Coase, developed rapidly since the mid-1970s. In 1975, Williamson coined the term New Institutional Economics in his groundbreaking book *Markets and Hierarchies*. He added the term "new" to distinguish his institutional economics from the Original Institutional Economics.[33] The New Institutional Economics of Williamson acknowledges the important role of institutions, but it does not abandon neoclassical economics (NCE) as the original institutional economics did. Williamson tries to expand on it by bringing the role of institutions within a common framework together with neoclassical economics. He considers his NIE to be complementary to NCE, it addresses other issues but uses the same methodology (Groenewegen, Spithoven and Berg, 2010).

As Arrow (1987: 734) observed, NIE does *"not consist of giving new answers to the traditional questions of economics—resource allocation and the degree of utilization. Rather it consists of answering new questions, why economic institutions emerged the way they did and not otherwise."*

In other words, whereas NCE focusses on getting the price right, NIE focusses on getting the institution right (Williamson, 1994). Coase (1992: 4) made the relevance of this focus on institutions quit clear in his Nobel Prize Lecture with an example:
"The value of including such institutional factors in the corpus of mainstream economics is made clear by recent events in Eastern Europe. These ex-communist countries are advised to move to a market economy, and their leaders wish to do so, but without the appropriate institutions no market economy of any significance is possible. If we knew more about our own economy, we would be in a better position to advise them."

The objective of NIE is to explain the institutions which coordinate transactions and to evaluate their impact on economic performance. The core of the New Institutional Economics is formed by transaction cost economics (TCE), positive agency theory (AT)[34] and the theory of property rights (PR). However, the exact boundaries of NIE are not fixed. Other theories that are also often considered to be part of NIE are economic analysis of the law, public

32 A good example of the latter is dynamic frequency selection that made it possible for RLANs (Wi-Fi) to share a frequency band with radar applications.

33 Original Institutional Economics will be discussed in the next sub-section.

34 Agency Theory (AT) deals with the contractual relationship between a principal (the owner, authority) and an agent (the actor that performs the task). The agent can always choose the level of his commitment. His actions which will affect the welfare of both parties is difficult to be observed by the principal. The normative agency theory is aimed at calculating the optimal contract (incl. monitoring arrangements) which align the objectives of the principal and the agent. Positive agency theory is a non-mathematical branch of agency theory which is aimed at analyzing the mechanisms which are actually brought into play by the economic agents within the framework of an agency relation. It applies, in particular, to organizational architecture and corporate governance (Charreaux, 2002), but is also of relevance to analyze the relationship between a regulator and a regulated firm (Debande and Drumaux, 1996).

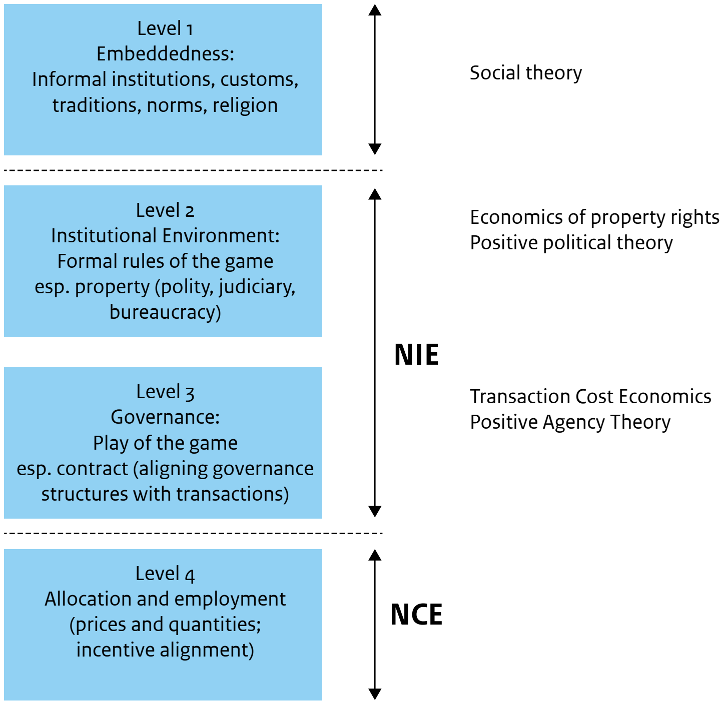

Figure 2-2 The four-layer "Economics of Institutions" model, adapted from Williamson (1998, 2000).

choice theory, and constitutional economics.
A common denominator is that the institutional framework is object of research and that NIE seeks to consider the implications of any given institutional arrangement for economic behavior (Williamson, 1998; Groenewegen, Spithoven and Berg, 2010). Richter (2005: 8) made an assessment of NIE in which he came to the conclusion that "*NIE is not characterized or defined by a selection of fields but by the intellectual bond of its methodology*".

In new institutional economics, the methodological individualistic approach of neoclassical economics is maintained: the actors have constant and given characteristics and actor behavior is structured by the natural, technological and institutional environment. Transaction cost minimization is added to the maximization of profits and utility. NIE explains the role of institutions to lower these costs.

The field of study of NIE and its relationship with neoclassic economics (NCE) can be explained through the use of a model that was introduced by Williamson (1998).[35]

The bottom level (level 4) refers to the day-to-day operation of the economy. At this level the optimal allocation of resources (including labor) is located. This level is the domain of NCE. In the basic model of 'received microtheory' as Williamson (1975) called it, NCE does rigorous analysis in a virtual world in which consumers maximize their utility and firms exist to maximize their profit. All actors

35 Williamson introduced this model during the Hennipman Lecture in Amsterdam on May 13, 1997. A revised version of that paper was published in "de Economist" (Williamson, 1998).

behave fully rational based on complete and relevant information, markets are perfect, i.e. market prices reflect scarcity and provide all relevant information to take efficient decisions, and transactions are costless and instantaneous. In such a world, end states (equilibria) exist in which there is an optimal distribution of scarce resources whereby nobody can improve his situation by renegotiating the outcome. In this world, the firm is a production function that exists to transform resources into products and services with the aim to maximize profits. Institutions are omitted in the solving of optimization problems. They are either absent or implicitly assumed to exist and to function perfectly (Groenewegen, Spithoven and Berg, 2010).

To explain the relevance of institutions, NIE abandons some of the strict assumptions of NCE. NIE scholars argue that mainstream economics is on a "too high level of abstraction" (Williamson, 1975). NIE tries to bring these assumptions of perfect information, zero transaction costs and fully rational behavior closer to reality, through the introduction of transaction costs and more realistic assumptions on human behavior, such as bounded rationality and opportunistic behavior. The bounded rationality of actors means that their ability to absorb information and to take decisions based on this information is limited. Asymmetry of information known by actors gives a possibility to behave opportunistically, i.e. shirk and cheat, e.g. by providing wrong information on the quality of the good or service to be delivered. As a consequence of this complex and uncertain environment, actors are no longer able to eliminate all uncertainties through complete contracting. To reduce risk and transaction costs actors create institutions, such as vertical integrated firms, a variety of contracts, forms of cooperation and industry associations to deal with those uncertainties and to minimize transaction costs (Correljé, Groenewegen, Künneke and Scholten, 2015). Government influences transaction costs by writing and enforcing constitutions, laws and regulations.

Williamson makes a distinction between the institutional environment (level 2) and institutional arrangements (level 3). The level just above the virtual world of NCE is the level of the institutional arrangements (governance), or what Williamson calls the "play of the game". The narrow focus of competition in idealized markets is replaced by modes of organization of firms and contracts to coordinate economic activity. The vertical or horizontal structure of business firms and the boundaries between transactions mediated internally and those mediated through markets are examined and explained. Positive agent theory and transaction costs economics are used to explain the various contractual arrangements and organizational structures of firms, state-owned enterprises, regulatory agencies and cooperation of firms within industry organizations and standardization organizations (Groenewegen and Künneke, 2005).

Williamson showed that a range of private and public institutional arrangements exists to minimize transaction cost. Important aspects are the degree of the asset specificity of the good or service transacted, the frequency in which transactions occur and the environmental uncertainty associated with the transaction. The degree of asset specificity and uncertainty have implications for opportunistic behavior and the need for safeguards.

If the asset specificity is low and transactions are frequent, there will be a high level of competition and high substitutability between comparable goods and services of competitors. In such an environment, the goods or service can be traded easily on the traditional market. Since the goods and services are of a standardized kind, it is possible to compare the goods and services of various sellers. Hence, there will be information available of the trustworthiness of a seller. This will provide an incentive to sellers to behave responsibly. If the asset specificity is higher and the number of trades becomes less frequent, there will be a greater dependency between the buyer and the seller. This will give more possibilities for opportunistic behavior, e.g. the bounded rationality of the buyer will make it difficult to determine the correctness of the suppliers actions. Hence, this uncertainty will make transactions more risky. There will be a need to build some safeguards in contracts, e.g. through long-term contracts. If the asset specificity and the uncertainty are high enough, it may become more efficient to make the good within a vertically integrated firm. If the asset specificity and the uncertainty become even higher, public governance through regulation or even a state owned enterprise may be required to allow transactions to take place (Williamson, 1998; Correljé, Groenewegen, Künneke and Scholten, 2015).

Those contractual arrangements and organizational structures are embedded in the institutional environment. This is the level of what Williamson calls the "*formal rules of the game*", such as the constitution, the political system, laws, regulations and the definition and enforcement of different configurations of property rights. Well defined enforceable property rights, an independent judicial system and an objective bureaucracy are important factors to provide actors with the right incentives to maximize their profit and utility and to minimize their cost (Rutherford, 2001; Correljé, Groenewegen, Künneke and Scholten, 2015). Different configurations of property rights (private, state, common, or the absence thereof), monitoring of actor behavior and the enforcement of these property rights influence the behavior of actors differently and produce different outcomes. The economics of property rights and positive political theory are used to explain how polities affect the transactional environment, how the different configurations of property rights influence the behavior of actors differently and produce different outcomes, and how, when and why states enforce or violate property rights and contracts (Ménard and Shirley, 2005). These differences in the institutional environment are used to explain the differences in the economic performance of countries and to explain differences in performance of privatized telecommunication sector (Levy and Spiller, 1994) or other privatized utilities in different countries (Finger and Kunneke, 2011).

At the top is the level of social embeddedness. It is the level of the informal institutions that shape society such as norms, customs, traditions and habits. These informal institutions are not explicitly formulated nor designed. These foundations of society change very slowly and are considered as a given for the NIE economist. They are not part of the solution space, but part of the explanation. Analysis of the informal institutions belong, according to Williamson, in the domain of "social theory".
The informal institutions are considered important because of their strong influence on the institutional environment of level 2 and the institutional arrangements of level 3.

In summary, the focal point of NIE is on the analysis and design of the institutions at layer 2 and layer 3. Institutions and institutional change are generally analyzed as ways of reducing transactions costs, reducing uncertainty, internalizing externalities, and producing collective benefits from coordinated or cooperative behavior (Rutherford, 2001). The focus is often on private solutions. Only when market failures[36] are not corrected by the private actors themselves, public governance structures should regulate the behavior of the private actors. The role of the government is mainly explained in terms of "getting the institutional environment right", whereby "right" is defined as at the lowest (transaction) cost. Solutions to deal with market imperfections are to be chosen based on the

[36] Market failures refer to a situation in which the market on its own fails to produce an efficient distribution of resources. Market failures concern public goods, information asymmetries, externalities, natural monopolies and market power (Mankiw, 2004; Jaag and Trinkner, 2011).

efficiency loss and the cost of the available solution (Groenewegen, Spithoven and Berg, 2010; Correljé, Groenewegen, Künneke and Scholten, 2015).

An example can be found in the regulation of network infrastructures. Some infrastructures, such as the electricity grids and the gas pipelines can be considered as "natural monopolies". One possibility to regulate these natural monopolies is by imposing regulated access to competitors. However, regulated access may come with a loss of (dynamic) efficiency. The owner may have little incentive to develop its network further and the competitors will not invest in an alternative as long as they have cheap access to existing infrastructure (Jaag and Trinkner, 2011). In the case of the regulation of the monopoly of fixed telephony, there was another possibility to introduce competition that did not have this negative impact on investments and innovation. Owners of the cable television network were allowed to provide telephony services over their cable network in competition to the telephony company (Groenewegen, Spithoven and Berg, 2010).

Proper functioning of the market can be considered one of the more fundamental 'public values' to be safeguarded through governmental monitoring and intervention. The government is regarded as a system monitor that only intervenes when necessary. Governmental involvement can be regarded as a three layered approach. First, rules that make the market function properly. Second, interventions that correct behavior of the actors and thirdly, rules to realize public values.

The first category of interventions preserves the appropriate functioning of the free market: it are the rules to guarantee equality among the actors, equal access to relevant information, no possibility to abuse power, etc. These are the rules of fair competition embedded in competition policy. The second category of interventions concerns sector specific interventions to make actors behave conform the market norms, e.g. owners of property rights behave 'rightly' when they sell their license when a price is offered which is higher than the net present value obtained from the current and perceived future use of the right. The interventions can be rules attached to the property right (e.g. an obligation to use a property right), but the intervention may also be provisioning of information, e.g. on the ownership of private property rights and the prices involved in the trading thereof. The third category are the specific rules to realize public values. These rules will constrain actor's behavior, e.g. by imposing obligations on the delivery of services. Rules about the equity in access to the radio spectrum belong to this category (Correljé, Groenewegen, Künneke and Scholten, 2015; Lemstra, Groenewegen, De Vries and Akalu, 2015).

2.2.2 Original Institutional Economics

Coase was not the first economist that brought the importance of institutions to the attention of economists. The term "institutional economics" was first brought to the general attention of the economics profession by Walton Hamilton in a conference paper of the American Economic Association in 1918. The school of institutional economics became a significant element in the American economics in the interwar period (Rutherford, 2001). It is nowadays commonly referred to as "Original Institutional Economics"

OIE).[37] It is based on the tradition of Thorstein Veblen, John R. Commons, Wesley C. Mitchell, Clayrence Ayres and others. The original institutional school already argued that institutions

[37] Until the Williamson coined the term New Institutional Economics, it was mostly known as Institutional Economics. Sometimes the term "Old" is used instead of "Original". I prefer the word "Original" because the term Old has a connotation of being outdated. The term neo-institutionalism is sometimes used to denote the post-war institutionalists starting from Ayres that based their work on Veblen's evolutionary theory of institutions and John Dewey's theory of instrumental valuation, see Bush (2009). In the remainder of the text, neo-institutionalism is considered as part of OIE.

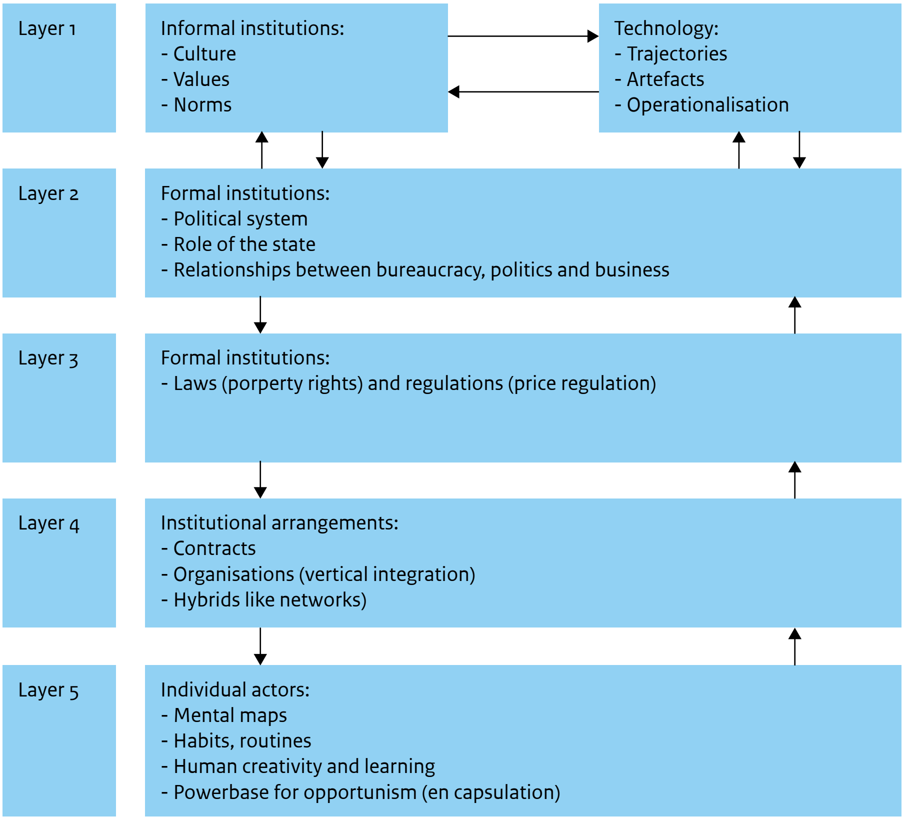

Figure 2-3 A layered model of the domain of original institutional economics (Groenewegen and Van der Steen, 2006).

were a key factor in explaining and influencing economic behavior. However, the OIE economists take a completely different view on economy than mainstream economists. They argue that mainstream economics is too narrow minded with their model based on markets and (perfect) competition with fully rational actors. Customs and habits and the changing nature of technology, business organizations, and the role of the state are largely omitted in this model (Klein, 1993). They see the economy not just as a system in which allocative decisions are made through the price mechanism. They see the economy as "[a]n open and evolving system, situated in a natural environment, affected by technological changes, and embedded in a broader set of social, cultural, political, and power relations" (Hodgson, 2000).

The original institutional economists were first of all interested in issues of institutional change, in the analysis of processes. The following analytical framework based upon their ideas can be used to explain the difference between OIE and NIE (Groenewegen and Van der Steen, 2006).

Compared to the layered structure of NIE (Figure 2-2) the differences are to be found in the extension of the model with the technology and the political layer, the different attributes of the actors, and the feedbacks between the layers.

In OIE, the economic system is a dynamic system with also changes in consumer preferences and technology. The economic system should not be described in terms of [static] equilibria in distribution through market forces (efficiency). The economy is an evolving process in which societal values like its handling of security, privacy, equity and freedom play a significant role. In this dynamic view governments should explicitly formulate policy objectives and design the instruments to realize these goals (Klein, 1993). The purpose of the framework of OIE is to understand these processes of change, of institutional development. Not the prediction of an optimal end state is the objective, but the explanation and understanding of complex processes of institutional change (Parada, 2001; Groenewegen and Künneke, 2005).

Actors of political, social or economic nature with different interests, capabilities and different degrees of power will take decisions. Power and habits of the various actors play an important role to explain the process of institutional change. "*To the extent of their power, individuals, teleological by nature, acting alone or collectively, pursue ends that refer to their habitual inclinations by use of means that are given by these same inclinations.*" (Stanfield, 1999: 6). OIE tries to explain this process, without regarding consumer preferences and technology as a given. In contrast to NIE, these are also variables to be explained.

OIE considers markets not as a neutral coordination mechanism. They are considered to be shaped by specific individuals and groups that attempt to organize the market in such a way that they serve their private interests. Next to this "lower efficiency", markets and other non-market institutional arrangements can be designed to serve the "higher efficiency" of the public interest. Markets are seen as political constructs that can be used as a tool to realize specific societal values that *ought* to be, like a more equal distribution of income, or more attention for the cultural heritage in the community. Special interest groups will influence the political process to design the market. It is a process of power play and conflict, because a change in the rules will imply an adjustment of the distribution of cost and benefit. Consequently, there will always be groups that will contest the outcome. As a result, markets will be in a constant state of adaptation, transition and evolution. Moreover, the values themselves will be judged and deliberated. Hence, markets will influence the norms and values in society and both private and public values are constituted in interaction (Correljé, Groenewegen, Künneke and Scholten, 2015; Groenewegen, 2015).

OIE was very influential during the first half of the 20th century, but its influence began to decline during the 1950s overwhelmed by the enthusiasm for the Keynesians' ideas (Parada, 2001). The main criticism on institutional economics was that it lacked rigorous and systematic theoretical foundations. Their work was regarded in mainstream economics as at best nice descriptions of economic issues. "*Without a theory they had nothing to pass on except a mass of descriptive material waiting for a theory or a fire*" (Coase, 1984: 230).

This statement must be seen in perspective. OIE scholars make use of theories, although they may be underdeveloped and are leaning on social sciences, such as anthropology and history, than the more quantitative economic theories used in orthodox economy. Veblen and Commons both emphasize the importance of theoretical explanation and theoretical development, although their theoretical foundation was not grounded in economic theory. For instance, Veblen was attempting to develop a theory of economic and institutional evolution along essentially Darwinian lines (Hodgson, 1998; Stanfield, 1999).

Along with the foundation on social sciences comes a method used by social scientists. According to (Stanfield, 1999: 236), OIE relies "*less heavily upon econometric techniques…and more on the comparative methods* *developed by anthropologists to collect information and pursue generalizations about the economic activities of human groups*." In their analysis the original institutionalists take a holistic, systemic, and evolutionary approach and proceed by what Wilber and Harrison (1978) called "pattern modelling." This entails generalization and the discovery of trends through qualitatively exploring potential relationships between variables. It is a multidisciplinary approach in which different techniques are applied. Wilber and Harrison explain that the methodology of the original institutionalists certainly is neither deductive nor based on methodological individualism. They take an approach in which the evolution of the (economic) system can be explained as a result of a process in which actors interact both with other actors and with the surrounding environment; so called methodological interactionism (Groenewegen, Spithoven and Berg, 2010). Hence, OIE differs both in scope and method from orthodox economy (Stanfield, 1999).

In sum, OIE explains the dynamics of institutions from a broad perspective, with a wide range of interdependent explanatory variables. Their approach of "pattern modeling" is open-ended and multidisciplinary, which makes it simultaneously rich in content and relatively low in rigor (Groenewegen, Kersholt and Nagelkerke, 1995).

2.2.3 Building bridges between NIE and OIE

The work of Williamson, which builds on neoclassical economics, clearly differentiates NIE from OIE. Since the original work of Williamson, the new institutional economics expanded into issues that traditionally belonged to the domain of the original institutional economics, such as political institutions and issues concerning institutional change. Many of the concerns and approaches of the new and the original institutional economics started to overlap. Consequently, it is nowadays difficult to draw a clear demarcation line between the two schools of institutional economics (Hodgson, 2007).

In that respect it is interesting to note that the work of the other Nobel laureates whom are regarded as founding fathers and mother of NIE are linked to the world of OIE: Ronald Coase (Medema, 1996), Douglass North (Groenewegen, Kerstholt and Nagelkerke, 1995; Rutherford, 1995) as well as Elinor Ostrom (Groenewegen, 2011a; Chanteau and Labrousse, 2013). The only exception seems to be Williamson.[38]

Hodgson (2007) and Groenewegen (2011a)[39] argue that the key demarcation between the old and the new institutionalism is in their methodology, in the way they model the actors and their relationship with the institutional environment.
New institutionalism is based on the model of rational individual actors with given characteristics like bounded rationality, opportunistic behavior, and the application of the rule of cost minimization. Actors perform transactions in a given environment of technology, natural resources and formal and informal institutions. The most (cost) efficient mode of coordination can be deducted for the given attributes of the actor and the given structure. This will lead to an equilibrium that is only disturbed by an exogenous change in the structure or the characteristics of the actor.

OIE methodology is different. OIE institutionalists focus on the interaction between institutions and actors. It is characterized by methodological interactionism and a model of the actors that is more complex in the sense that habits and power play a role. The economy is regarded as an evolving system with actors of different nature (political, economic and social) with different interests and capabilities and with different amounts of power.

[38] Even Williamson refers regularly to the work of John R Commons. However, the transactional theories of Commons and Williamson are significantly different (Kemp, 2006)

[39] See also Groenewegen, Kerstholt and Nagelkerke (1995).

The economic system is in a constant state of flux[40] as a result of a process in which actors try to influence other actors and try to change the structure. In their view is the understanding of the process of institutional change the central question of institutional economics (Correljé, Groenewegen, Künneke and Scholten, 2015).

In that respect, NIE and OIE can be seen as complementary. Both approaches develop very different frameworks, theories and models and have different philosophical underpinnings They have relevance for answering different questions under different conditions (Groenewegen, 2011a).
NIE focuses on the comparison and evaluation of alternative governance structures. It can explain or even predict what the most efficient institutional arrangement is given the preferences of the actors and the institutional environment. Whenever one of the exogeneous variables changes, it will explain a change towards a new efficient governance structure. It is a comparative static approach. It does not explain how this change from the old governance structure to the new structure will come about nor can it explain why this efficient governance structure will not always come about. OIE is more focused on the dynamics of institutional change. It can be used to explain why in some countries governance structures only change gradually, whereas in others there are more radical changes. Nowadays some institutional economists are considered to take a pluralistic approach. Their theoretical framework is interdisciplinary and they apply both theories of NIE and OIE. North, Greif, Vatn and Ostrom are considered examples of such an integrated approach (Groenewegen, Spithoven and Berg, 2010; Groenewegen, 2011a).

This is also what will be done in this thesis. The theoretical foundation for this thesis is the world of NIE, but some elements that are regarded as part of the world of OIE will be included. The reason is that the research question relates strongly to the kind of questions asked in OIE. It is about the public interest to be safeguarded to realize the "higher efficiency". However, OIE is considered more relevant to study and analyze the process of how institutions and actors try to influence the public interest to pursue their own private interest, how as a result initial allocations of specific radio spectrum usage rights come into being and how radio spectrum governance regimes will change over time. This research is not about the analysis of this process of change. In this research we will analyze how the public interest as an exogenous factor can be taken into account in the comparison and design of the two new governance approaches next to the existing radio spectrum management regime, whereby "economic efficient use" is taken as a starting point. The proper functioning of the market is considered as being one of the more fundamental public values to be safeguarded. Governmental involvement is thereby regarded as a three layered approach, as described in section 2.2.1. First rules to "get the institutions right" to enable market exchange, second, interventions to preserve correct functioning of the market and third, rules to adjust the functioning of the market to realize public interests.

Actors are thereby presumed to act rational based on given preferences and motivations. The behavior of these rational individual actors is presumed to be efficient. The government makes efficient laws and regulations and the private actors make efficient governance structures. We will not deal with situations in which institutions are not efficient and exist only because they serve the interest of a small group. OIE is considered more relevant for the analysis of that type of question (Groenewegen, 2011b).

Hence, the methodology used in this research is that of NIE, methodologic individualism: the

40 Veblen sees institutions as a product of the past process. They are adapted to past circumstances and therefore never in full accord with the requirements of the present (Groenewegen, 2011a).

analysis of social phenomena through seeing the motivations and actions of rational individual agents in a given structure. However, it are not the neoclassical fully rational agents. Agents are bounded in their rationality and may show opportunistic behavior. The rational agent is assumed to take account of available information, probabilities of events, and potential costs and benefits in determining preferences, and to act consistently in choosing the self-determined best choice of action (Blume and Easley, 2008). These bounded rational agents are closer to reality, where agents make decisions that are logical, based on the limited information available to them.

That actors are regarded as rational agents who act within a given structure does not mean that the structure cannot be changed. How institutional change and changes in technology are addressed in this thesis will be explained later. First institutions will be defined and the relationship between institutions and technology and policy will be explained in the following sections.

To conclude, our point of departure is the world of NIE. However, some elements will be included that are seen by some as pertaining to the world of OIE. There are more explanatory variables involved than usual in NIE, such as technology and the characteristics of the particular resource at stake: the radio spectrum, and there is more emphasis on the public interest next to economic efficiency.

2.3 What are institutions?

The term institution is generic and used in several different ways. The definition seems to vary according to the perspective that is taken and the problems that are tackled. In the view of OIE institutionalists institutions shape the individual and his preferences. John R. Commons defines institutions as collective action in control, liberation and expansion of individual action (Commons, 1931). In that respect Commons is talking about the "institutionalized mind" (Hodgson, 2000). Institutions will influence not only the behavior of actors but also their preferences. The focus is on the interaction between institutions and the actor.

NIE institutionalists take the rational individual with his utility maximizing preference as a given. In their view, institutions are constructed to deal with uncertainties in human interaction. In NIE, the definition of North is widely used (Parada, 2002). North (1991: 97) defines institutions as "*the humanly-devised constraints that structure political, economic and social interaction*".

In this definition, constraints can be formal (rules, laws, constitutions) or informal (norms of behavior, conventions, and self-imposed codes of conduct). Institutions give incentives to actors to guide and structure their behavior in situations that require coordination among two or more actors. They play an essential role to reduce uncertainty for individuals and society as well by defining and limiting the set of choices of an individual in human interaction. Institutions reduce the risks of opportunistic behaviour and reduce costs of interaction (North, 1990; North, 1991).

The use of the word constraint in this definition seems to imply that actors are always hindered by institutions. However, institutions do not only constrain, but can also open up possibilities. It may enable choices and actions that otherwise would not exist (Hodgson, 2006). Hodgson (p.2) explained this with a very simple example: "traffic rules help traffic to flow more easily and safely". The same can be said for rules for the use of the radio spectrum. Rules on the use of spectrum can provide possibilities for others to use the spectrum as well. Therefore, the definition of Hodgson (2006: 18) is used in this thesis:[41]

[41] Hodgson proposed this definition based on an analysis of the definition of North and others.

"Institutions are systems of established and embedded social rules that structure social interactions."

Hodgson uses the term systems of rules because there is not a clear distinction between the purposefully designed formal institutions and the informal institutions. Formal institutions will always depend on informal (non-legal rules and inexplicit norms) in order to operate.

Not all rules can be regarded as an institution. A rule must be shared among actors, must be well understood by the actors and must be enforced (Crawford and Ostrom, 2000; Ostrom, 2007b). The enforcement will be different for formal institutions than for informal institutions. Formal institutions are enforced through the legal system (such as courts) and regulatory agencies, while informal institutions are enforced by someone's peers or others (Hodgson, 2006). In this case, sanctioning leads to loss of reputation, social disapproval, withdrawal of cooperation or withdrawal of rewards (Scharpf, 1997).

Sometimes the words institution and organization are used interchangeable. North clearly separates one from the other. North sees institutions as the "*rules of the game*" and organizations as "*the players of the game*" (North, 1990). This interchangeable use of institutions and organizations is probably due to the fact that the internal structure of an organization can be regarded as a special kind of institution. An organization can be regarded as a group of individuals, with a common intent to achieve objectives, that sets up criteria for the boundaries and membership and lays down the principles for the chains of command. Organizations can be regarded as what Scharpf (1997) calls "*composite actors*". Composite actors are themselves constituted by institutions. These institutions define inter alia the membership of the composite actor, the purpose of the composite actor and the resources that are available. In this thesis organizations can be regarded from the outside, as actors which play the game, unless explicitly stated that the internal structure of the organization is relevant.[42] Just like institutions, organizations can be formally or informally constructed. Thus defined, the term organization includes in our context not only industry firms and operators, but also the ITU, standardization organizations such as ETSI and IEEE, governmental agencies and other composite actors (Scharpf, 1997; Polski and Ostrom, 1999; Hodgson, 2006).

2.4 Institutions, technology and (public) policy

The behavior of users of spectrum and other actors involved will not only be structured by institutions. Other factors like the technology and the characteristics of the resource, the radio spectrum, itself will also influence their behavior. These factors are not independent. Ostrom (1990) showed that there is a delicate balance between technology and institutions in the governance of common pool resources, especially the entry and authority rules used to control access and use of the resource (Ostrom, 1990). The specificities of these rules will favor certain types of technology to exploit the resource over other types of technology.
For example, it will be impossible to introduce bi-directional radio communication technology in a band if the rules would only allow unidirectional broadcasting transmissions.

Technology itself is often, so-called, 'unruly' in nature. Technology is important but does not determine the governance structure in its totality, i.e. technology can drive a transformation towards a new governance structure, but there remains a

[42] For instance to explain the internal structure and working methods of the ITU and other (inter)national organizations.

range of possible institutional arrangements.[43] It is a matter of choice by the multiple (groups of) actors which governance structure will be in place. This choice is influenced by both technology and the surrounding institutional setting, such as market forces and government regulation (Koppenjan and Groenewegen, 2005). For instance, access to spectrum for mobile telephony is usually arranged through licenses. However, this is not a technological prerequisite. The use of exclusive licenses is used to create a market with a limited number of mobile operators with an (inter)national service offering. However, other institutional arrangements are possible, but these would lead to other market structures and service offerings.

The relationship between institutions and technology is not direct, technologies do not shape institutions and institutions do not craft technology. It is the interaction between the actors through which technology will have an influence on institutions and vice versa. This interaction between technology, institutions and actors is shown in Figure 2-4.

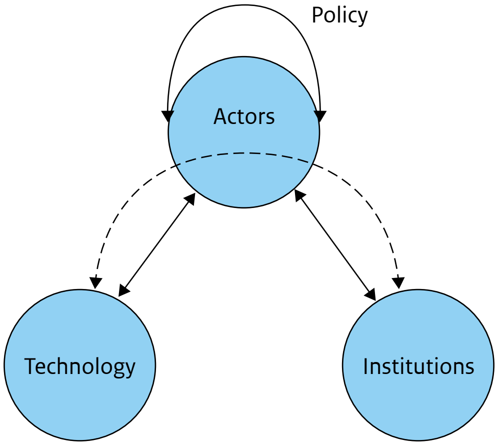

Figure 2-4 A dynamic model of interaction between actors, institutions and technology.

The actors will intentionally enter in interaction among each other to try to achieve specific outcomes. This is what is defined by Scharpf (1997) as policy.[44] In their interaction the actors are guided by the structure, being both institutions and technology. They will try to influence and change the structure if this contributes to the realization of their objectives.

In the interaction among actors there is not necessary an overall goal. Each actor has its own reasons to participate and is performing behavior in order to pursue its own interests. This may raise problems in the interaction. Scharpf (1997) defines 3 broad types of problems which might lead to policy problems and, possibly, a need for public policy: (1) coordination problems, (2) collective action problems and (3) redistribution problems.[45] These will be discussed below.

43 Even in the broadcasting band from the example above, there is a possibility to introduce various institutional arrangements, e.g. with local licenses per broadcasting station, or a license for regional or nationwide coverage, or if even for unlicensed use of broadcasting technology (albeit probably on a rather low power level).

44 Scharpf (1997: 36) defines policy as intentional action by actors who are most interested in achieving specific outcomes.

45 Scharpf uses the term “Externalities and collective good problems” for the second class of problems. However, this may create some confusion between the first class of problems and the second class, e.g. network externalities can be a reason for a government to define or impose technical standards to ensure compatibility.

First of all, *coordination problems* among private actors may occur. Coase already showed that individual actors are only able to resolve coordination issues through voluntary agreements if the transaction costs are lower than the benefits. If the transaction costs are becoming too high compared to the benefits coordination problems will occur, leading to a situation in which the coordination will not take place. Public policy may play a crucial role in reducing the transaction costs, for example by setting up a proper institutional environment, in which property rights are clearly defined and protected, by defining contract law, by establishing a legal system for the enforcement of contractual obligations, and by defining or imposing technical standards that ensure the compatibility of products and services (Scharpf, 1997).[46]

Sector specific regulations in the network industries (e.g. railways, electricity, postal services and telecommunications) often include provisions on compatibility and interconnection. Interconnection was an important factor for governmental involvement in the development of telegraphy, telecommunications and other network industries. For instance, the ITU (then: International Telegraph Union) was set up by administrations to create a framework for international interconnection by standardizing telegraphy equipment, setting uniform operating instructions and common international tariff and accounting rules (Codding, 1952).[47]

Collective-action problems may occur when individual actors choose actions in an interdependent situation. If each actor in such situations selects strategies purely based on short-term self-interest, individual actors will take actions that generate lower joint outcomes than could have been achieved (Ostrom, 2010). In radio spectrum there will be an interdependency between the action of various individual actors.
As stated already in the introduction, the radio spectrum can be regarded as a so-called common pool resource,. A common pool resource is a resource that is shared by a group of users, whereby the sharing faces two dilemmas: (1) it is difficult to exclude anybody; and (2) the use of the resource by one individual affects the use by another individual.48 Collective action problems may then arise if property rights are either undefined, or owned in common without access restrictions i.e. access to the resource is either open to all or the use of the resource is unrestricted for the group of owners. If purely self-interested actors cannot be restricted in their use of the common pool resource there is a risk that the "tragedy of the commons" occurs as described by Hardin in 1968 (Hardin, 1968). In that case, the common use of the resource is at risk through over-consumption, i.e. the appropriation of the resource exceeds its ability to be provisioned or replenished.[49]

In the literature, the term common pool resource is often associated with the term common property regime. However, the term common pool resource only refers to a resource with the particular characteristics that are mentioned above (Ostrom and Hess, 2007). These two characteristics - difficulty of exclusion and rivalry - create a need to restrict access and create incentives to invest in the resource to mitigate the problems associated with open

46 Interconnection (of networks) and compatibility (of services offered over these networks) are closely linked, see Economides (1996).

47 This does not mean that there always is a need for governmental involvement to solve interconnection issues. The internet is a classic example of successful private coordination without governmental involvement to deal with interconnection.

48 Both characteristics are true for the radio spectrum. It is difficult to exclude anybody from using the radio spectrum and the use of the radio spectrum by one individual actor will have an effect on the use of the radio spectrum by other users due to interference. See also Annex I.

49 In our case of the radio spectrum, overuse will lead to congestion through a too high level of interference. Note also that radio spectrum is available again for alternative use as soon as it is released.

access, such as congestion, overuse or even destruction of the resource. Ostrom and others have made extensive studies on the emergence and sustainability of successful governance regimes for common-pool resources (Ostrom, 1990). Ostrom et al. observed that the tragedy of the commons only occurs when resource users do not communicate with each other and have no way to develop trust in each other or in the management regime. Under more typical circumstances of resource use, however, users can communicate and have ways of developing trust. Under these conditions it is possible that the users will agree on a set of rules (i.e. an institutional form) to govern their use so as to sustain the resource and their own economic return from it (Ostrom, Dietz, Dolsak, Stern, Stonich and Weber, 2002).

Through her observations, and that of others, it was found that an astounding variety of property rights systems is used to restrict access and create the necessary incentives to govern common pool resources. These can be classified in 4 broad types as given in Table 2-1 .

Regime	Characteristics
Open access	Absence of enforced property rights
Communal property	Resource rights held by group of users who can exclude others
Individual property	Resource rights held by individuals (or firms) who can exclude others
Government property	Resource rights held by government that can regulate or subsidize use

Table 2-1 Types of property regimes to regulate common pool resources (Feeny, Berkes, McCay and Acheson, 1990)

Ostrom et al. observed that especially small scale local resources with a limited group of users can be governed by the users themselves. In case of local small scale resources, users are able to engage in direct communication and it is relatively easy to obtain information about the state of the resource and on the intentions of other resource users.

When the resource is becoming larger and more complex with multiple types of use, coordination among users may become difficult, because users lack a common understanding of the state of the resource and users will have difficulty to agree upon the types of uses and constraints necessary to conserve it, and they frequently have substantially diverse interests. Hence, the coordination costs to sustain large and complex resources with multiple types of use can become high when compared to small and relatively homogeneous resources (Ostrom, Burger, Field, Norgaard and Policansky, 1999).

Hence, large and complex resources may require more formal rules through government involvement. For example, the government can define and enforce tradable individual property rights and use arrangements and provide more formal mechanisms for arbitrating disputes. When the coordination costs rise further, the government can take ownership, whereby the governments retains formal property rights and controls individual access and use through a variety of entry and production restrictions (Scharpf, 1997; Libecap, 2005).Private property rights are intended to address conflicting interests by facilitating tradeoffs. However, the introduction and distribution of property rights may be rejected by some resource users on equity grounds. This may give rise to *redistribution problems*. Redistribution problems may arise under two conditions. First, there may be situations in which (otherwise attractive) policy purposes can only be attained at the expense of identifiable individuals or groups, e.g. the identification of a frequency band for mobile communications that was in use for other purposes.

Here, the issue will necessarily have to be resolved in the policy process to balance the public interests against the private interests of the involved groups.

Second, the existing distribution of assets may itself become a policy issue. For instance, it may be socially unacceptable within a society if all frequencies for broadcasting are in the hands of a limited and small number of commercial entities. Societies differ greatly in the extent to which (market-generated) inequalities are made a policy issue; but in each of them, the state's power to tax and regulate is at least to some extent used to help the weaker actors (Scharpf, 1997). The problem of equity might also be called a problem of a social efficient distribution.

2.5 Institutional analysis

The reality of institutional analysis, i.a. the deregulation and governance of the radio spectrum, or any other network industry, is very complex. A lot of factors and groups of actors with different motivations are involved and many interdependencies exist. In order to analyze the institutional arrangements and the role of the government therein, one needs to know what to look for, i.e. what factors are likely to be important, and consequently what factors can be safely ignored. Certain simplifications will have to be made in the analysis. In our daily life all kind of phenomena are explained based on a strategy called common sense. The phenomenon is approached in an implicit, ad hoc fashion, using assumptions that have arisen from past experiences. Although such a method can be successful in daily life with many comparable situations where one can learn from past mistakes, the method is inherently flawed. The assumptions remain implicit and largely unknown. One simply assumes they are correct (Sabatier, 2007), until proven otherwise.

A distinctive aim of the scientific approach is to provide systematic and responsibly supported explanations (Nagel, 1979). This approach is characterized by the ontological assumption that clear and logically interrelated sets of critical relationships underlie the bewildering complexity of phenomena. Such coherent sets of propositions are abstractions of reality which can be used to understand, explain and predict fairly general sets of phenomena (Sabatier, 2007).

2.5.1 *Duality of the structure*

When doing scientific analysis it should first be clear which variables are to be explained (endogenous) and which variables are potentially explanatory variables (exogenous). In Williamson's NIE this distinction is quite clear. The governance structure is the endogenous variable to be explained by the exogenous environment of the technology, natural resources and the institutions as well as the given preferences of the actor.

However this becomes seemingly complicated in our case where the institutional setting and the technology are not fixed. Actors are in an interaction to make collective decisions on changes in technology to exploit the radio spectrum or make collective decisions on changes in the institutional setting, as illustrated in Figure 2-4. The behavior of actors is structured and guided by both institutions and technology, or what we could call the structure, but at the same time the behavior of actors may influence the very same structure.

This interaction between the actor and the structure is what Giddens calls the "duality" of the structure. The structure is "*both the medium and the outcome of the practices which constitute social systems*" (Giddens, 1981: 27). Structures shape the behavior of actors but it is also the behavior of actors that constitute (and reproduce) structures. In this view the actor and the structure are not opposed to one another, but they presuppose each other. Giddens calls this the "*theory of structuration*". It is not a coincidence that Giddens turns the word "structure" in a verb. With this neologism he indicates that the structure is not fixed, but changes over time (Sewell, 1992).

However, this may lead to a problem in performing a static comparative institutional analysis. If the institutional factors that explain a particular pattern of behavior are analyzed, the institutional setting simply can not be modelled simultaneously as causes and consequences of that behavior (Diermeier and Krehbiel, 2003). It is only possible to explain behavior as a result of the institutional setting if this institutional setting is taken as given (as exogenous).

The key to avoiding confusion in the institutional analysis is to distinguish between levels or orders of institutions. If actors are interacting to change rules in an institutional setting they are at the same time constrained by the institutional setting of the upper level (Kiser and Ostrom, 2000; Diermeier and Krehbiel, 2003). This can be simply explained by Figure 2-2 which distinguishes four different levels. If actors are in interaction to change institutional arrangements on level 3, the institutional environment of level 2 is to be held constant. This will be explained in more detail further down. In making this assumption the researcher has to take account of the time scales on which changes tend to take place on the various levels. The institutional arrangements of level 3 will change more often than the institutional environment of level 2. In turn, the time scale in which the informal institutions, customs and norms of level 1 change is considerably longer than that of level 2.

2.5.2 Framework, theory and models

There are various levels of abstractions of reality used to understand and explain the complex and dynamic reality. Elinor Ostrom (2005b) has developed a very useful distinction between three different classes of abstractions. Ostrom makes a distinction between frameworks, theories and models. This nested set of concepts range from the most generic to the most specific types of abstractions (Ostrom, 2005b; Schlager, 2007).

The relationship between a framework, theories and models is illustrated in Figure 2-5.

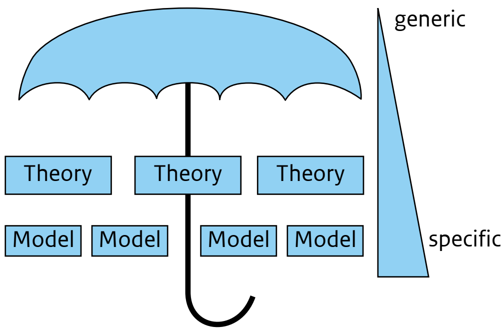

Figure 2-5 Framework, theories and models.

A framework is used to organize analysis. A framework helps to specify the general sets of variables of interest and the relationship among those variables that are relevant for the analysis. It provides a coherent structure to the inquiry. "*They attempt to identify the universal elements that any relevant theory would need to include*" (Ostrom, 2005b: 28). Frameworks help to generate the questions that need to be addressed in the analysis.

Theories are used to link and explain phenomena under certain specific conditions. They enable the analyst to focus on the part of the framework that is relevant for answering certain kinds of questions. Theories provide the necessary relationship between the set of relevant variables, as sets of propositions explaining why phenomena occur. However, theories can only provide these explanations under these specific conditions, i.e. theories are not universally true but are only true in situations where these specific conditions hold. In that respect, Coleman (1964: 516) uses the term "*sometimes true theories*". For instance, neoclassical theories are built on three assumptions: 1) Consumers have rational preferences among outcomes, 2) Consumers maximize utility and firms maximize profits, and 3) Consumers act independently on the basis of full and relevant information (Roy Weintraub, 1993).[50] Different theories are applicable to different specific conditions. In that respect, theories are often described as lenses through which researchers look to the situation at hand. Several theories are typically compatible with a particular framework.

Models are constructed out of theories by using precise assumptions about a limited set of parameters and variables. Hence, models are more specific than theories. A variety of models may typically be constructed from one theory (Blaug, 1992). They are necessary intermediaries between the development of a "pure theory"[51] and its application to the analysis of empirical facts (Menard, 2001). Models can be used to test hypotheses and to predict outcomes. However, models are never better than the theories they are built on and can only describe or predict outcomes in situations that approximate the initial conditions of the model. For instance the model of perfect competition in neoclassical theory is only valid under very specific conditions (on i.a. product homogeneity, sufficiently large numbers of buyers and sellers and the absence of barriers to enter or exit) within the more general assumptions of neoclassical theory. In other words, models are a representation of a specific situation. It is usually much narrower in scope and more precise in its assumptions than the underlying theory (Sabatier, 2007).

In the research of this thesis on institutional analysis, a framework helps to think about phenomena, to order material and to reveal causal relationships. Important elements that are already addressed in the introduction which may have to be taken into account to answer the research question are the specific characteristics of the radio spectrum as a common pool resource, the technology to exploit the resource and the specificities of the right to use the radio spectrum and the large variety of actors involved. The framework can then be used to analyze the actions of the government vis-à-vis actions of private actors, individually or collectively. In that framework, we can then apply theories on property rights, on collective action and on rational choice. The framework that is chosen will be further discussed in the following subsections.

2.5.3 Institutional analysis and the need for collective action

Institutions are fundamentally invisible, shared concepts that exist in the minds and routines of participants in policy situations (Ostrom, 2005b). They are made visible through the behavior of actors and the outcome of their interaction. Therefore, North described institutional analysis as "*at base the study not simply of the rules of the game but of the individual responses to such rules*" (North, 1987: 422). Ostrom (2005b; 2007b) and Scharpf (1997) identify a number of challenges in performing institutional analysis. The core problem of institutional analysis is the diversity of the institutions and the amount of factors affecting policy interactions. A framework can be used in the determination of the relevant factors and the causal relationships between these factors, as explained in the previous section.

There exist a number of different frameworks for policy analysis (Sabatier, 2007). Given the research question at hand and the methodology chosen, as explained in section 2.2, we are interested in a framework that can be used to analyze and compare the behavior of (intendedly) rational actors, including the government, under various institutional arrangements. This requirement fits with the purpose of the family of institutional rational choice frameworks. According to Sabatier (2007: 8):

[50] Although Coleman referred in that respect to theories in social sciences, the same can be said for theories in natural sciences. This is best illustrated by an example. Newton's laws of motion only hold under specific conditions, inter alia the speed of an object is low compared to the speed of light and the object is small compared to the distances involved, i.e. Newton's laws of motion are only "true" for macroscopic objects under everyday conditions.

[51] A "pure theory" might be defined as a set of purely analytical propositions derived from deductive reasoning. This in contrast to "applied theory" which is derived from empirical assertions (Hutchison, 1966).

"Institutional rational choice is a family of frameworks focusing on how institutional rules alter the behavior of intendedly rational individuals motivated by material self-interest".

Institutional rational choice frameworks assume that policy actors are 'intendedly rational'. The starting point is the rational actor that tries to realize its goal of maximizing its own self-interest. However, the strict assumptions are not always to be followed completely. Actors may be modelled with somewhat relaxed assumptions; taking account of the fact that actors do not have complete information, that information asymmetry exists and actors have bounded rationality.

In our case of the exploitation of the radio spectrum (or in the exploitation of any other common pool resource) the actions of the actors will not be independent. In this circumstance the actors will benefit from collective action. The interdependent strategies of actors and the benefits of collective action as opposed to purely self-interested independent action can be explained in these institutional rational choice frameworks in terms of game theoretic concepts (Scharpf, 1997; Sabatier, 2007).

The benefits of collective action: the Wireless Power Game

A formal game in game theory consists of the following basic elements: *players*, *strategies* and *pay-offs*. Players are those actors that actually are capable of making purposeful choices among alternative courses of actions; strategies are the courses of action available to a player; the pay-offs represent the valuation of the given set of possible outcomes by the players involved. A game exists if the courses of action are interdependent, i.e. the course of action of a player will depend on the action of other players or on information the player has about the strategy of other players (Scharpf, 1997).

Game theory starts with the assumption that all players are perfectly rational. Thus, players will maximize their own self-interest under conditions of complete information and unlimited computational capacities. Players may be involved in *non-cooperative* or *cooperative* games. A game is cooperative if players have the possibility to reach binding agreements before each player makes his move. In a non-cooperative game all players will simply choose a strategy that, given the other players' strategies, leads to an outcome that is maximal in their preference ordering.

Let's take an example of a simple game called the Wireless Power Game. In this game there are two neighboring house owners which both have a wireless network in their home. The power of the transmitters can be either high or low. In a high power setting the power is such that the transmitters disturb each other's reception.
A reduction of the power of both transmitters will improve the situation. However, if only one of the neighbors reduces his power he will improve the situation for his neighbor and not his own reception. This is shown in Figure 2-6.

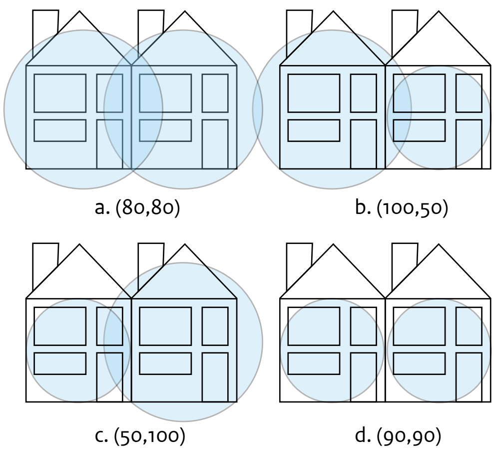

Figure 2-6 The four possibilities of the Wireless Power Game and their pay-off.

If both players use a high power setting they will only reach a quality of 80% due to the interference of their neighbor. If one player has a high power setting and the neighbor a low power setting, the quality will rise to 100% and that of the neighbor will drop to 50% due to the reduced power combined with the increased interference from the neighbor's transmitter due to the high power setting. However, if both players reduce their power level they will have a quality of 90% each. The quality will be somewhat reduced from 100%, but it will be higher than in the situation with both a high power level, because there is hardly any interference.

In this game, the dominant strategy will be to use a high power setting. Whatever the strategy of the other player is, the pay-off will be better with a high power setting than with the low power setting (80% against 50% and 100% against 90%). None of the players will have an incentive to reduce its power, because it will make its own situation worse. This mutual strategy to not reduce the power denotes a *Nash equilibrium*. In a Nash equilibrium, neither player has an incentive to change its strategy given the other player's strategy. However, if both players would reduce their power the situation would be better for both players. This game is a variant of the famous Prisoner's Game. In such a game, the players are trapped in a social dilemma. They are trapped in a Nash equilibrium in which both players can do better if they both change their strategy (Sandler, 2001).

In many real-life situations such a game is not played once but repeatedly. In these situations participants can use the information of the previous round in their choice for a certain action. One of the most famous conditional strategies for a repeated social dilemma game is "Tit for tat" (Axelrod, 2006). In this strategy a player starts with cooperation and takes the same action as the other player in all subsequent rounds. In the above game, the player starts with a low power setting and the power will be increased if the other does it and the power will be reduced if the other player reduces its power. This kind of strategy can be found in various real life situations, such as a tariff war between operators or investments to be made to increase the offered data rate to customers in a fixed or mobile network.

Such a strategy is very easy in a repeated symmetrical game with only two participants. Each participant can monitor the action of the other participant and punish the other participant through future actions (Ostrom, 2005b). If the number of players is larger it will be less easy to notice if all other players are cooperating and the sanction (increasing the power in our example) is not targeted exclusively to the non-cooperative player but to the group as a whole.

This game theoretical approach gives an accurate description of the problem. However, it does not give an accurate description of the complete solution space. The players in the example above may decide to set up an agreement. Whether such an agreement can be reached and what it should look like depends on a number of factors. If there are only two players involved that can trust each other it will be rather easy to reach an agreement. It will be harder to reach an agreement if more players are involved, e.g. if the power game is played in an apartment building. These players may also have different pay-offs due to the fact that the apartments differ in seize or the valuation of the quality varies because at the lobby someone is running a coffee bar with as a paid service wireless access. Players can also decide to find a technical solution that automatically keeps the power at the lowest level to reach a certain quality. In other words, the players can decide to play a game on another, higher, level (of collective-action) were the outcomes generated represent changes in the operational rules at the lower level.[52]

Cooperation in a large group can incur a free-rider problem. Some players will consume more than the agreed fair share in the use of a common resource or do less than their fair share in the efforts to reach an agreement, e.g. to develop a technical standard. This is especially the case if it is hard to notice if a player is not cooperating or if it is hard to sanction non-cooperative behavior. In such a case the dominant strategy for an individual player will be not to cooperate.

An example of free riding can e.g. be found in investments to be made to make more efficient use of a common pool resource, in our case the radio spectrum. The amount of spectrum available in the 2.4 GHz band for local wireless networking is rather limited. If the number of users increases, their transmissions will interfere with each other. Eventually, a situation comparable to the situation in Figure 2-6a will occur. All players are in a situation that the quality of their use of the resource is deteriorated due to the use of the same resource by others. One of the solutions could be to develop a new technology that makes more efficient use of the spectrum, i.e. uses less spectrum so that more users can be accommodated without interfering each other. A player could decide to put a lot of effort and associated costs in the development of this new technology. However, if this player actually uses this new technology he will use less spectrum and therefore other players will benefit from his action. Nobody will have an incentive to develop this new technology or to use this new technology on his own, because others will free-ride on the costs to be made in the development and use of this technology.[53]

The collective-action problem as described by Olson (1965) and the Tragedy of the Commons as described by Hardin (1968) can be regarded as a repeated Prisoner's Dilemma with multiple players with free-riding at the heart of the problem. If the dominant strategy is followed by all actors the collective benefits will not be realized (Ostrom, 1990; Scharpf, 1997).

Olson (1965) argued in his seminal book on collective action that if the size of a group increases the probability of free riding also increases. Olson gives two reasons. First, if the group size increases the ability to notice free-riding decreases and, second, if the group size increases the transaction costs will increase. However, if there are a few players with a strong incentive to provide the collective good the likelihood of providing the collective good increases. Overall, he came to the conclusion that without selective incentives to motivate participation, collective action is unlikely to occur even when large groups of people with common interests exist. Although Olson's arguments are often true, there is a number of other variables that have an influence on collective action (Sandler, 2001; Ostrom, 2007a). What is needed is a closer look into the structures and interactions that

52 Although the actors are in this case in a game which involves cooperation, this does not mean that this is a cooperative game. In a cooperative game, players have the possibility to reach a binding agreement on cooperation before making a move. Hence, cooperative gaming is a game among coalitions of players, with the best possible coalition as a result. A non-cooperative game is played among individual players (Sandler, 2001).

53 This kind of action can really be noticed in the Wi-Fi band. The band used for Wi-Fi used to be limited to 83.5 MHz in the 2.4 GHz band. Because of the huge growth in the use of Wi-Fi, administrations took the decision in the WRC2003 to allocate another 555 MHz of spectrum in the 5 GHz band as well. However, the uptake of the use of the 5 GHz band was not as fast as expected. There is still very limited use of the 5 GHz band and most growth of Wi-Fi is still in the 2.4 GHz band (Hazlett, 2006; Dijken, Brouwer and Lippman, 2015). This is probably due to free rider problems associated with the development and the use of 5 GHz technology. A user that decides to use the 5 GHz band will have to invest in new equipment, but at the same time others that keep using the 2.4 GHz band will profit from this investment because this 5 GHz user will leave the 2.4 GHz band.

permit the adoption and enforcement of collectively binding decisions (Scharpf, 1997; Ostrom, 2005b). This closer look is the topic of the next subsection.

2.5.4 *The Institutional Analysis and Development framework*

The previous two subsections showed that there is a need for a framework that focusses on the incentives for collective action and the outcomes of collective actions between the various actors in the exploitation and governance of the radio spectrum. There are various frameworks which can be used to analyze how institutional rules can affect behavior of individual rational actors. Two well-known institutional rational choice frameworks are the actor-centered institutionalism framework (ACI) from Mayntz and Scharpf (Mayntz and Scharpf, 1995; Scharpf, 1997) and the Institutional Analysis and Development framework of Elinor Ostrom and others from the Workshop in Political Theory and Policy Analysis at Indiana University, Bloomington (Kiser and Ostrom, 2000; Ostrom, 2005b).[54]

Actor-centered institutionalism proceeds from the assumption that social phenomena are to be explained as the outcome of interactions among intentional (individual and/or collective) actors, but that these interactions are structured, and the outcomes are shaped by the characteristics of the institutional settings within which they occur (Scharpf, 1997: 1). The ACI framework is for the purpose of this analysis somewhat limited because it focuses entirely on the institutional setting as explanatory factor for the outcome of interaction among actors. It does not take account of the technology and the characteristics of the resource as explanatory factors.

The characteristics of the resource (the radio spectrum) and the technology that is necessary to exploit the radio spectrum are considered relevant factors in the governance of the radio spectrum, as both the technology and the characteristics of the radio spectrum will have an impact on the amount of interference and hence on the need for collective action.[55] Therefore, the institutional analysis and development framework (IAD) of Elinor Ostrom et al. is selected as the basis to answer the research question.

The IAD framework has been developed to enable systematic analysis of 'institutional arrangements' and to compare alternatives. The origin of the IAD framework dates back to the 1970s. In these years Elinor Ostrom and other scholars at the Workshop in Political Theory and Policy Analysis at the University of Indiana were trying to understand how the diverse paradigms in political science affected the thinking about public administration and metropolitan organization. In these early days the framework was applied as a foundation to conduct an extensive number of empirical studies on police service delivery in metropolitan areas (Polski and Ostrom, 1999). In these studies, Ostrom challenged the (at that time) popular belief that consolidation and centralization of police services was the most effective way to provide the public service to citizens. Ostrom demonstrated that local small-scale police forces cooperating with citizens were more effective in the delivery of those services than large-scale centralized police forces (Boettke, Palagashvili and Lemke, 2013).

The IAD framework was first described in 1982 by Kiser and Ostrom. A key element of the IAD framework is that it describes three levels of action. Constitutional choices configure a space within which collective choices are made, which in turn shape how individual (or group) actions are decided upon at the operational level (Kiser and Ostrom, 2000; Ostrom, 2005b).

54 Also known as the Bloomington School.

55 This will be further explained below.

The IAD framework evolved during the years in its application from public services to other research areas, most notably the analysis of institutional arrangements related to common-pool resources. Elinor Ostrom applied the framework on detailed existing case studies also written by other authors to analyze common pool resources. The result is probably the best-known work using the IAD framework, Elinor Ostrom's book, *Governing the Commons (1990)*.

Although the framework is strongly related to the governance of common pool resources, its use is much broader. It has been used in a number of categories for policy analysis and design, including the following (Polski and Ostrom, 1999):

- Economic development issues including infrastructure and privatization;
- Common-pool resource management;
- Public services and governance;
- Constitutional design;
- International relations.

These analyses covered a great number of fields, such as the financial sector, health, knowledge and agriculture. It has been proposed as a tool for the analysis of the privatization and regulation of the public services including the telecommunication sector (Araral, 2009).

The IAD framework

Figure 2-7 provides a schematic representation of the IAD framework.[56]

At the heart of the framework is the behavior of the various actors in action arenas. The participants in an action arena respond to incentives that come from three sets of factors:

1. the characteristics of the physical and material conditions (goods and services);[57]
2. the characteristics of the community;
3. the characteristics of the rules-in-use;

First, the incentives of participants in an action arena will be determined by the physical and material conditions of the resource. These include not only the characteristics of the resource but also the capabilities related to providing and producing goods and services. These include production inputs like capital, labor, and technology, as well as sources of finance, storage, and distribution channels and the scale and scope of the provision and production of goods and services.

In the analysis questions can be asked such as: Is the resource characterized by scarcity or by abundance? Is there a wide diversity of goods and services that can be used or harvested from the resource, or is the use of the resource limited? Are there diverse uses of the resource possible and if so are these compatible with one another or not? Is productivity distributed in a temporal and spatial evenly manner? Is the resource resilient, or vulnerable to shocks? Are the physical characteristics of the resource such that it is relatively easy to make exclusive access- and/or monitoring arrangements?

In our case of the radio spectrum, not only the characteristics of the resource and its capability to provide applications and services are of importance, but also the technology used to deliver those applications and services. These characteristics give

[56] This figure represents the framework as presented by Ostrom in her earlier work. Ostrom (2010) abandons the enclosure of the action situation in an action arena with participants because the capabilities of participants to contribute to the action situation are determined by the exogenous variables. In this thesis the older version of the framework, including the term "action arena", is used to emphasize that the participants will deal with action situations in particular settings.

[57] E. Ostrom (2005) uses the term "biophysical world". It is a term that can be used for natural resources that were studied when the framework was introduced, but it doesn't fit well to the technologically related resource of radio spectrum. Therefor I use simply the term "physical world".

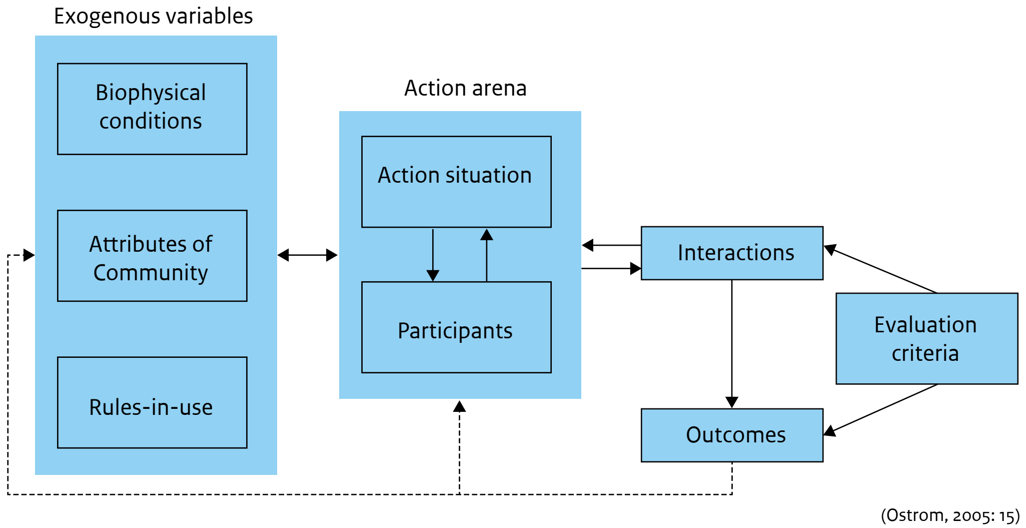

Figure 2-7 The IAD-framework.

rise to various problems, which can be classified as appropriation externalities, assignment problems and technological externalities (Ostrom, Gardner and Walker, 1994). Appropriation externalities arise from the phenomenon of interference; one user's increased use of the radio spectrum (e.g., through an increase in transmission power or an increase in the service area) can reduce the ability of other users in the vicinity to use the same part of the radio spectrum. The heterogeneity of the (propagation) characteristics of the radio spectrum and the heterogeneity of the services lead to assignment problems because a large variety of users might want to have access to the same, most attractive, part of the radio spectrum. Technological externalities occur due to the fact that a change of technology by one user can have an impact on the costs (or e.g. the quality of service) of other users. Questions can then be asked about the consequences of the heterogeneity of the propagation characteristics of the radio spectrum on the delivery of applications and services and on its influence on the access and monitoring arrangements in the different parts of the radio spectrum.[58]

Second, the incentives of participants in an action arena will be determined by the attributes of the community. These attributes include demographic features of the community, generally accepted norms about policy activities, the degree of common understanding potential participants share about activities in the policy area, and the extent to which potential participants' values, beliefs, and preferences about policy-oriented strategies and outcomes are homogeneous.

Questions can be asked such as: What are values and preferences with respect to strategies for achieving outcomes, as well as outcomes for the various

58 The non-homogeneous propagation characteristics make some parts of the spectrum more suitable than others for different kinds of applications. For the same reason interference is more of a problem for the lower part of the frequency spectrum than the higher part. This is further explained in annex I.

actors? Are these preferences about the use of the resource widely divergent? Are the sub-groups with different preferences about resource use more or less equal in size or power? What knowledge and information do actors have about the relationship among policy-oriented strategies, actions, and outcomes? What are the actors' beliefs about the strategy preferences and outcomes of other actors?

In the case of radio spectrum this translates to the wide diversity of user (groups) using the radio spectrum for various applications or to provide services: radio amateurs, commercial service providers, professional users, public service providers, governmental bodies that need spectrum to perform their public task (e.g the military and emergency services) and a large variety of users of wireless devices. Other players that are involved are manufacturers of wireless devices and infrastructure and of course the government as the prime coordinator of spectrum. Questions can then be asked about the preferences of the diverse user groups, about the homogeneity within the user group (e.g. incumbent mobile operators may have different incentives than potential market entrants), and how the values and preferences of the government relate to those of the various private user groups.

Third, the incentives will be determined by the rules-in-use that constrain and affect the behavior of actors. The focus is on the formal and informal rules that are operational to explain policy-related actions, interactions, and outcomes. An institutional analysis should distinguish between three levels of rules that cumulatively affect the actions taken and outcomes obtained in any policy situation (Polski and Ostrom, 1999; Kiser and Ostrom, 2000). At the operational level, actors are interacting with each other and the relevant physical/material world, making day-to-day decisions about the exploitation of the resource. The operational rules are the ever-day rules that directly affect the decision making of these actors in political and economic settings. These rules can change relatively rapidly. Operational rules stipulate

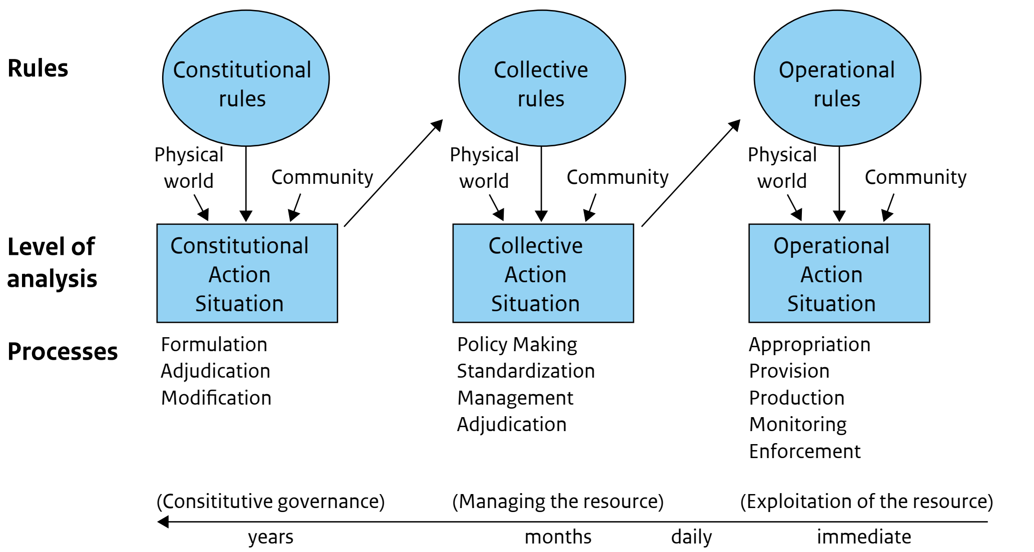

Figure 2-8 Three levels of analysis. Adapted from (Ostrom, 1990: 53)

for example what goods and services can be produced and provided, by whom, in what quantities, when and where? The second level is the collective-choice level of analysis where actors interact to make the rules for the operational level. These are the rules that are used by the users and the authorities to manage the resource. Collective-choice rules determine who is eligible to participate in the activity to adapt the operational rules, and the specific rules to be used in changing the operational rules. These collective-choice rules change at a much slower pace. The third level is the constitutional level. This level of analysis can be used to explain the design of collective-choice mechanisms. Constitutional rules determine who is eligible to participate in crafting collective-choice rules and the rules to be used in crafting the set of collective-choice rules that, in turn, affect the set of operational rules. Constitutional-choice rules change at the slowest pace. According to Ostrom (2005b), it is even possible to think of a "metaconstitutional" level overarching all the others, which is comprised of the informal institutions, customs and traditions of society (Polski and Ostrom, 1999; Kiser and Ostrom, 2000; Ostrom, 2005b).[59]

At each level there can be one or more action situations involving various sets of participants in which different types of decisions are made. Participants are thereby restrained by the institutional setting and other factors in their strategic options. The choices of participants lead to *patterns of interaction* and results in *outcomes*. Both the outcomes and the patterns of interaction are evaluated. It is most likely that different groups of actors will use different evaluation criteria. This kind of criteria may also be used by the analyst to investigate certain patterns of interaction and outcomes. This evaluation may induce new incentives for further action or may be a driver for change in the original exogenous variables thereby restructuring the situation (Polski and Ostrom, 1999; Ostrom, 2005b). A government may for instance want to change the rules on access and use of the resource if the goals of an economic and social efficient distribution are not met.

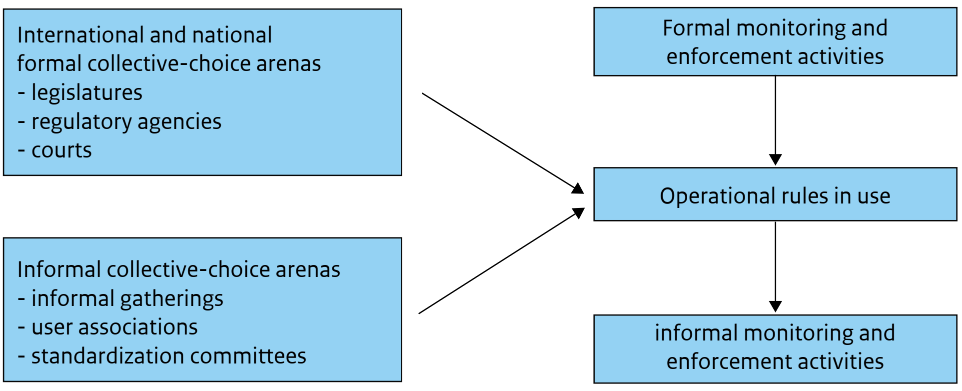

Figure 2-9 Collective action in formal and informal arenas. Adapted from (Ostrom, 1990: 53)

[59] This "meta-constitutional level is, according to Ostrom (2005b) comparable to the first level of the layered model presented by Williamson.

In the case of spectrum, we already identified various institutional arrangements (of property rights, unlicensed access and command-and-control) that will have different influences on the applications and services to be provided. The government and the private actors will gather in various formal and informal (inter)national action arenas, e.g. to allocate spectrum, to standardize technology, to formulate policies, to assign frequencies, to monitor and enforce its use and to trade property rights, as shown in Figure 2-9.

Structure of the action arena

At the heart of the framework is the action arena in which various actors observe information, select actions, engage in patterns of interaction and realize outcomes from their interaction (McGinnis, 2011). The action situation is described in terms of a formal game. In real life situations the action situation will be often so complex that it is not possible to describe it as a complete formal game. But, that does not mean that a game theoretical approach is useless. A game theoretical approach can be used to describe the structure of more complex action situations in a nonmathematical form (Scharpf, 1997; Ostrom, 2005b).
The structure of the action situations within the arena can be described and analyzed by using a common set of variables. The IAD framework uses a cluster of seven variables. The following questions can be used to explain behavior of various actors in an action situation (Polski and Ostrom, 1999):

- i What are the **positions** or roles that actors play in this situation?
- ii Who are the **participants**?
- iii What **actions** can participants take, and how are actions linked to outcomes?
- iv What **information** about the action situation is available to participants?
- v What is the level of **control** that each participant has over action in this situation?
- vi What **outcomes** are possible in this situation?
- vii What **costs and benefits** do participants incur when they take action in this situation?

The internal structure of an action arena is found in Figure 2-10.

This cluster of seven variables relates to seven types of rules (Ostrom, 2005b):

1. **Boundary rules** that specify how actors were to be chosen to enter or leave these positions;
2. **Position rules** that specify a set of positions and how many actors can hold this position;
3. **Choice rules** that specify which actions are assigned to an actor in a position;
4. **Information rules** that specify channels of communication among actors and what information must, may, or must not be shared;
5. **Scope rules** that specify the outcomes that could be affected;
6. **Aggregation rules** (such as majority or unanimity rules) that specify how the decisions of actors are to be mapped to outcomes;
7. **Payoff rules** that specify the distribution of the cost and benefits and costs over the actors positions.

Actor behavior

In an action situation the actors can be thought of as a single individual or as a group functioning as a single collective or corporate actor. To analyze the behavior of individual actors assumptions will have to be made about (Kiser and Ostrom, 2000; Ostrom, 2005b):

1. the information actors have about the decision situation;
2. the actors valuation of possible actions and potential outcomes;
3. the actors calculation process to decide upon strategies.

In other words, the choice of strategy in any particular situation will depend on the way individual actors perceive and valuate the costs and benefits of various strategies.

To do institutional analysis, it is a methodological requirement to apply a model for the behavior of

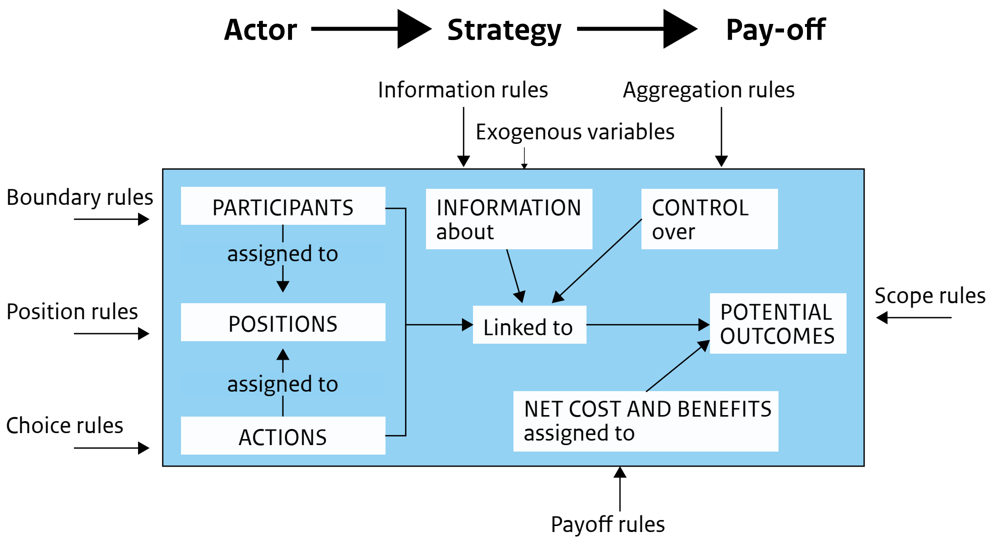

Figure 2-10 The internal structure of an action arena (adapted from Ostrom, 2005b: 33).

the actor which holds these assumptions on actor behavior fixed (Kiser and Ostrom, 2000; Diermeier and Krehbiel, 2003). When analyzing various institutional settings, it is only possible to explain changes in the strategy of actors and the outcome as a result of a change in the institutional setting (or other exogenous variables) if the model for the actors' behavior is held constant during the analysis. Otherwise, it will be very difficult to conclude if a change in strategy and outcome is to be explained by a change in the institutional setting or by a change in the model for the actor's behavior.

The most well-established formal model of individual behavior used in institutional analysis is that of Homo-economicus. In this model actors have complete information, well-ordered preferences and they maximize the net value of expected returns for themselves. Under these assumptions, actors behave as a rational egoist. These assumptions can be very useful in institutional analysis of an open competitive market setting. In an open and competitive market there will be many sellers of comparable goods. Differences in prices then reflect relevant information to make a rational choice. However, in many situations of interest, these assumptions do not hold. For instance, there may differences in the quality of the goods and services that are provided. Information on the differences in service offering are not always readily available, which make it harder to compare various offers (Ostrom, 2005b).

In spectrum governance most actors are not individuals but are firms and other composite actors that in competition with one another are seeking access to spectrum and compete in the market for services or the related market for equipment. In this field not only private actors but also public actors are active, such as emergency services and public broadcasters that need access to spectrum to supply their service.

These actors operate within a complex situation which leads to uncertainty and a need for information that is not readily available but has to be searched for. Costs will be involved in this search for information. The result of this is that actors will have to base their decisions on limited information.

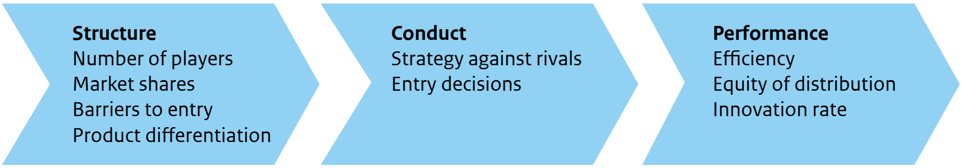

Figure 2-11 Structure-Conduct-Performance.

Moreover, actors have only limited information-processing capabilities and they will have limited time to make decisions. Hence, their rationality is bounded. They will act intendedly rational.

Actors will have different objectives, powers and strategies, but they also share a common body of information and knowledge about the nature of the resource and its use. These similarities in usage, technology and information lead to considerable similarities among actors and to the development of a characteristic structure of interrelationships between the actors. Vincent and Elinor Ostrom (1999) pose that this is not only the case for private firms in a particular industry but this is also applicable in the case of relations between governmental bodies in the provisioning of public goods and services.

Inter-industry studies in the field of industrial organization have provided many useful insights into the behavior of actors across markets and within markets under real world conditions. It takes account of the fact that firms will have to deal with real-world frictions such as limited information, transaction costs, government actions, and barriers to entry for new firms into a market that may be associated with imperfect competition. Within the field of industrial organization, the Structure, Conduct and Performance (SCP) paradigm has been developed, which is very useful as it can be used to explain and predict strategic behavior of actors in the market.

The behavior of actors (market conduct) is explained and predicted based on relatively stable, observable variables that describe the market structure within which the actors are active. The behavior of the actors in the market determines the market performance. The relationship between the market structure, the market conduct and the market performance is illustrated in Figure 2-11.

The market structure is a set of variables that are relatively stable over time and affect the behavior of the actors away from their behavior in a market of perfect competition. The market structure is described through the use of three key dimensions: the market concentration, product differentiation and conditions of entry, which include both barriers to enter and exit the market. The variables can be further divided in intrinsic structural variables and other, so-called derived, variables. The intrinsic structural variables are determined by the nature of the product and the available technologies.
The derived variables are dependent on the characteristics of the actual market itself, such as the number of firms that are active in the market (the market concentration), the conditions of entry and the product differentiation. The market structure is used to explain and predict the strategic behavior of actors in the market: the exercise of market power, investments in research, in development, collusion etc. This strategic behavior in the market affects the economic performance of the market (Schmalensee, 1989; Church and Ware, 2000).

2.6 The role of case studies

Having made clear why and how the Institutional Analysis and Development framework can and will be used to answer our research question, it is time to explain why a case study approach will be taken to perform institutional analysis in the field of radio spectrum governance.

In natural sciences it is very common to conduct experiments in which a single factor can be isolated and systematically varied. Experiments provide insight into cause-and-effect by demonstrating what outcome occurs when the isolated factor is altered. This approach is more complicated in social science and can only rarely be used (Lijphart, 1971; Scharpf, 1997).[60] The complexity of the problem at hand and the fact that there is no grand all-encompassing theory of institutional economics make it sheer impossible to perform experiments that could be used to examine propositions.

Alternatively, historical descriptive case studies could be used to get an understanding of the complex process in which technology, institutions and actors interact. Case study research has evolved into a distinctive approach to scientific inquiry and is considered to be appropriate to use when a holistic, in depth investigation is needed of a broadly defined research topic with complex multivariate conditions and not just isolated variables (Yin, 2003a). Yin (2003b: 13) defines case study as "*an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomena and context are not clearly evident*". In the context of this research, "*case studies are considered as important ... for understanding the role of institutions in societies*" (Alston, 2008: 103).

Hence, a case study approach fits the exploratory nature of our main and sub-questions. Our questions are aimed at providing an in depth understanding of the role of the government in the institutional environment and arrangements to coordinate the exploitation of the radio spectrum and how various institutional environments and arrangements involving private coordination contribute towards efficient and effective exploitation of the radio spectrum. This coincides well with the essence of a case study as formulated by Schramm (1971: 6): *the essence of a case study the central tendency among all types of case study, is that it tries to illuminate a decision or a set of decisions: why they were taken, how they were implemented, and with what result*. These are the kind of questions that are of relevance to answer our research question.

In this research, use will be made of multiple historic case studies. Multiple case studies create a possibility to do comparative analysis of real-world phenomena to discover causal relationships. If applied in the field of institutional analysis, this is what Coase (1964) called "*comparative institutional analysis*".[61] Comparative analysis of real-world phenomena is generally the only way to discover causal relationships in doing policy oriented research. It involves an intense analysis of a few carefully selected cases (Lijphart, 1971; Scharpf, 1997). So, the next question is which historic cases to select to perform the research. In essence there are two different approaches that can be taken to select the historic cases. One approach is to use the *most similar* cases. In this approach, cases are selected that are similar in as many variables as possible with the exception of the phenomenon to be examined (Przeworski and Teune, 1970). The problem is that the potential number of different constellations of

60 There is a branch in economics called experimental economics which involves the design and conduct of experiments to examine propositions implied by economic theory.

61 Aoki (1996), Greif (1998) and others developed a new field of comparative institutional analysis which uses a game theoretic approach to comparative studies of institutions. See Aoki (2001) for an overview of this field of comparative institutional analysis.

situational and institutional factors will be so large in the type of research at hand that it is unlikely that exactly the same factor combination will appear in empirical cases. This will make it extremely difficult if not impossible to find the *most similar* cases needed to perform the comparison (Scharpf, 1997).

Another approach is to select historic cases which differ the most in order to investigate the phenomenon (Przeworski and Teune, 1970). This approach of maximum variation is chosen to select cases. Historic cases will be selected which differ the most in the key variable of investigation (Lijphart, 1971; Patton, 1990). The case studies will be used for a systematic analysis of the coordination activities between actors for various spectrum governance regimes. The cases will be selected along the three axis of Figure 1-1. Distinct historic case studies will be used that describe the introduction of command-and-control by the government, the introduction of private property rights and the introduction of unlicensed access. An important factor in the final selection of the historic case studies is that they are very well described in the literature and various, independent, sources of information are available (Yin, 2003b). The actual selection of historic case studies will be discussed in the next section.

One of the more difficult tasks of performing case studies is to prevent the research from becoming simply a collection of "good stories". To go beyond the descriptive case studies and narrative explanations, it is important to make a disciplined and analytical assessment of the historical cases, also known as an "*analytical narrative*". *The term "analytical" conveys the use of a theoretical framework or set of theoretical concepts and the term "narrative" conveys the use of historical qualitative evidence* (Alston, 2008: 103), The IAD framework offers this descriptive language and an ordering system to isolate what is exogenous and what is endogenous to the actors in the setting that we are trying to understand. It provides the means to make an analytical narrative that describes the causal relationship between on the one hand the institutional and other situational factors and on the other hand actor behavior (Scharpf, 1997; Yin, 2003b; Ostrom, 2005b).

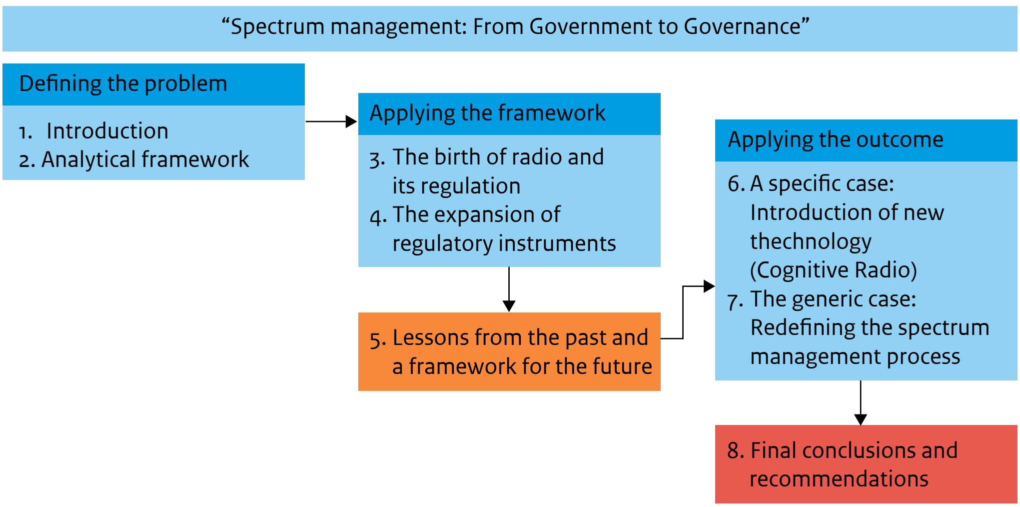

Figure 2-12 Structure of this thesis.

2.7 Structure of this thesis

The thesis is structured in three parts, as shown in Figure 2-12.

The first part provides the necessary background needed for the analysis of the problem. This part consists of the chapters 1 and 2. Chapter 1 describes the problem and poses the research questions. Chapter 2 (this chapter) describes the analytical tools that are used to answer these research questions. It provides the theoretical foundation and introduces the analytical approach for the analysis.

The second part of the thesis continues the research with a systematic analysis of the coordination activities between actors for various spectrum governance regimes. Case studies are used to analyze these coordination activities that takes place in specific and distinct situations. The cases will identify tensions and the role of the various actors to deal with those tensions. This will provide insight in the applicability and specific design of the various regimes under certain situations. As stated in the previous section, historic case studies will be chosen along the three axis of Figure 1-1, being governmental control, a market for property rights and technology for unlicensed access. The historic case studies that are selected are given in the table below.

Axis of coordination	Historic case study
Governmental control	The Birth of Radio and its international regulation
Market (Private property rights)	A comparison of the uptake of mobile communications in the United States and Europe
	Privatizing the air waves in Guatemala
Technology (Unlicensed access)	Wi-Fi: Private coordination to develop technology for unlicensed access

Table 2-2 Selected historic case studies along the three axis of coordination.

The second part with the analysis of historic case studies starts in chapter 3 with an historical case study on how governments became involved in spectrum management. This case study describes the birth of the radio and the early private initiatives from Marconi up to the crafting of the international regulatory framework in 1927, which is the foundation of the current spectrum management regime. This case study identifies the triggers behind the coordination mechanisms in the current "command & control" regime and the problems that are associated with it. This case study is chosen for two reasons. First, the case study will give insights in the drivers for government involvement in the coordination activities. A second and for the research very important aspect is that this case study starts with a green field, a practically untouched and unregulated resource with open access, in which the regulatory environment was gradually introduced. This means that this is the simplest of cases that can be chosen to analyze governmental involvement in these coordination activities.

This case study is followed by historic case studies along the two other axis of coordination in chapter 4. The chapter starts with a comparative case study on the difference in treatment of 2G in Europe with a government guided approach and the US where the coordination on the use of certain technology was left to the market in a property rights regime. This case study is used to further explore the tensions between the objectives of the government and private sector in a command-and-control regime compared to a regime that is based on private property. This is followed by a case study on the development of Wi-Fi, one of the best known and documented examples of the introduction of a spectrum management regime based on open access. The last case study of this chapter described the introduction of a regime based on individual property rights in Guatemala (privatization of the air waves in Guatemala). Although, there are also other countries that (gradually) introduced property rights in spectrum, Guatemala was chosen because it took a big step in the privatization of the radio spectrum, resulting in "*perhaps the most liberal spectrum regulatory policy in the world*" (Hazlett, Ibarguen and Leighton, 2006: 6).

The second part of the thesis ends with chapter 5. In this chapter the various cases are compared. This comparison is used to draw some intermediate conclusions and to provide an answer to the subquestions on the coordination activities that have to take place in the governance of spectrum and the (existing) role of the government therein. These lessons from the past will be used to develop a framework that can be used to analyze the coordination activities between private actors and the government. The central element of the framework is the alignment of the objectives of the government to safeguard the public interest with the objectives of the private actors.

In the third and final part of the thesis this alignment framework will be used to conclude on the policy implications for spectrum management. The framework will first be used in a specific case, the more forward looking case study of "the introduction of new (cognitive) radio". In this specific case, the alignment framework is applied to analyze the coordination between private actors and the government in the case of the introduction of new (cognitive) technology in the United States. Based on these findings, policy recommendations will be made that can be used for the introduction of new technology to exploit the radio spectrum. Next to this specific case, policy recommendations will be drawn for the generic case of radio spectrum management in chapter 7. In that chapter the research questions will be answered through the proposal of a redefined spectrum governance process. The chapter will also provide suggestions to implement this redefined spectrum governance process in the (inter)national spectrum management arenas. Both chapter 6 and chapter 7 will capture recent experience in the Netherlands with this new role of the government in the spectrum governance process. The thesis ends with a chapter which summarizes the main findings of the research and the conclusions that can be drawn from this research.

3 The birth of radio and international regulations

This chapter will examine the behavior of government and other actors in the coordination activities related to the exploitation of the radio spectrum from the birth of radio communications until the realization of the international radio regulations as defined in 1927. These radio regulations still form the basis for the national and international regulations in use today.

The case study starts with the early days of radio when Marconi started his experiments. In those early days the resource was an open and untouched pasture. When Marconi stepped in to use the radio spectrum, there was no interference and no reason for coordination. So the question is, why did there arise a need for coordination, what kind of coordination was needed and what were the incentives of government to participate in this coordination?

The focus of the analysis is on the decisions that were taken by various governmental and private actors in this coordination activity; why were these decisions taken? What were the motives and incentives of those actors to participate in this coordination activity and to take those decisions? And what was the effect of those decisions? To what extend is the behavior of the actors in the action arenas influenced by not only the institutional setting, but also by the characteristics of the resource and the services and applications that it can provide and the characteristics of the community that is involved in this interaction, as explained in chapter 2?

"If you would understand anything, observe its beginning and its development."

Aristotle, Greek philosopher, 384-322 BC

3.1 The birth of radio communications

Although electro-magnetic waves have always been around as a natural phenomenon, the part of the electromagnetic spectrum that we now call the radio spectrum remained unused and unclaimed until the end of the 19th century.[62] At that time the technology was being developed to turn a particular part of the electromagnetic spectrum into a valuable resource for communication without wires. Heinrich Hertz was the first who deliberately entered this open and untouched pasture.[63] In 1888 Hertz did experiments to create and detect electromagnetic waves, thereby confirming the existence of these "radio waves" as postulated by the theoretical works of James Clerk Maxwell in 1864 (Cichon and Wiesbeck, 1995). [64]

Since then, many scientists and engineers have contributed to the development of equipment that could be used to transmit and receive radio waves. Among them were Tesla, de Forest and Fessenden in the United States, Braun and Slaby in Germany, Popov in the USSR, Lodge in the U.K., Branly in France, Righi in Italy and Bose in India (Belrose, 2006). However, the birth of radio is generally credited to Marconi.

The reason that Marconi is credited for being the father of radio is because he did not only do experiments with radio waves, he also realized the commercial value of its use. Marconi started his experiments at home, the Villa Griffone in Pontecchio, Italy. Because Marconi found little commercial interest for his invention in Italy, he travelled to London in early 1896 at the age of 21, accompanied by his Irish mother, to commercialize it. As a first step, he went to the patent office to declare the birth of wireless telegraphy and to secure his commercial interests. The filing of a patent for a wireless[65] telegraph system by Marconi on June 2, 1896 is generally regarded as the birth of radio and thereby the commercial use of the radio frequency spectrum. It was the first patent related to wireless telegraphy ever granted (Hong, 1994; Meyer, 1995).

The scientific contribution to the development of radio transmission covered by this patent is generally seen as limited and the patent was contested by others.[66] However, there is general agreement that Marconi made a significant contribution to the practical and commercial use of radio waves, an until then unexploited resource.[67]

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[62] The term "radio" is derived from the Latin word "radius" in its meaning of "ray".

[63] David Hughes already performed demonstrations with the transmission and detection of radio waves in 1879. However, he did not know the scientific nature of his demonstrations (Constable, 1995). Heinrich Hertz was the first person who set up experiments to prove the existence of radio waves, as postulated by the theoretical works of James Clerk Maxwell, and rule out other phenomena. The international systems of unit for frequency (cycles per second) was named Hertz in his honor for this scientific breakthrough.

[64] Radio waves are a subset of electromagnetic waves. The radio spectrum is considered to encompass all electromagnetic waves with a frequency lower than 3000 GHz. Hertz did his experiments in the radio spectrum. In the experiments that verified the existence of electro-magnetic waves, he identified waves with a wavelength of 9.6 m (31.25 MHz) (Cichon and Wiesbeck, 1995).

[65] The words "wireless" and "radio" are more or less interchangeable. Especially in those early days the term "wireless telegraphy" and "télégraphie sans fil" were commonly used to denote what the system was: a telegraph system without wires. Nowadays, the term radio is more commonly used. Edward C. Hubert put it as follows in his article Radio vs. Wireless, in the *Radio News* of January 1925 (p. 1165): "There is no difference between radio and wireless except the spelling."

[66] Marconi used to a large degree technology that was developed by others; Righi's spark transmitter, a version of the Branly and Lodge coherer, and the vertical aerial of Dolbear which was also used by Tesla. Oliver Lodge claimed that the patent contained his own ideas which he failed to patent (Brittain, 2004; Belrose, 2006). However, this claim was probably made on national sentiments (Hong, 1994).

[67] The Nobel Prize in Physics 1909 was awarded jointly to Guglielmo Marconi and Karl Ferdinand Braun "*in recognition of their contributions to the development of wireless telegraphy*" (ITU, 1965).

Marconi realized that radio could be used to provide wireless telegraphy in places where the normal (wired) telegraph could not be used. He had especially ship-to-shore and ship-to-ship communications in mind, for naval operations, to enhance maritime safety and to provide ship-to-shore public correspondence.

His focus on ship-to-ship and ship-to-shore communications was not only because Marconi saw a new business opportunity but also because he was restricted by existing regulations. The British government had a monopoly on telegraphy and any other communication by means of electric signals.[68] The exclusive privilege given to the British Post Office limited Marconi in the services he could provide.[69] However, this privilege was only for communications within British territory. It was not applicable to communications exchanged by wireless telegraphy with foreign countries nor with ships beyond the limits of the territorial waters (Neilson, 1903). In 1899 the Marconi Company applied for a license to use the system on land in England, but the British Post Office refused to grant it (Howeth, 1963; Bertho Lavenir, 1991).[70]

All his work in these days was about adding ideas and making improvements to radio equipment to make it suitable for communication purposes. He was building on the scientific work of others. Marconi's patent application of June 1896 was titled "improvements in transmitting electrical impulses and signals, and in apparatus therefor." The main contribution of this patent was on the use of antennas and on improvements in the sensitivity of the receiver. Both were intended to improve the range over which communications is possible (ITU, 1965; Meyer, 1995).

Marconi's commercial intentions became apparent from the fact that he filed an update of the application on 2 March 1897. This update made the patent very strong, despite its humble name. The update made it such that it covered wireless telegraphy as a whole and not just some improvements. Shortly after Marconi's patent was granted on 2 July 1897, Marconi formed the "*Marconi Wireless Telegraph and Signal Company*" (renamed to Marconi Wireless Telegraph Company in 1900) to exploit his patent (Hong, 1994).[71] It was the first company with a production facility for wireless equipment. There were many rivals experimenting with radio, but in those early years there was no other manufacturing company (ITU, 1965; Pocock, 1995).

Marconi's next step was to find customers for his new company. One of the first assignments was life press coverage of the Kingston Regatta, a yacht race, from a ship in July 1898 (Howeth, 1963; ITU, 1965). In these early years, Marconi did experiments to further improve the range of the equipment, and he also did numerous demonstrations to get exposure for his equipment. It was a continuous struggle to keep the performance of his wireless systems ahead of anything his competitors could achieve. After numerous demonstrations in Italy and England, he

68 This monopoly of the national Post and Telephone Office was the case in many western European countries, including the Netherlands. The Dutch monopoly on telegraphy included wireless telegraphy was made explicit in the "Telegraaf- en Telefoonwet" of 1904. This law stipulated that a license was needed for public wired and wireless telegraphy. A Royal Degree of 6 March 1905 extended the need for a license to all (public and non-public) telegraphic communications (Vogt, 1958).

69 Marconi also did experiments with land based communications and in 1901 Marconi even did experiments with a mobile radio set (ITU, 1965).

70 This was not the only case in which Marconi encountered a problem with a monopoly on a telegraphy service. After Marconi claimed to have realized a successful transmission from Newfoundland to England the Anglo-American Cable Company asked him to stop the experiments, because they saw it as an infringement to their monopoly on telegraphy (Bertho Lavenir, 1991; Weightman, 2003).

71 Marconi also applied for a similar patent in the United States. The equivalent U.S. Patent, No. 586,193 was granted on 13 July 1897 (Howeth, 1963).

realized for the first time communication across the English Channel from England to France in March 1899. He continued his experiments to go much further. On the 12th of December 1901, Marconi reported to have succeeded to receive signals from a transmitter located at Poldhu, Cornwall (UK) at a receiving station on signal Hill, near St. John in Newfoundland at the other side of the Atlantic Ocean, a distance of 3500 kilometers (Weightman, 2003; Brittain, 2004; Belrose, 2006).

All Marconi's experiments and demonstrations gave attention to his Company in the general press. He was very successful in doing that. For the general public, the name Marconi became associated with the invention of wireless telegraphy. The world did not understand what Maxwell, Hertz, Tesla, Lodge, Branly, Popov, Fessenden, and many others had done, and their achievements had not been publicized in the general press. This contributed to the fact that Marconi is seen as "the father of wireless telegraphy" (Howeth, 1963; Belrose, 2006).[72]

The first customers for equipment from the Marconi Company were companies that provide coastal services i.a. Lloyds, the marine insurance company's association who used wireless equipment for some of its more remote signal stations (light ships) and the Italian Navy in 1898. The experiments and demonstrations of wireless telegraphy also got the attention of the Royal Navy. In the summer of 1899 a series of very successful tests were done under active service conditions during fleet maneuvers. However, the military had a serious technical reservation. The equipment of Marconi was untuned. This means that a receiver was sensitive to every transmitter within range and everyone who possessed an appropriate device could receive the transmitted signal in a very broad frequency spectrum. This emphasized the fact that wireless messages were difficult to keep secret. However, secrecy was an important requirement not only for the military, but also for commercial users (Howeth, 1963; Friedewald, 2000).

Marconi received another British patent in 1900. This patent covered the tuning of both the sending and receiving stations. This famous "four-sevens" patent of Marconi ((British patent 7777; granted 26 April 1900) was not without its difficulties. It was based on patents of Lodge and Braun. This patent survived British litigation, partly because Marconi decided to buy Lodges' patent when the Marconi patent was contested by Oliver Lodge.[73]

Marconi's "syntonic system" had some advantages that made it commercially attractive: tuning increased the range considerably, it made radio communication possible by more stations simultaneously, the interference between stations

[72] The first president of the Institute of Radio Engineers, Robert H. Marriott (1925: 160), once said about Marconi: *"He played the part of a demonstrator and sales engineer. A money getting company was formed, which in attempting to obtain a monopoly, set out to advertise to everyone that Marconi was the inventor and that they owned that patent on wireless which entitled them to a monopoly."* (see also Belrose, 2006). Gavin Weightman (2003) wrote a fascinating story of Marconi's demonstrations and experimentations and his continuous struggle to keep ahead of his competitors. Raboy (2016) wrote a more detailed biography of Marconi.

[73] Marconi also applied for the patent in the United States. The U.S. equivalent (U.S. patent No. 763,772) was granted 28 June 1904. After the First World War the Marconi Company claimed that the American Government used wireless equipment that infringed on his 1904 American patent without paying royalties. Finally in 1943, the United States Supreme Court took a decision which invalidated Marconi's 1904 American patent on the grounds that its tuning was not original, as its content was already covered by the patents of Lodge (U.S. patent No. 609,154 of 16 August 1898), Braun (U.S. patent No. 750,429 of 26 January 1904) and primarily Tesla (U.S. patent No. 645,576 of 20 March 1900) (Belrose, 2006).

was reduced considerably[74] and it made unauthorized reception of messages more difficult, because the appropriate tuning frequency had to be known (Friedewald, 2000; Hong, 2001).[75]

The British Royal Navy entered into a long-term commitment with the Marconi Company in 1900. The contract covered the installation of radio equipment on 26 ships, the building of 6 coastal stations, the training of the personnel as well as the maintenance for a period of 14 years, the lifespan of the related British patents. It was the first major order for radio sets in the world (Howeth, 1963; Pocock, 1995).

The patents gave Marconi a very strong position in those early days. The Marconi company had practically a monopoly on radio apparatus for ship-to-shore communications (Bertho Lavenir, 1991; Friedewald, 2000). The attempts of competitors to develop their own radio systems led to numerous patent suits of the Marconi Company, on infringement of Marconi's patents. The first company in the US that started the competition was probably the United States Electrical Supply Company of W.J. Clarke who started to sell equipment in 1899. However, he was not very successful. His equipment was inferior to the equipment of Marconi (Howeth, 1963). The efforts of the De Forest Wireless Telegraph Company (1902) were also not very successful. He used a receiver based on the same principle as Fessenden, who sued De Forest for infringement of his patent. Fessenden set up the National Electric Signaling Company (NESCO) in 1902. NESCO used technology that diverged from the technology used by Marconi. It was based on the patents of Fessenden. Fessenden's receiver was more sensitive compared to that of Marconi. However, he wasn't quite as successful as a business man (Howeth, 1963; Weightman, 2003).

One of the first notable competitors was the German based AEG. The equipment of AEG was based on patents from Slaby and his assistant Arco.[76] Slaby had substantial support from the German Kaiser Wilhelm II and the German navy (Friedewald, 2000).

Just as the German navy, who backed AEG, the navies of other countries showed interest in wireless telegraphy. For reasons of national security their preference was for sets of domestic manufacture, even if that meant that the radio sets were technically inferior. The French and Japanese navies were reported to still be using untuned equipment (of national make) as late as 1904 (Pocock, 1995).

The sale of equipment to merchant shipping companies was not going very smooth. The equipment was expensive, there was a need for trained personnel and the benefits were not clear from the outset. Therefore, the Marconi Company decided to change its tactics. The Company decided to sell not only the equipment but wireless telegraphy as a service.

Another reason for Marconi's change of tactics was probably the monopoly of the British Post Office on public telegraphy. If wireless telegraphy is sold as a service, the Marconi Company would own both the

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74 That interference between stations was already an issue in these days was clearly demonstrated during the America Cup of 1901. Marconi, De Forest, and the American Wireless Telephone & Telegraph Co. participated in an attempt to cover the races. The latter firm intentionally created interference to prevent the transmissions of the other two participants from being received (Howeth, 1963; Pratt, 1968).

75 Of course, it is always possible to search for the appropriate tuning frequency. However, this will not be an easy task, because this is only possible in the time period that a transmission is made.

76 Slaby's first experiments were based on a replication of Marconi equipment. He acquired the required knowledge of the Marconi system during a demonstration of Marconi he had witnessed in the spring of 1897 (Friedewald, 2000; Weightman, 2003).

shipboard installations and the coastal stations; the shipping companies would hire both the sets and their operators from Marconi. Hence, ship-to-shore radio was operated as a series of private telegraph lines which didn't infringe the monopoly of the British Post Office on public telegraphy (Pocock, 1995).

Marconi set up a new company to deliver wireless telegraphy services in 1900, the Marconi International Marine Communications Company. He built his own land based radio stations along the sea-trade routes on the shores of Britain, Ireland, Belgium, Italy, Canada and New Foundland. He trained his own radio telegraphists and placed them on all ships he equipped with a wireless radio station. These radio telegraphists, or marconists as they were called, were only allowed to communicate with Marconi wireless stations both land based and onboard of other ships (ITU, 1965; Friedewald, 2000).[77] By doing so, he created a, very successful, private business using the common resource of radio spectrum.

Marconi's strategy and business head start gave rise to a fear of a worldwide monopoly by Marconi. Various accounts were reported of Marconi's abuse of dominant market power. As an example, the French government complained that a number of French radio stations at the coast of France were rendered useless as a result of the Marconi Company's refusal to accept correspondence from other companies (Neilson, 1903; Codding, 1952; ITU, 1965).

Marconi's dominance was especially seen as troublesome because the British already dominated international wired telegraphy. The possibility to escape this dominance through the use of wireless telegraphy was now endangered by the dominant position of Marconi in this field. This was seen as a problem for both military and other national interests. One of the consequences was that under pressure of the Kaiser the two leading manufacturers of wireless equipment in Germany, AEG and Siemens & Halske AG, joined forces through the formation of the Gesellschaft für drahtlose Telegraphie GmbH in 1903 (Friedewald, 2000).[78] Another consequence was that the behavior of the Marconi Company led to governmental involvement in the use of radio waves.

3.2 The birth of radio regulations

The following anecdote may have been the trigger for governmental involvement in the exploitation of the radio spectrum. In 1902, Prince Heinrich of Prussia made a visit to the United States. On his way back to Germany, he tried to send a courtesy telegram to President Roosevelt. However, his radio telegraphist did not succeed to pass the message. His radio telegraphist was unable to connect to the American coastal station, which was operated by Marconi, because his ship was equipped with a wireless station of German make (Howeth, 1963; Bertho Lavenir, 1991).

If this event really triggered the start of international coordination on the use of the radio spectrum is probably lost in history. Fact is that Kaiser Wilhelm II of Germany, who happened to be the brother of Prince Heinrich of Prussia, convened an international conference on the use of radio waves in 1903, with the intention to establish a basis for the international regulation of the radiotelegraph service (Neilson, 1903).

[77] This refusal of the Marconi Company to connect to stations of another make was also already part of the contracts with the Italian government and with the British Lloyd Company (Neilson, 1903; Pocock, 1995).

[78] The Gesellschaft für drahtlose Telegraphie GmbH was renamed to Telefunken in 1923.

3.2.1 Preliminary Conference on Wireless Telegraphy

By invitation of the German Kaiser, representatives of nine countries[79] gathered in Berlin in August 1903 for the *Preliminary Conference on Wireless Telegraph*. That these countries had a military interest as part of their national interest can be drawn from the fact that the military were represented in all national delegations.

The German host of the Conference, Herr Kraetke, Secretary of State of the Postal Department of the German Empire, gave a clear indication of the German intent in his opening address (Neilson, 1903: 6):[80]
"It is desirable to make regulations calculated to assure the working of the new service, by placing general above local interests. Just as wireless telegraphy is not the product of a single nation, just as it projects its waves beyond the frontiers separating nations, so the protection necessary for its free development can only be secured with the concurrence of all the maritime nations by means of an international understanding. The task before you is to seek a basis for such protection as would benefit all radiograph installations, without distinction as to the system adopted."

With his speech Herr Kraetke referred in a general sense to the fear of Germany for a monopoly of Marconi. This fear was also reflected in the German proposals that were sent together with the invitation. Paragraph 1 of the first article of the proposal reads (Neilson, 1903: 1):
"Radio-telegrams originating from and destined for ships shall be received and forwarded without regard to the system employed."

The head of the German delegation, Herr Sydow, Under-Secretary of State of the Postal Department, made this fear for a monopoly by Marconi more explicit in his explanation of the intent of the proposals that were sent together with the invitation (Neilson, 1903: 7).
"The object aimed at by the Propositions under Art. 1. is, then, in the first place, to prevent the creation of a monopoly in favour of a single system, and, in the second place, to avoid disturbances of the different systems between themselves. It is towards such a monopoly in favour of a single system that there appears to be an aspiration in one direction. By arrangements which the Wireless Telegraph Company has concluded with the British Lloyds, the latter undertakes to employ the Marconi system exclusively in its stations, and not to permit these stations to communicate with ships equipped with other systems."

In his concluding remarks of the explanation he rephrased the problem as a "tragedy of the commons":
"The German Government, is therefore, of opinion that systematic opposition to the monopolising of wireless telegraphy, the demand that the different systems should be admitted to co-operation, and at the same time the formulation of rules to prevent, as far as possible, reciprocal interference, are the only means to avoid a contest of each against all."

The proposal included stipulations to prevent interference between stations as well as stipulations for the charging of the exchange of messages (Neilson, 1903). According to an explanation given by Germany, the regulation of the charges of the exchange of messages was necessary to enable free competition (Neilson, 1903: 22):
"Free competition between the different systems, which is the principal subject of our deliberations, will only be possible if the charges for the exchange of radio-telegrams be reasonable, and if each station obtain a share proportionate to its working expenses."

Since both the British Royal Navy and the Italian Navy had a long term commitment with the Marconi company, it came as no surprise that especially the British and Italian delegations expressed difficulties with the German proposals. In a reply to the German proposals Italy stressed the

[79] Germany, Austria, Spain, the United States of America, France, Great Britain, Hungary, Italy and Russia (Neilson, 1903).

[80] The official proceedings and convention are in French. Neilson, an employer of the Eastern Telegraph Company, made an English translation that was officially accepted by the British Post Office.

importance of Marconi for the development of radio (Neilson, 1903: 30):
"For several years now Marconi has successively made inventions through his most able but very laborious and costly experiments, constantly rendering his system more practical and more efficient. In addition, during these years he has himself directed, sometimes even at the risk of his life, the installation of 45 coast stations of ordinary power in different parts of the world; of three stations of great power in England, Canada and the United States; of several stations on board Italian, English, French and American war vessels; of 32 stations for the commercial vessels of the principal shipping lines of the world. I am able to state that I have personally seen his apparatus fitted upon the ships of the Norddeutscher-Lloyd, Hamburg-American, Transatlantique Française, Cunard, and American lines."

The deliberations didn't lead to consensus. The Conference drafted a protocol containing regulatory principles to be used as the basis for a future international agreement on the use of wireless telegraphy. The final protocol contained the following regulatory principles and obligations on the exchange of messages between ships and shore stations:

- the principle that coastal stations are bound to exchange messages with ships without distinction as to the systems of wireless telegraphy used by the latter;
- the obligation to publish all relevant technical information to facilitate communications;
- the principles for fixing the tariffs applicable to telegraph traffic exchanged between ships at sea and the International Telegraph System;
- the obligation to give priority to distress calls;
- the obligation to prevent interference as far as possible;
- an exemption for governmental stations not open for public correspondence (mainly military and naval stations) from the provisions, with the exception of the obligation to prevent interference.

As said, complete agreement was not reached. Great Britain and Italy didn't sign the agreement. Great Britain made a general reservation to the Final Protocol of the Conference with an explicit reference to the article related to the first requirement. During the conference they already made clear that they didn't have the legal power to impose such an obligation.[81] The Italian government made some specific reservations because they were bound by the contract with Marconi (Neilson, 1903).

It was also agreed that Germany should invite all the maritime States of Europe, the United States of America and other interested maritime governments to meet next year at Berlin for a Conference of a more general character (Neilson, 1903).

3.2.2 First Radio Telegraph Conference of Berlin

As agreed during the meeting in 1903, the German government sent an invitation to all interested maritime governments to attend a Conference in Berlin. As a result, representatives of 29 countries gathered together in October 1906 for the *International Radio Telegraph Conference of Berlin*.[82] The deliberations resulted in the first *International Radiotelegraph Convention* and *Radio Regulations*. The Convention contained the fundamental rules for the regulation of radio telegraphy and the rules dealing with the organization of the Conference. The Radio Regulations were annexed to the

81 Mr Lamb of the British delegation made clear that it was especially difficult to impose such an obligation to a ship outside the territorial waters and to stations in a foreign country (Neilson, 1903: 7).

82 Originally, the Conference was planned to be held in 1904, shortly after the closure of the Preliminary Conference. The outbreak of the Russo-Japanese War caused its postponement. The Conference was opened on 3 October and closed on 3 November 1906. There were 27 countries deliberating: Argentina, Austria, Belgium, Brazil, Bulgaria, Chile, Denmark, Egypt, France, Germany, Great Britain, Greece, Hungary, Italy, Japan, Mexico, Monaco, the Netherlands, Norway, Persia, Portugal, Rumania, Russia, Siam, Spain, Sweden, Turkey, United States and Uruguay. In addition there were 2 observing countries: China and Montenegro (Conférence Radiotélegraphique International de Berlin, 1906). Codding (1952) gives a detailed account of the deliberations.

Convention. The Radio Regulations contained the detailed rules on the radio telegraphy service.

The Berlin Radiotelegraph Convention was based on the same principles as agreed upon in 1903, although much more detailed. The principle question was the obligation to exchange messages with ships without distinction as to the radio system being used. The other main issues were the priority handling of distress calls, the obligation to prevent interference as far as possible, interconnection with the international telegraph network and the principles for the tariffs being charged for the exchange of telegraphs (Conférence Radiotélegraphique International de Berlin, 1906; Codding, 1952).[83]

The Convention confined the scope of the regulations to maritime communications, in particular coastal stations open to public correspondence and all radio stations on board commercial vessels. All other stations, especially naval and military installations, were exempted from the obligations, with the exception of the provision to prevent interference and the obligation to give priority to distress calls.

It was not possible to reach complete agreement on the subject of obligatory intercommunication. There was agreement on the principle that all coastal stations and stations on board ships were bound to exchange messages without distinction of the radio systems being used. However, the Final Protocol attached to the Convention contained a possibility to reserve the right to exclude certain stations from this obligation. Eighteen of the twenty-seven contracting parties declared that they would not reserve such right.[84] There was no agreement on the obligation for intercommunication between ship stations. This obligation was put in a supplementary agreement, annexed to the Convention. This supplementary agreement was eventually signed by twenty-one of the contracting parties.[85]

All contracting parties were obliged to give all data necessary to facilitate communications. The International Bureau of Telegraph Administrations[86] was asked to collect and publish this information. The Bureau was also tasked to act as a administrative entity between Conferences.

The Convention also contained rules on the organization of the Conference and subsequent Conferences. It was agreed that the provisions were to be contained in a Convention and supplementary Regulations. Conferences of plenipotentiaries can change both the Convention and the Regulations. Administrative conferences can only deal with the Regulations. Each conference shall set the time and place for the next meeting. Only delegates of Governments are allowed to take part in these Conferences. Countries were to have only one vote.

There was quite some discussion about what was actually meant by a "country", i.e. if colonies could be regarded as a country and have their own vote. It was agreed that subsequent conferences may decide that colonies, possessions, protectorates, or a part thereof, can be considered as forming a country. However, the number of votes at the disposal of a government, including its colonies, possessions, or protectorates, shall in no case

83 The official Convention and annexed Regulations are in French. An English translation of the Convention and the annexed Regulations is available from both the British and the U.S. government (The Electrician, 1907; Navy Department United States of America, 1912).

84 The countries that reserved that right were: Denmark, France, Great Britain, Italy, Japan, Persia, Portugal, Spain and Turkey.

85 This supplementary agreement was not signed by Great Britain, Italy, Japan, Mexico, Persia and Portugal.

86 The International Bureau of Telegraph Administrations in Bern was the Bureau of the International Telegraph Union set up by decision of the second International Telegraph Conference of Vienna in 1868.

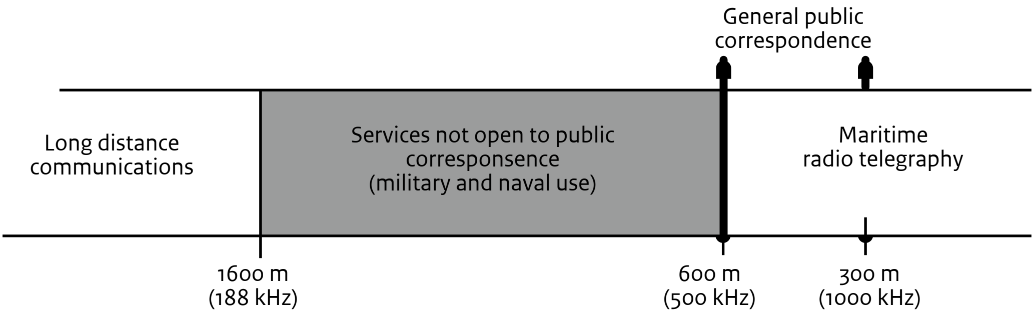

Figure 3-1 Frequency allocation table of 1906.

exceed six. This was to prevent a dominant position for countries with a large number of colonies, notably Great Britain.

The Convention went into effect on 1 July 1908. All contracting parties were obliged to ratify the Convention as soon as possible. There were also provisions to enter the Convention as a non-signing party at a later stage and a possibility to denounce the Convention.

A procedure for arbitration was set up in case of disagreement between two or more contracting Governments regarding the interpretation or execution of the Convention or the Regulations annexed to it. It was decided that each concerned Government could choose an arbiter not having an interest in the issue. The arbiters take a decision by absolute majority of votes. In case of a division of votes, the arbiters choose another arbiter from a non-involved Government. In case this is not possible, each arbiter shall choose a Government. The arbitrator is chosen by drawing of lots.

The Regulations that were annexed to the Convention contained detailed operational rules on the maritime radio telegraphy service; technical requirements for the radio stations, the procedures to follow for the exchange of radio telegrams, the interconnection with the international telegraph system and the tariffs to be set. The Regulations were to "*have the same force and go into effect at the same time as the Convention*" (1907: Article 11).

It was decided to use wave lengths of 300 meters and 600 meters for general public correspondence.[87] Wave lengths above 1600 meters (below 188 kHz) could be used for long distance communications. The band between 600 and 1600 m (188 - 500 kHz) was reserved for "services not open to public correspondence", i.e. for military and naval use. This is shown in Figure 3-1.

There were a number of provisions to prevent interference. The shipboard station needed to be able to tune to a specific frequency (a syntonized system) and there was a limitation to the output power of the station.[88] These requirements had to be enforced by the granting (and withdrawal) of

87 In those days radio frequencies were denoted by their wave length. The wave length is equal to the speed of the wave (speed of light) divided by the frequency. The speed of light is dependent on the substance the wave is travelling through; therefore the wave length is also not fixed. This is why the use of frequency is more common nowadays. The speed of light in the atmosphere is roughly 300,000 km/s. The wave lengths correspond to a frequency of respectively 1000 kHz and 500 kHz.

88 There was also the general requirement that the choice of apparatus for all stations was unrestricted, but, as far as possible, should keep pace with scientific and technical progress.

licenses for ship stations and only to allow trained and certified operators to use the radio. Specified information about all authorized ship stations and coastal stations had to be provided to the International Bureau.

The Regulations made also a basic form of sanctioning possible. If after complaints by another government, a ship still fails to abide to the Convention and the Regulations, the complaining government was entitled to authorize its coastal station to refuse communication with the ship in question.

It was also decided to use a specific Morse signal for ships in distress: • • • — — — • • • (SOS) repeated at brief intervals.[89] As soon as a station perceives the signal of distress it *"shall cease all correspondence and not resume it until after it has made sure that the correspondence to which the call for assistance has given rise is terminated"* (The Electrician, 1907: part IV, Article XVI).

3.3 Expansion of the maritime service

The use of maritime radio communications was still limited in 1906 and it was mainly used for military purposes. Herr Kraetke, the head of the German delegation at the 1906 Conference, mentioned in his opening address an estimate of around 400 coastal stations existing or under construction, most of which were open for public correspondence, and an estimate of around 250 merchant ships fitted with radio equipment. Hence, there were less merchant ships fitted with radio equipment than there were coastal stations. He further stated that the number of warships equipped with radio equipment was probably much higher than that of merchant ships and coastal stations together (Conférence Radiotélegraphique International de Berlin, 1906).

Radio equipment was gradually introduced further on-board commercial ships after the 1906 Conference. At first, the radio was primarily seen as a means to send radio telegrams;[90] for the ship owner to give instructions to the captain or for the passengers to send a message upon arrival. It was seen as a costly and often unnecessary device by merchant shipping companies. The use of radio for distress and rescue became apparent after a few spectacular rescues in which radio played an important role, such as the rescue after the collision between the *Republic* and the *Florida* in 1909.[91]

In 1910 the United States Congress passed the Radio Ship Act. This law required that, as of 1 July 1910, all ships sailing from an American port carrying 50 passengers or more be fitted with an efficient radio set and operated by a skilled, licensed operator. This law applied not only to ships under American registry, but also to ships of foreign registry leaving a port of the United States (Codding, 1952; Wedlake, 1973).

These developments led to a considerable increase in the use of radio. The dominance of the Marconi Company eroded gradually, especially due to the rise of the German Telefunken Company, which was backed by the German government and German

[89] There are numerous explanations given to this signal, such as "Save Our Ship", "Sink Or Swim" and "Save Our Souls". However, it is not meant to be interpreted as being three separate letters. It is a short signal that is chosen because it is easy to pick up out of other signals (Wedlake, 1973).

[90] These radio telegrams were often called a radiogram, or a Marconigram if the ship was equipped with a radio system from the Marconi Company.

[91] The SS Republic collided with SS Florida off the East Coast near New York. Radioed calls for assistance resulted in saving the lives of about 1650 persons and created such an impression upon the public that radio soon became looked upon as a seagoing necessity (Howeth, 1963).

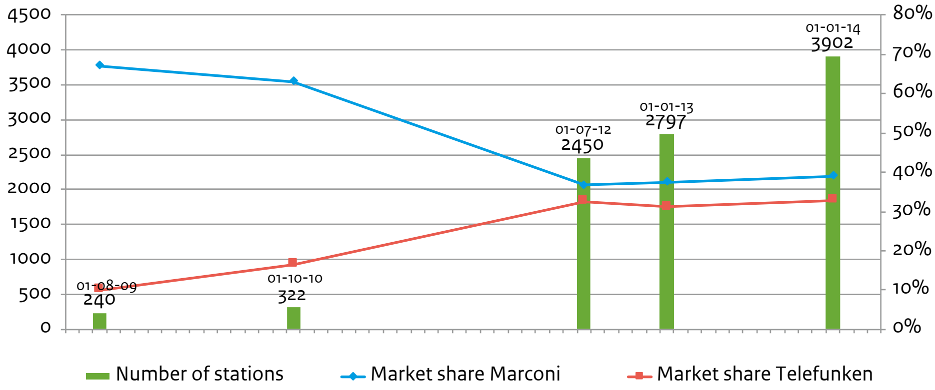

Figure 3-2 The growth of maritime radio and the share of the Marconi Company (adapted from Friedewald, 2000).

navy. There were no other companies that were seriously attempting to organize an international radiotelegraph service (Tomlinson, 1945). Figure 3-2 clearly shows the demise of the monopoly of the Marconi Company and the rise of Telefunken (Friedewald, 2000).[92]

The Marconi Company also came under political pressure due to its behavior. Marconi continued to reject communications with ships equipped with other radio systems, reasoning that the International Radiotelegraph Convention of 1906 had not yet been ratified by all of the participating nations. Marconi's rejection provoked worldwide protest not only to the Marconi Company but also to the British government. The British government was blamed for the delay in the translation of the Radiotelegraph Convention into national law. Wanting to remain credible, the British government, took an important decision. It decided to buy all British coastal stations and open them in accordance with the International Radiotelegraph Convention for communication with all systems. On 29 September 1909 all British coastal stations were taken over by the British Post Office. Just as in many other European countries and most of the rest of the world, where the coastal stations were owned and operated by the government.[93] One of the few exceptions was the United States, where the coastal stations remained privately owned and operated, although under strict governmental control. Governmental control was ascertained through a strict licensing regime for both the stations and the operators (Wedlake, 1973; Friedewald, 2000).

Alongside with the growth of maritime radio, a number of ancillary services were introduced. The first to be provided was a news service for the passengers. Operators of the luxury transatlantic

92 The phenomenal increase in the use of maritime radio is also demonstrated by the figures of the International Bureau of the International Telegraph Union. The first statistics published by the Bureau listed 76 coastal stations of which 14 were open to public correspondence and 246 ship stations of which only 52 were open to public correspondence. At the time of the London Conference in 1912 the statistics of the Bureau listed 286 coastal stations and of which 155 were open to public correspondence and 1577 ship stations of which 926 were open to public correspondence (Conférence Radiotélégraphique Internationale, 1913). However, these statistics were only collected from the Contracting Parties to the Berlin 1906 Convention.

93 In most Western European the coastal stations were operated by the national Post Office, which was also responsible for wired telegraphy. The famous Dutch coastal station "Scheveningen Radio" was build and operated under governmental control in 1904.

liners used it as a premium to provide their customers with daily news bulletins. A more important service was the periodical transmission of a time signal. In 1910 the French Bureau des Longitudes send out a time signal every night from a powerful wireless station on the Eiffel Tower. Shortly afterwards followed by a daytime service. In Germany, the Norddeich wireless station followed to broadcast time signals. The time signal was used for the adjustment of the ship's chronometers, which were important instruments for navigation. On the initiative of the Bureau des Longitudes, the *International Time Conference*[94] was held in October 1912. A common format for the time signals and a schedule for the transmission of these signals were decided upon (Paris Bureau of Longitudes, 1915).

In 1911, the first weather service was introduced. These weather radiograms were very short and limited to information about air pressure, force and direction of the wind, the state of the sky, the state of the sea as well as gale warnings for the North Atlantic. By the end of 1913 a regular service was provided along the Atlantic coast (Paris Bureau of Longitudes, 1915; Wedlake, 1973; Friedewald, 2000).

An important new development that took place during the period before World War I was the development of the direction finder. Dr. Ettore Bellini and Captain Tosi already produced a system that could be used to determine the direction from which wireless signals were coming in 1906. Further development towards a practical system was at first slow because the receivers were in these days not sensitive enough. The rights for the Bellini-Tosi system were bought by the Marconi Company in 1912 and from that point development went on rapidly. This instrument could be used for assistance in navigation to enter and leave a harbor. The navy could use it to locate ships of the enemy. The instrument was just in time ready to play its part in the Great War (Howeth, 1963; Wedlake, 1973).

3.4 London 1912: Strengthening Safety of Life at Sea

At the Berlin Conference of 1906 it was already decided to review both the Convention and the Regulations in London in 1912. Just two months before the convening of the London Conference a terrible disaster occurred. On 14 April 1912, the *Titanic* struck an iceberg during her maiden voyage. Both the old distress signal CQD[95] as well as the new signal SOS was sent. It could not prevent the loss of the Titanic with 1503 souls (ITU, 1965).[96]

This recent disaster had a profound effect on the London Conference. The British Postmaster-General Mr. Herbert Samuel put it as follows in his opening remarks (Conférence Radiotélégraphique Internationale, 1913: 100-101)[97]:
"The recent disaster of the «Titanic», which we all lament, has shown the necessity for a wider use of radiotelegraphy on the open sea, and for the investigation of new methods to make it more effective in its important duty of preventing disasters and assisting in rescue work."

94 Conférence Internationale de l'Heure, Paris, 15-23 octobre 1912.

95 CQD was a distress signal used by the Marconi Company which became commonly used internationally. The signal was composed of CQ, the general call signal for "to all stations", followed by the letter D for "distress". It was not meant to mean "Come Quick, Distress" or "Come Quick Danger" (Wedlake, 1973).

96 Although there were ships within radio reach, most of them did not know about the disaster as they had no radio equipment on board. A radio message from another ship intended to warn the Titanic had not come through as the operator of the Titanic had been busy on another conversation. Moreover, "the spark sets used a very wide bandwidth, two chatting operators practically blanketed any other vessel within 100 kilometers that might have wanted to use the air" (ITU, 1965).

97 This is an English translation. The original proceedings are in French.

As tangible evidence of the intention of Great Britain's desire to make radiotelegraphy more effective in open sea, the head of the British delegation announced that Britain would adhere to the supplementary agreement, which contained the obligatory intercommunication between ships regardless of the system used. This announcement was followed by similar declarations of Italy and Japan and a statement that Portugal, which was not present at the Conference, would also adhere to the supplementary agreement. As a result, the obligation for intercommunication became part of the Convention itself (Conférence Radiotélégraphique Internationale, 1913; Tomlinson, 1945).

Already before the end of the Conference the Marconi Company made the following statement about this decision (Conférence Radiotélégraphique Internationale, 1913: 438):
Given the decisions of this Conference, and without awaiting the entry into force of the new Convention, the Marconi Company has given to all ships equipped with sets of his system, the order to intercommunicate with all other ships, irrespective of the system used by the latter.

A number of decisions were made to make radiotelegraphy more effective in the safety of life at sea (International Radiotelegraph Convention, 1912; Tomlinson, 1945):

- Obligatory installation of radio sets on certain categories of ships;
- Obligation to have an operator on duty;[98]
- Obligation to have an emergency radiotelegraph set;
- More rigid requirements for licensing of radio sets and for the granting of operators' certificates.

The Conference didn't consider itself competent to impose obligations for the presence and use of radio sets on board ships. This problem was circumvented by the definition of three classes of ship stations. The classes were based on the working hours of the radio station onboard:

1. Stations always open,
2. Stations having limited working hours,
3. Stations having no fixed working hours.

It was up to the individual governments to determine the category in which a ship station was placed. In addition there were also two classes of certificates for the radio operator. All ship stations that were used for public correspondence needed to have at least one first class operator. Ships that used radiotelegraphy only for their own service could suffice with a second class operator.

The definition of these classes and the related obligations were further refined at a Conference on "Safety of Life at Sea" that took place in London in 1914. The SOLAS Convention that was the outcome of this Conference stipulated the obligation to have a radio set onboard of all ships carrying 50 or more persons (Convention for the Safety of Life at Sea, 1914).[99]

Another problem, not related to safety of life at sea, that had to be tackled was the routing of radio-telegrams. To limit interference, it was already

[98] The Marconi Company proposed to have an automated alarm system instead. German and French companies had been experimenting with a similar invention. Agreement could not be reached, because the type of signal to be used was specific for the Marconi system (Conférence Radiotélégraphique Internationale, 1913; Tomlinson, 1945).

[99] The SOLAS Convention is still in use as an international treaty concerning the safety of merchant ships. It is in several occasions updated and amended since 1914. Chapter IV of the current Convention covers the provision of radiocommunication services by the contracting governments as well as ship requirements for carriage of radiocommunications equipment. The Chapter is closely linked to the Radio Regulations of the International Telecommunication Union. The Convention is under the responsibility of the International Maritime Organization. The IMO is a specialized agency of the United Nations which is responsible for measures to improve the safety and security of international shipping.

decided in Berlin that "*In general, the shipboard stations shall transmit their radiograms to the nearest coastal station*". Transmission to another coastal station was only allowed "*if the transmission can be effected without interfering with the service of other stations*" (Berlin Regulations, Article XXX, Navy Department United States of America, 1912).

According to the British delegation, there were no official complaints registered, though there had been numerous occasions when such complaints would have been justified (Tomlinson, 1945). The first real complaints were made during the discussion on the routing of radio telegrams. There were complaints of Dutch ships in the Mediterranean communicating with their powerful home station at Scheveningen and of Austrian ships in the eastern Mediterranean communicating with Pola on the Northern Adriatic. After long discussions, it was agreed that long distance communications was allowed on a specifically for that purpose assigned wavelength of 1800 m, as long as it not interferes with the service of other stations, and the radiotelegram is intended for the country in which the coastal station is located and comes from a ship registered to that country (International Radiotelegraph Convention, 1912; Tomlinson, 1945).[100]

The Conference only dealt with the regulation of maritime services. The Belgian colony of the Congo came to the Conference with a proposal to regulate communication between fixed radio stations and Italy came with a proposal to include aerial radio stations.[101] However, it was concluded that there was no need for official action on other services then the maritime service, apart from the general rules to prevent interference as far as possible and the priority for distress calls (Conférence Radiotélégraphique Internationale, 1913).

The London Convention and Regulations were signed by 43 countries, and ratified by all but four of them before the outbreak of the First World War. In addition, there were 9 other countries that adhered to the Convention by that time. At the start of the next Conference in 1927, the Convention was ratified by 41 countries and 97 countries adhered to it (Conférence Radiotélégraphique Internationale, 1928: 65).

3.5 Assessment of the birth of radio regulations

Marconi made his intentions with this newly discovered resource very clear from the outset. The first thing that Marconi did when he entered this open and practically untouched resource was to claim it by patenting the technology needed to enter it. Especially the updated version of 1897 of his first patent made it very strong. All his subsequent behavior was focused on making wireless telegraphy a commercial success. He did experiments to improve the range of his system and he made numerous demonstrations to attract customers.

Marconi's possibilities to exploit the resource were influenced by existing regulations on (wired) public telegraphy. The regulations on public telegraphy were so general that it did not only cover wired telegraphy but also wireless telegraphy. This restricted his possibilities to offer commercial services. He found a possibility to circumvent the monopoly of national wired telegraph companies on public telegraphy by offering wireless telegraphy to ships at sea as a service based on private lines between Marconi equipment on both the ships and the shore. Private telegraphy fell outside the scope of the regulations on public telegraphy.

[100] After agreement was reached, the Dutch delegation promised to renew its instructions to Scheveningen Radio to abide strictly to the Regulations. The statement was greeted with loud applause (Conférence Radiotélégraphique Internationale, 1913).

[101] At that time, there were already some aircrafts been fitted with a radio set.

This ties in with the solution of the British government to implement obligatory interconnection from all ships with the coastal stations. The government did not stipulate Marconi to interconnect.[102] Their solution was to take over all coastal stations and transfer them to the British Post Office, the governmental body which held the monopoly on public telegraphy.

The behavior of the Marconi company to refuse interconnection was used as a trigger for international governmental involvement. However, iIt was not just a problem about the dominance of one market player who refused interconnection. Governmental involvement was also based on the public interest of safety-of-life at sea and above all of a national interest to defend the national industry. Various countries, including Germany, were eager to defend their own industry. This was not only related to industry politics but also relates to the role of radio in military communications. In the bigger countries, the military were a driving force behind the creation of the radio industry. Great Britain already held a very strong position in international wired telegraphy and radio was seen as a means to circumvent this monopoly. For the military, radio communications provided the ability to communicate without the need to rely on the telegraph systems operated by other nations.

Given the fact that the intentions for international regulations were driven by fears of domination of a country in international communications, the safeguarding of public interests and national (military) interests, it was a logical step for governments to assume responsibility. As part of the convention, rules were set up that rulemaking was the prerogative of Administrations, the representative entity designated by the government, typically the organization responsible for the operation of the national telegraph system. One of the main discussions on this topic was on the prevention of countries (especially Great Britain) to obtain a dominant position in rulemaking through their colonies and other possessions and protectorates.

The international framework that administrations set up in these early days was intended for the use of the resource with only one service in mind. The preliminary Conference in 1903 and the Conferences in 1906 and 1912 only dealt with wireless telegraphy and especially with the public interests associated with maritime use of wireless telegraphy.

The technology of tuning was used to safeguard the public interest of public correspondence and safety-of-life at sea. Associated operational rules were set up to implement these interests. As part of the operational rules, information on the use of the resource was collected as a means to ease interconnection. The disaster with the Titanic strengthened the public interest of safety-of-life at sea. As a result, the 1912 Conference was almost completely devoted to making the operational rules more effective in securing the safety-of-life at sea.

The other operational rules that were set up were targeted to prevent interference. Users were given as much freedom as possible with the constraint to limit the disturbance to each other's transmissions to the minimum.

As a result, the rules restricted access to the resource. A strict licensing regime was in place for both the radio stations and the operators. The authorization itself was left to the national administrations. Access to the resource was further restricted by the manufacturers through the use of patents.

Although there were some basic rules drawn on enforcement and sanctioning, there was no need to draw up rules on the monitoring of correct behavior of the users. Monitoring was part of the daily routine of the radio telegraphist. If a radio telegraphist wanted to start a transmission, he had to listen

102 They already made clear in the conference of 1903, that they didn't have the legal power to do so. See section 3.2.1.

whether the channel was free. Inappropriate use could be reported to the responsible government for follow-up.

The international regulations allowed for as much (business case) freedom as possible for the maritime service with the exception of a few standardized channels for the exchange of public messages and distress messages and the exclusion of a frequency band which was reserved for military and naval use.

3.6 Expansion to other services

At the London Conference it was agreed that the next Conference would take place in Washington in 1917 (Conférence Radiotélégraphique Internationale, 1913: 434). However, the outbreak of World War I led to a suspension in the progress of international regulations, but considerable progress was made in radio technology. At the start of the Great War, radio was mainly used for maritime purposes and not seen as an absolute necessity. There were still many merchant ships without it (Wedlake, 1973).

The dominant position of Great Britain on long-distance cables led other nations to the use of radio for their communication needs. Radio became invaluable in the operations of both the army and the navy. It greatly changed the tactics in the theatres of war. Probably the biggest change in warfare was made due to the use of radio in aircraft operations (Codding, 1952; Bertho Lavenir, 1991).[103]

Advancements made in radio technology during and after the Great War gave a big boost to the development of radio services for other purposes: land mobile services, long distance services, regular broadcasting services, aircraft radio communication services as well as radio navigation services for maritime and aeronautical use were established.

3.6.1 Aviation services

The development of aviation and wireless communications were from the outset closely linked. Wireless is the only means to communicate with an aircraft in the air. Aviation made steady progress during World War I. When the distances an aircraft could fly increased, the need arose for navigation aids. Radio provided an accurate and reliable means for aerial navigation. Aircrafts were fitted with a direction finder which could be used to take bearings from ground stations, without being dependent on ground stations to fix their position for them (Wedlake, 1973).

Commercial air services were introduced shortly after the Great War. The first regular commercial passenger airline service started in August 1919 between Paris and London. Chains of ground stations were set up for flight control and navigation. With this commercial uptake of air services the need arose for interference free aviation services for navigation purposes and to provide information to the aircraft concerning weather, landing facilities and other information for a safe operation of all flight stages (Wedlake, 1973).

The Paris Peace Conference created the International Air Convention to deal with technical, operational and organizational aspects of international civil aviation. Representatives of twenty six countries met in Paris in 1919 and drew up the Convention for the Regulation of Air Navigation. The Convention established the International Commission on Air Navigation (ICAN) to take care of future modifications to the

[103] The Great War was not the first war in which radio communications played a role. The Boer War of 1899-1902 was the first war were wireless telecommunications was used. However, wireless communications did not meet the expectations of the British Army, but it did draw the attention of the British Royal Navy (Austin, 1995). Radio communications played also an important role during the Russo-Japanese War and in the Turkish-Italian War (Codding, 1952).

Convention.[104] Any modifications of the Articles of the Convention must be formally adopted by the contracting States before they become effective (Regulation of Aerial Navigation, 1919).

By Article 35 of the Convention, the contracting States agreed to cooperate in international measures concerning, among other things, the use of wireless telegraphy in air navigation and the establishment of the necessary wireless stations (Regulation of Aerial Navigation, 1919).

Article 14 of the Convention covered the provisions with regard to wireless equipment carried onboard the aircraft. The provisions on radio equipment were much alike the provisions that were set up for maritime services. It was agreed that a license was needed for all radio equipment carried onboard the aircraft and that the equipment shall be operated by specific licensed members of the crew. It was also stipulated that all aircraft capable of carrying ten or more people were obliged to have wireless equipment onboard. The ICAN was tasked to determine the methods of employing the equipment (Regulation of Aerial Navigation, 1919).

3.6.2 The proliferation of broadcasting

Wireless telegraphy enables communications from one point to any number of receivers within range. This fact was used in maritime communications to 'broadcast' weather reports and other general information. The amount of information that could be transmitted was very limited and the information could only be received by trained listeners. In these early days, the only way to transmit information was through switching the radio transmitter on and off. Information was transferred using Morse code with shorter and longer periods of radio transmission. It was a rather crude system which didn't enable transmission of the human voice or music.[105] To transmit the human voice, there was a need for a transmitter which could sent out a smooth and continuous wave and a receiver that could detect it. Speech and music can then be sent by altering the amplitude (or later the frequency) of the carrier wave such that the continuous wave followed the rhythm of the speech or music.[106]

The first experimental broadcasts of the human voice and music are credited to Reginald E. Fessenden. Fessenden already transmitted the human voice over the air in 1900, although over a very short distance. In 1906, on Christmas Eve, he is accounted to have publicly demonstrated the first ever broadcast of a program of speech and music in the form of two speeches, a song, and a violin solo. However, the quality of the received signal was very poor (Wedlake, 1973; Belrose, 2002).

Transmission of speech and music with a reasonably good quality was only possible after the invention of the electric valve (or radio tube). It was Lee de Forest who improved the electric valve such that it could be used to build up the strength of the signal before transmission and after reception as well as to generate the continuous high frequency carrier

[104] The ICAN/CINA (Commission Internationale de Navigation Aerienne) established its headquarters in Paris in 1922. It remained active until 1947. In that year the tasks of ICAN were transferred to ICAO, a specialized agency of the United Nations that is still active.

[105] These early radio systems were called a spark system. A spark transmitter is a very primitive device in which the radio wave is made through the use of two electrodes with a small gap between them. If a high voltage is applied over both sides of the electrodes a "spark" is generated. The name is still used in the German language. The German word "funken" (literally: to spark) means to transmit by radio.

[106] If the amplitude of the continuous wave is varied in the rhythm of the information, it is called Amplitude Modulation. If the frequency is varied, it is called Frequency Modulation.

waves necessary for broadcasting speech and music (Codding, 1959).[107]

Lee de Forest started the "De Forest Radio Telephone Company" in 1906, the world's first commercial enterprise for radio telephony. He is claimed to have made the first ship-to-shore radio telephony transmission in 1907. De Forest began a series of public demonstrations to arouse interest in radio telephony. In 1908 he obtained permission to broadcast a program of records from the Eiffel Tower. The broadcast was being heard over a wide area by French military stations which were taking part in the experiment. In 1910 he again attracted attention with a broadcast of a performance of the Italian tenor Caruso directly from the stage of the Metropolitan Opera House in New York (Codding, 1959; Wedlake, 1973).

Relatively few people were able to listen to these experimental broadcasts. Most of the existing receivers were in the hands of government agencies or commercial companies. There was, however, a growing group of radio enthusiasts who were making their own radio sets, not for profit, but for pleasure. Some confined themselves to receiving, but the more adventurous built their own transmitter. The activities of the latter amounted to the first unofficial broadcasting stations (Codding, 1959; Wedlake, 1973).[108]

The development of radio broadcasting suffered a temporary set-back as a result of World War I. In most countries involved in the war the governments took control of all commercial wireless stations and ordered amateur stations to dismantle their equipment.[109] However, during the War tremendous advances were made in the three-electrode valve and the cheap mass-production of it. The years that followed saw the vast development of technology for radio equipment based on radio tubes that gradually superseded the rude spark systems used for wireless telegraphy (Codding, 1959; Wedlake, 1973).

Regular broadcasting services started to flourish in the early 1920s. One of the first broadcasts that is often mentioned in the literature is the broadcast of a concert of the prestigious opera singer Dame Nellie Melba in England on 15 June 1920. It was organized by the Daily Mail and broadcasted by an experimental broadcasting station of the Marconi Company. Other broadcasts were also made but the Post Office banned broadcasting in November 1920 due to complaints of interference to aircrafts and military communications.

The Post Office came under growing pressure to allow wireless broadcasting. This pressure came from the manufacturers of electric valves and receivers and from the fast growing number of amateurs and hobby listeners who were forced to listen to stations from abroad, such as the very popular Sunday concerts from The Hague, The Netherlands, because there was no British service. In January 1922 the Post office issued a new experimental license to the Marconi Company shortly followed by a number of other experimental licenses. These licenses had very strict usage conditions attached to it.

To avoid a free for all chaos in the air, the Post Office asked the Marconi Company together with five other big manufacturers and a representative of the smaller companies to form the British Broadcasting Company, which was superseded by the British

107 The valve of de Forest was based on the work of Fleming. Lee de Forest improved it by adding a tiny grid between the plate and the filament. This improvement made it possible to control the current and to use it not only as a detector but also as an amplifier. De Forest called his radio tube an Audion. He applied for a patent at the end of 1906 (Codding, 1959; Wedlake, 1973).

108 In a number of countries, there were restrictions on the transmission of radio and in some even on listening to radio transmissions, see section 3.6.3.

109 See also section 3.6.3

Broadcasting Cooperation in 1926. The BBC started broadcasting in November 1922 from a station sited at the Marconi House in London. The station was shortly followed by stations in other cities to form a network of stations that covered the whole country (Wedlake, 1973; Meyer, 1995).

The broadcasting of the Dutch radio-pioneer Henricus Schotanus à Steringa Idzerda on the 6th of November 1919 is regarded as the real start of the first scheduled radio broadcasting program in the world. He started that day with regular broadcastings under the name of “Radio Soireé Musicale”. The radio programs were announced in the newspaper. The radio programs even attracted listeners in England, where no regular radio broadcastings were taking place in these days. The “Daily Mail” even sponsored the broadcasting programs for a while. Idzerda made these broadcasts to attract customers for radio sets of his company (Wijfjes, 1985; Rollema, 1995).[110] The first regular broadcasting service in the United States started about a year later, on 2 November 1920 by station KDKA. This broadcasting station was set up by the Westinghouse Electric Corporation to attract new customers for their radio sets.[111] From that time on broadcasting conquered the United States.

While broadcasting started as a means to promote the sale of radio equipment, it obtained a new dimension as broadcasting became more widespread. In a next step, the use of radio waves for broadcasting obtained a political dimension, as a means of ‘spreading the word’, be it the words of a political party, a religious organization or other groups representing a special interest. Broadcasting became associated with the public interest of freedom-of-speech.

110 Technisch Bureau Wireless, in 1918 renamed to NV Nederlandsche Radio-Industrie.

111 KDKA is still on air as a local news radio in Pittsburgh, Pennsylvania. KDKA is currently owned and operated by CBS Radio.

In 1925 there were already close to 600 broadcasting stations in the United States. This number outreached the available amount of channels by far with a chaos in the ether as a result. An attempt by the government to restrict the number of stations and its transmissions failed. These restrictions were successfully challenged in court. The existing radio legislation was inadequate to prevent interference in the broadcasting band (Codding, 1952; Coase, 1959).

The House of Congress and the Senate quickly agreed on legislative measures to regulate broadcasting. The Radio Act of February 1927 established the Federal Radio Commission.[112]
The Radio Act authorized the FRC to strictly regulate the radio waves by issuing licenses. Licenses had very strict conditions on the transmission characteristics of the radio station and the working hours. Licenses could not be transferred to anyone else without the approval of the Commission. The license gave the licensee full freedom in the content of the radio program. The Commission was prohibited from censoring programming.[113]

Europe saw a more orderly uptake of broadcasting. Almost every European country introduced one or more regular broadcasting services under careful supervision by the government (Tomlinson, 1945). However, the frequency and the power of the broadcasting stations were chosen based on national interest. European stations found themselves being interfered by other stations abroad. The same “chaos in the ether” happened on an international scale in Europe as was happening on a national scale in the United States (Codding, 1952).

112 The Federal Radio Commission was the predecessor of the Federal Communications Commission which was established in 1934. The regulatory powers of the FRC (and of its successor the FCC) did not extend to governmental use of the radio waves. Governmental use was, and still is, subject to the authority of the President.

113 The Radio Act did only impose some general restrictions on radio programs. Obscene, indecent or profane language was prohibited (Coase, 1959).

The existing international and national regulations were not adequate to cope with the uptake of broadcasting at both sides of the Atlantic. Interference became widespread, a 'tragedy of the commons' occurred in the air.

The Swiss radio enthusiast and broadcaster Maurice Rambert invited state administrations, private organizations and radio industry to a Preliminary Conference for an International Agreement on Wireless Telephony to be held in Geneva on April 22-23, 1924.[114] The intention of the Conference was to find a solution to the problem of interference, filling the gap between the national regulations and existing international regulations. Although the Conference itself was not very successful, it was the stepping stone towards the establishment of the International Broadcasting Union.

The BBC invited all European broadcasting companies to meet in London in March 1925. The Conference was followed by another one on 3 and 4 April 1925 in Geneva. At that conference, ten European broadcasters established the non-governmental Union Internationale de Radiophonie (UIR), also known by its English name International Broadcasting Union (IBU). The IBU had its headquarters in Geneva.[115] The IBU was created with a view to discuss the problem of interference and to come to a voluntary redistribution of broadcasting frequencies among the European broadcasting stations (Woolley, 1995; Lommers, 2012).

To solve this problem a Conference was held in Geneva in July 1925. The Conference drew up a plan for the distribution of wavelengths to European broadcasting stations based on a formula involving area, population, and the extent of telephone and telegraph traffic. The "Geneva Plan" allocated 83 exclusive wavelengths between 200 and 550 m (545 – 1,500 kHz) to primary stations and 16 shared wavelengths between 200 and 580 m (517 – 1,500 kHz) to secondary stations for local purposes. In order to accommodate all broadcasting stations it had to use some frequencies that were previously been used by the maritime service. As a result, the band available for broadcasting was expanded at the expense of the maritime service (Codding, 1952; Wormbs, 2011).

3.6.3 Amateur radio

It were not only professionals who followed Marconi and other companies in its practical experiments with radio. A vast number of amateurs had become interested in radio and performed experiments. Some European countries were very restrictive in their allowance of radio amateurs. In the Netherlands it was not only forbidden for amateurs to transmit, it was officially even forbidden to listen to radio transmissions.[116] The ban on listening was only dropped in 1914 just before the start of World War I. However, it was reintroduced the same year when the War started. The ban was finally lifted in 1917 (Rollema, 1995).

The United States was less restrictive and at first there were no restrictions for radio amateurs. Soon there came complaints from commercial operators and the military about interference from amateur stations. The US government decided, per Radio Act of 1912, to ban all radio amateurs to wavelengths below 200 m, which were considered useless for commercial purposes. Subsequently, radio amateurs started to explore these relatively unknown "short waves" (Codding, 1952, 1959).[117]

114 The official name of the conference was *"Conférence préliminaire pour une entente internationale en radio-téléphonie"*.

115 The UIR was in 1929 renamed to Union Internationale de Radiodiffusion. The IBU was disbanded in 1950. Its assets were transferred to the just established European Broadcasting Union (EBU).

116 There were a restricted number of licenses issued before 1914 to radio amateurs to perform experiments.

117 The amateurs were not the only ones that experimented with short waves. Others, including Marconi, also performed experiments with short waves (Marconi, 1957).

During World War I the activities of the amateurs were restricted. When after the World War the restrictions were lifted, amateurs renewed their efforts. Vacuum tube technology became available at relatively low cost, which resulted in a significant increase in range and reliability. In 1920, signals from American amateurs were heard in Europe on 200 m (1500 kHz). The first two-way transoceanic amateur radio communication took place in November 1923 between an amateur in the United States and an amateur in France on 100 m (3 MHz). Using even shorter wavelengths, other amateurs found that they could easily conduct two-way communication across the Atlantic. As soon as the amateurs had demonstrated the value of the short waves, commercial and governmental services invaded the field. For the first time reliable long-distance point-to-point communication was possible (Codding, 1952, 1959).

Throughout the world amateurs started to explore the remarkable potential of the short waves for international communications. Amateur radio became an international hobby. In 1925, the amateurs started to organize themselves internationally to represent the interest of the radio amateurs. During the Easter holidays of April 1925, radio amateurs from 23 countries in Europe, North and South America, and Japan met in Paris to create the International Amateur Radio Union and to adopt a constitution. The IARU devoted itself to encouraging the development of national societies in as many countries as possible, coordinating international Amateur Radio communication, and representing the interests of radio amateurs at international radiocommunications conferences and meetings (IARU, 2012).[118]

[118] On April 17, 1925, the constitution of the IARU was unanimously adopted by the organizing Congress. At a closing assembly on the following day, officers were elected and the actions of the Congress ratified by representatives from 25 countries. Thus, April 18 became the official "birthday" of the IARU and is now designated World Amateur Radio Day.

3.6.4 Long-distance communications

The amateurs were not the first to start long-distance communications. The concept of wireless long-distance communications dates back to the experiments of Marconi in Newfoundland in 1901. After he succeeded in the first transatlantic transmission, he was forced to leave Newfoundland. The Anglo-American Cable Company asked him to stop the experiments, because they saw it as an infringement to their monopoly on telegraphy. Marconi decided to cross the border to Canada. With the active encouragement and financial assistance of the Canadian Government, a high power station was constructed at Glace Bay, Nova Scotia, in order to continue the long-distance tests with a view to establish radiotelegraphic communication on a commercial basis between England and America. After a few more years of experimentations, a commercial service was started between Glace Bay, Nova Scotia and Clifden, Ireland in 1907. Service was at first unreliable. Marconi built ever-more-powerful stations, using ever-lower frequencies, and was able to offer full service in 1912 (Marconi, 1909; Belrose, 1995; Burton, 1997).

Long-distance radio communications was recognized by many governments as having strategic value. The international cable network was dominated by Great Britain and cables proved to be vulnerable for cable cutting during the War. Germany, France, Italy, Japan and the United States followed Marconi and began to work on their own worldwide wireless networks to link up their colonies and allies to avoid having to use British cables. Good use was made of the newly discovered short waves for reliable long distance communications with a relatively low output power and much shorter antenna installations then on the previously used long waves.

These international wireless networks were either operated by the national Post Office, another specialized governmental telecommunication agency or by a private firm under strict control of government. The United States had no large

American operating company before the Great War. The American market was dominated by the American Marconi Company. After the War the US government intervened. All American companies involved in radiocommunications were invited to pool their patents. Foreign companies were denied operating rights and were invited to sell their assets to the newly formed Radio Corporation of America. RCA became the monopolistic supplier of transoceanic telegraphy and ship-to shore communications under control of the civil government and the Navy. The patent pool permitted the radiocommunications industry to emerge in the United States. This led France to combine the principal French radio interests in the Compagnie Générale de Télégraphie Sans Fil (TSF). Italy and Germany had similar organizations, respectively Italcable and the Telefunken owned operator Transradio (Quack, 1932; Tomlinson, 1945; Bertho Lavenir, 1991; Casasempere Garcia and Yuste, 2010).

Great Britain had of course a somewhat different view. For them wireless was a supplement to the international telegraph cables rather than a replacement. The Post Office gradually took over the operations of stations in Great Britain. The Marconi Company continued its production of equipment and the construction of stations both domestic and abroad. The operations of international cable and radio communications were merged later, in 1928. A new company, Imperial and International Communications Limited acquired shares in the cables belonging to the Eastern and Associated Telegraph Companies, took over the international communications section of the Marconi Company and the Post Office's Atlantic cable and radio stations (Tomlinson, 1945; Bertho Lavenir, 1991; Burton, 1997).[119]

The production of radio equipment and the operating of services became dominated by four large companies, Marconi, RCA, Telefunken and TSF. They held most of the patents. In 1922, the "Big Four" formed the Commercial Radio International Committee. They agreed the mutual use of each other's patents until 1945, which gave them control of domestic production of apparatus. They also agreed to divide the world into "operating territories". This arrangements made it very hard for others to enter the field (Tomlinson, 1945; Casasempere Garcia and Yuste, 2010).

[119] In 1934, the company changed its name to Cable and Wireless.

3.7 Washington 1927: Arrangements for a multiple-use common pool resource

At the London Conference of 1912 it was agreed that the following Conference would be held in Washington in 1917 (Conférence Radiotélégraphique Internationale, 1913). Due to the outbreak of World War I and several other reasons, this Conference was postponed until the autumn of 1927. The huge expansion in the use of radio is reflected in the participation of the conference. At the Conference were nearly 300 government delegates from 79 countries and in addition about 75 representatives of communication companies and interested international organizations. Among those were the international organizations formed around the various services to represent their interests. As agreed in London in 1912, all decisions were to be made by representatives of the administrations through a majority vote among administrations. Private companies and international organizations were permitted to attend the meeting, but they didn't have the right to vote (Conférence Radiotélégraphique Internationale, 1928; Terrell, 1928; Tomlinson, 1945).

The Conference took the London Convention and Regulations as its basis. Secretary Hoover pointed out in his opening address that the London Conference had to deal with only a few frequencies for the call and exchange of maritime

communications but that the present conference had to address the full range of frequencies. He stated that (Conférence Radiotélégraphique Internationale, 1928: 62-63):[120]
"transoceanic communications, radiotelephone, broadcasting, air communication and navigation and the thousands of amateurs engaged in international communication, research, and experimentation had resulted in an enormous expansion of the original application of radio. The multiplicity of uses, their present and future requirements necessarily increase the possibilities of interference, and confusion".
Based on this deliberation he concluded that:
"the distribution of frequencies to various international services will be one of the most important tasks of this conference and I am sure it has your full attention."

Extended discussions on the scope of the Convention followed. Although the name remained a "Radiotelegraph Convention", the scope was extended to encompass "all radio communication stations open to the international service of public correspondence" and a number of special services governed by the Regulations.[121] The Convention was also made applicable to all radio communication stations for international service, whether or not the stations are open to public correspondence. An internal or national radio communication service which is likely to cause interference with other services outside the limits of the country in which it operates is considered as an international service from the viewpoint of interference (International Radiotelegraph Convention, 1928: Art. 1 and Art. 2; Stewart, 1928). Hence, the scope was widened in such a way that the Convention and the Regulations dealt with all radio stations capable of causing interference to a station of another country.

Next to changes made to encompass the enlarged scope of the Convention, a few other noteworthy changes were made to the Convention.[122] A new article (article 6) was inserted which dealt with the assistance between contracting governments to supply information concerning violations of the convention and regulations, as well as, if necessary, in the prosecution of persons infringing the provisions. The article on arbitration (article 20) was strengthened. In case of disagreement arbitration between two contracting governments was made obligatory.

The Washington Conference established a consultive committee for radio communications, similar to the one already established by the Telegraph Union for (wired) telegraphy and telephony. The purpose of the International Technical Consulting Committee on Radio Communications was to study technical and related questions. The studies could be carried out between conferences. The conclusions of these studies could then be presented to the next conference in order to eliminate the burden of exhaustive technical studies that had been necessary during the conference. The conclusions of the Committee were of a purely advisory nature.[123]
All decisions on changes of the Convention and the Regulations were to be made by conferences of plenipotentiaries of the contracting governments, each conference fixing the time and place of the next meeting (International Radiotelegraph Convention, 1928; Codding, 1952).[124]

120 This is a translation of the author. The original proceedings are in French.

121 Special services (services spéciaux) were defined in Article 1 of the Washington Radiotelegraph General Regulations as *"services of radio beacons, radio compasses, transmissions of time signals, notices to navigators, standard waves, transmissions having a scientific object, etc"* (International Radiotelegraph Convention, 1928).

122 See Stewart (1928) for a detailed account of the difference between the Washington Convention and Regulations and the London Convention and Regulations.

123 See Article 33 of the Washington Radiotelegraph Regulations (International Radiotelegraph Convention, 1928).

124 Washington Radiotelegraph Convention, Article 13 (International Radiotelegraph Convention, 1928).

The most important question at hand at the Conference was indisputable the question how to deal with the increased number of services and the increased potential for interference. The Conference decided to divide the available radio spectrum among the many existing radio services and to considerably expand provisions to limit the amount of interference. Both of these issues were incorporated in an extended change of the Regulations.

Probably the most important of the new provisions of the Regulations is contained in Article 5 which deals with the allocation of frequencies. It was agreed to follow the principle of allocation of frequencies to services, and not change the principle of allocations to e.g an allocation to countries. An elaborate table showing this allocation to the various services was incorporated into the article. The table shows the allocation of frequencies from 10 kHz up to 60 MHz. Frequencies above 23 MHz were not allocated, apart from two bands for the amateur service.[125] A simplified version of that table of allocations is given in Table 3-1 (International Radiotelegraph Convention, 1928; Terrell, 1928).

Frequencies	Services
10 – 100 kHz	Fixed service
100 – 550 kHz	Mainly maritime and aircraft services[1]
	radio beacons at 300 kHz
	direction finding at 375 kHz
	distress and calling at 500 kHz
550 – 1500 kHz	Broadcasting
1500 – 60 000 kHz	40 small bands for mobile services, fixed service, broad-casting and amateur service.

1 *The band 194 – 224 kHz is allocated to broadcasting in Europe.*

Table 3-1 A simplified version of the table of allocation of Article 5 in the Washington Regulations

The Conference recognized the importance of the short waves for long distance communications. It was recommended to use frequencies between 6 MHz and 23 MHz for that purpose. The status of the amateurs was acknowledged with the allocation of four exclusive bands and two nonexclusive bands to the amateur service (International Radiotelegraph Convention, 1928).[126]

The most difficult discussions were about the broadcasting service. *“Smaller European countries were unwilling to accept a frequency allocation which would prejudice their broadcasting services, and the great radio powers were unwilling to allow broadcasting services to extend over such a wide frequency band that other forms of radiocommunication would be seriously jeopardized”* (Tomlinson, 1945: 142). It was finally agreed that the band 160-194 kHz could be used for broadcasting in all regions where broadcasting stations already existed working on frequencies below 300 kHz and that the band 194-224 kHz was available for broadcasting in Europe.[127]

The allocation of frequency bands to specific services was necessary to minimize interference between services. The stations of all countries have equal rights to the use of the bands designated for a particular service. The table of frequency allocations and all other regulations were only applicable to radio stations capable of creating serious international interference. Freedom was left for the assignment of any frequency to any station which could not cause international interference (International Radiotelegraph Convention, 1928: Regulations, Article 5; Terrell, 1928).

125 The bands 28-30 MHz and 56-60 MHz were allocated to the amateur service and experiments (International Radiotelegraph Convention, 1928).

126 The bands 7-7.3 MHz, 14-14.4 MHz, 28-30 MHz and 56-60 MHz were exclusively allocated to amateurs. The bands 1,715 – 2 MHz and 3.5 – 4 MHz had to be shared with mobile services and the fixed service.

127 A full discussion on the subject can be found on p.141-152 of Tomlinson (1945).

The restrictions to limit the amount of interference were mostly of a general nature. "*It was recognized as inadvisable to write into the regulations definite provisions of a technical or engineering nature which might become obsolete during the next few years*" as technology progresses (Terrell, 1928: 413). Article 4 of the Regulations stated that "*radio waves emitted by a station must be maintained at the authorized frequency, as exactly as the state of technical development permits, and their radiation must also be as free as practicable from all emissions which are not essential to the type of communication effected. The interested administrations shall fix the tolerance allowed between the mean frequency of emissions and the recorded frequency; they shall endeavor to take advantage of technical improvements progressively to reduce this tolerance*" (International Radiotelegraph Convention, 1928; Terrell, 1928: 413).

The most important of the restrictions was very specific and dealt with the "spark transmitter". A spark transmission is not very clean. A signal is generated that contains a wide range of frequencies.[128] This was not a problem when radio came into existence but it became a problem when new services were looking for some unused frequencies available. It was decided that "spark sets" were gradually forbidden. The other changes made to the Regulations with respect to the London Radiotelegraph Regulations were to make the provisions applicable to the mobile service which now includes aeronautical mobile next to maritime mobile. These provisions deal primarily with the exchange of public correspondence and safety of life (Terrell, 1928; Codding, 1952).

3.8 Assessing the arrangements for this multiple-use resource

Initially, when the resource was only used for maritime communications, the (international) regulations primarily focused on the public interests with regard to the national (military) interest, safety-of-life at sea and interconnection for public corespondence. When other kinds of usage emerged, and more and more users started to use this resource, interference became more widespread and sharing became more problematic.

This problem started to occur after the London Conference in 1912. In the time period after the London Conference, the number of stations for maritime communications and long-distance communications was growing rapidly. However, the technology to use the radio spectrum was limited. The only part of the radio spectrum available for long-distance communications was the lower part of the radio spectrum. Short waves were at that time regarded as being useless.

Problems with interference became even more severe after the first World War. Both the number of radio communication services and the number of users of these services was growing at a rapid pace. All these services were some sort of wireless telegraphy, whereby the radio telegraphist listened into the channel to be sure that the channel was free before he started his own conversation. This working routine did not completely solve the problem of interference, but it at least gave a possibility to share the radio spectrum among various users.

The introduction of broadcasting in the 1920s intensified the problem. Since broadcasting is a one way service, it doesn't involve an operational routine of listening in to the channel to be used, as is done by other radio services. The characteristics of broadcasting made sharing much more difficult if not impossible.

Broadcasting altered the setting also in another aspect. It revealed a new public interest, that of "freedom-of-speech". The use of radio waves obtained a political dimension, as a means of

[128] The transmitted signal was called a "damped wave", which is a strong bursty sine wave that decays exponentially.

'spreading the word' to try to shape public opinion by all kind of special interest groups. The newly developing institutional arrangements now had to cater to political interests next to economic interests, which have no currency in common.

The huge uptake of various radio services, especially broadcasting, introduced rivalry among the various user groups using the resource. Eventually, this led to the well-known "tragedy of the commons" (Hardin, 1968). But, different from most other resources it was not a matter of depletion. It was a matter of congestion at a particular moment in time in specific geographical areas.

It re-enforced the role of government in the governance of the radio spectrum, as the only party that is positioned to address and resolve the conflict between the newly introduced objective of "freedom-of-speech" and the other public and private objectives in using this limited resource. Government had to establish a certain degree of equity between these diverse interests.

To solve the emerging tragedy of the commons, governments took the role of supreme coordinator of the spectrum. The *Washington Radio Conference* of 1927 marked the beginning of a new era for international radio regulations. At this Conference, the frequency range from 10 kHz to 23 MHz was divided into different frequency bands which were allocated to specific services: broadcasting, maritime, aeronautical, mobile, fixed and amateur services. Access to spectrum was regulated through the use of licenses and certification of the users.

The harmonized allocation of bands to services was made to ensure greater efficiency of operation in view of the increase in the number of radiocommunication services and the technical peculiarities of each radio service. Services with the same characteristics were grouped together to increase technical efficiency, to allow for interoperability and to reduce the phenomenon of interference between radio services. An associated legal framework of rules was used to regulate these services. This framework encompasses not only operational rules on the services themselves, but also rules on sanctioning and on rules to change the rules. Monitoring if users were following the rules was left to the users themselves. Monitoring was for all of the services, except broadcasting, part of the ordinary working routine. This made a more strict coordination for broadcasting necessary. This need for coordination was in the United States the trigger for more strict regulations and the formation of the Federal Radio Commission. In Europe, the coordination necessary for broadcasting was taken up by the users themselves and triggered the formation of the International Broadcasting Union (later European Broadcasting Union).

As a result of the decision taken by the Washington Radio Conference, the radio spectrum was not only subdivided between the various radio services, but as a consequence, the various user groups were separated as well. Each user group got hold of its own pieces of the radio spectrum. These were in most cases exclusively allocated to the radio service related to that user group. The rivalry between user groups was circumvented by dividing the multiple-use resource into a number of single-use resources for a restricted and dedicated group of users.

All users of the specific services had started to organize themselves in the period between World War I and the Washington Conference. As the rules didn't provide detailed rules on the actual use of the resource, these user groups had a certain freedom to make more detailed institutional arrangements about the use of their single-use (sub)resource. All of them did. The maritime and aeronautical community made agreements on the use of respectively the maritime service and the aeronautical service. Broadcasters in Europe made very detailed broadcasting arrangements. Even the radio amateurs around the world organized themselves and made detailed agreements about the use of certain wavelengths within the amateur service.

Not all users started to collaborate right from the beginning. Manufacturers and some of the bigger service providers tried to restrict the access to the resource as much as possible. They used patents and other means, such as denial of interoperability, to do so. The best example of this kind of behavior is given by Marconi. He patented radio with only one goal in mind: to rule the airwaves. Others could only enter the resource through the use of technology that circumvented the patents of Marconi. When others started to access the resource he changed its tactics by refusing interoperability.

Patents did not only play a role in the beginning of wireless telegraphy. It also played a role in wireless telephony and later in the formation of the RCA in the United States and the BBC in the United Kingdom. In the aftermath of the Great War, the four biggest companies tried to keep the resource restricted for themselves. They made arrangements that were favorable for the members of the group but were harsh for outsiders. Their main agreements involved a division of the world market and the formation of a patent pool for the group members.

In all cases coordination between users only took place within a restricted user group with a comparable and related interest, not only because they all were in the same kind of business but also because they had the shared interest of keeping outsiders out of their business. This homogeneity of the group and the similar use of the resource simplifies the coordination problem by reducing the uncertainty and creates a certain level of trust between the members of the group (Ostrom, 1990, 2010).

The problem of interference could be dealt with at the Washington Conference because of advancements in technology. Earlier radio systems with their broadly radiating *"spark transmitters and unselective receivers were a prescription for interference"* (Aitken, 1994: 692). More precise tuning, more selective receivers and the availability of the newly discovered short waves made it possible to split the multiple-use resource into a number of single-use resources.

Tuning technology was used to define and shape the boundaries of the single-use sub-resources. The rules restricted access to these sub-resources to certain user groups. Information on the (mis)use of these sub-resources was made available. Arbitration on mis-use was made part of the rules.

Already from the beginning, much effort was put in the rules on the creation of (operational) rules. An important aspect of these rules on rulemaking were the provisions who was eligible to take part in the deliberations and who was empowered to take decisions. The industry, (inter)national organizations and others could take part in the discussions, but it was up to the national administrations to decide on the rules. These rules provided only a framework for the operational use of the resource. Much of the detailed operational rules, and monitoring, were left to the user groups themselves.

3.9 Concluding remarks

The *International Radio Telegraph Convention of Berlin* in 1906 was the beginning of international regulation on radio communications. These regulations, which since then have been expanded and revised by numerous Radio Conferences, are now known as the Radio Regulations.

Today, spectrum management is still largely based on the same principals as agreed upon in Washington in 1927. Spectrum is at the global level governed by the International Telecommunications Union (ITU). The Radiocommunication Sector of the ITU (ITU-R) develops and adopts the Radio Regulations, a binding international treaty between nation states, with a voluminous set of rules, recommendations and procedures for the regulation of radio-communications. The Radio Regulations are based on avoidance of radio interference through the division of spectrum in bands which are allocated to one or more services out of some 40 different radio services[129]. A wide range of regulatory, operational, and technical provisions ensure that radio services are compatible with one another and harmful interference among services of different (neighboring) countries is avoided. The Radio Regulations are updated on a regular basis in response to changes in needs and to new demands at World Radiocommunication Conferences (WRC), which are held every three to four years (ITU, 2004).[130]

This regime of spectrum regulation is often called "command-and control" as if government is in total command and control. This is true if an overall view is taken. An in-depth assessment of the governance regime gives a much more nuanced picture. Technology made it possible to neatly separate the various user groups. These user groups had, and still have, much freedom in the further detailed operational rules in their part of the radio spectrum.

The "command-and-control" regime was set up in an era in which radio could become an essential feature of our modern society. Or to put it in the worlds of John Dunnam, alias Allan Chapman (1922: 50):
Radio is yet in its infancy, ... But one thing is certain. In the lifetime of those who witnessed its birth it will become a giant--but a benevolent giant who, instead of destroying will re-create our civilization.

[129] These radio services include services such as fixed, mobile, satellite, amateur, radio navigation and radio astronomy. Most bands are shared among primary and secondary services. Primary services have priority in case of conflicts resulting in harmful interference.

[130] See further Annex I.

4 Expansion of regulatory instruments

Chapter 3 dealt with the spectrum governance regime as set up by the Washington Radio Conference of 1927. The current spectrum governance regime is still based on the principle of a separation of the various services as established in 1927. However some adaptations to the regime have been made to cater for changes in the environment, since its introduction. This chapter will review in detail three cases in which adaptations to the original command-and-control regime were made. The main purpose of these cases is to identify the instances of coordination, the form of the coordination activities, the actors involved and their reasons or objectives for this shift in coordination. The insights obtained by this analysis of these various forms of coordination will be used in chapter 5 to learn from the past to understand the coordination problem and come to successful mitigation of the coordination problem to enable efficient and effective exploitation of the radio spectrum.

The first case deals with the coordination that took place in the advent of the introduction of a new technology, i.e. mobile telephony, and the coordination that took place to eventually enable mobile telephony to become a mobile communi-

> "It must be remembered that there is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage, than the creation of a new system. For the initiator has the enmity of all who would profit by the preservation of the old institutions and merely lukewarm defenders in those who would gain by the new ones."
>
> Niccolo Machiavelli, The Prince, 1513

cation service for a mass market. This case is subdivided in various episodes and covers the developments in Europe and in the US This case describes institutional changes which eventually led to a shift in coordination towards private property rights.

The second case deals with the history of Wi-Fi. It is an example that relates to the unlicensed use of the radio spectrum and shows a shift in coordination towards a technological solution for the coordination problem associated with interference between multiple users of the radio spectrum.

The introduction of property rights in Guatemala has been added as a third case. It is a case in which private property rights are introduced in general and not just for mobile communications. It is insightful as it shows some of the limits of a regime based on property rights.

4.1 Mobile communications: from licensing to private property rights

Marconi experimented with (land-based) mobile communications as early as 1901. However, he had to cease these experiments, because he was not allowed to offer land-based telegraphy in the UK, as the British Post Office had an exclusive privilege to offer land-based telegraphy. As a consequence, he shifted his efforts to maritime communications, as explained in chapter 3.

However, there was also another reason for this shift from mobile communications to maritime communications. In these early days the equipment was very bulky and hardly fitted in an automobile. Although the military already used transportable equipment, real experiments with mobile radios installed in automobiles started in the 1920s. By that time the technology had advanced so far that radios could be made that were small and rugged enough for installation in an automobile. The first experiments with mobile radio were taken in the same time period on both sides of the Atlantic Ocean. In 1921,the Detroit Police Department was the first to experiment with voice transmissions via mobile radio. Similar experiments were carried out in London two years later (Manninen, 2002). The Detroit Police was also one of the first to put mobile radio systems into regular operation in 1928. In the early 1930s several police forces and other public services throughout the world started to install mobile radio systems in their vehicles, Germany and Sweden being examples in Europe. By 1934, there were 194 municipal police forces and 54 state police forces in the United States which used mobile radio (Calhoun, 1988; Garrard, 1998). The first mobile radio system in the Netherlands was introduced by the *Radio Controle Dienst*[131] in 1934 (Schuilenga, Tours, Visser and Bruggeman, 1981).

These early mobile radio systems were built in the same way as broadcasting systems. A powerful transmitter was used to cover a large area from a high tower. This severely limited the possibility to re-use frequencies and limited the amount of calls that could be made simultaneously. These early mobile radio systems were used to provide communications in a closed system; the network was usually not attached to the public telephone network. Before the second World War these private mobile radio (PMR) systems were mainly in use by police forces, emergency services and other public services (Garrard, 1998).

During the second World War much progress in technology was made, which reduced the size and weight of the equipment. After the war, the first

[131] The Radio Controle Dienst was the governmental body responsible for the enforcement of the correct usage of radio frequencies.

public mobile telephony services[132] were introduced. However, the trajectories for the introduction of public mobile telephony were distinctly different in the United States and Europe. This section starts with the introduction and further development of (analogue) mobile telephony in both the United States and Europe. It then follows with the introduction of digital mobile telephony in both the United States and Europe and the development of mobile telephony into a service for the mass market. The case follows with the evolution of this service into mobile communications which offers not only mobile telephony but also mobile data services. The section ends with an assessment of the coordination efforts in the development of the mobile communication service.[133]

4.1.1 Introduction of mobile telephony in the US

The first public mobile telephony service in the United States was introduced in 1946. In that year South Western Bell, one AT&T' regional telephone companies[134], provided the first commercial car-borne service in St Louis, Missouri. The service was quickly expanded to cover the major cities in the United States (Meurling and Jeans, 1994; Manninen, 2002). This early Mobile Telephone Service (MTS) used six channels in the 150 MHz band. Interference between the channels forced South Western Bell to restrict the use to only three of the six available channels.

In 1947, a "highway service" was started along the highway between New York and Boston. The highway system operated on considerably lower frequencies in the 35-44 MHz band. These lower frequencies were thought to carry greater distances which would make them more useful to cover stretches of highway. However, there were big difficulties with the use of these frequencies, as these frequencies are reflected by the ionosphere. Due to these reflections the signals were spread out over very large distances across the country. This created interference in areas far-away, which severely degraded the quality of the highway service (Young, 1979).

Both the highway system and the urban MTS system were modelled as private mobile radio systems. A centrally located base station was set up which served the communication in a wide area. This set up had as a consequence that only as many calls could be made simultaneously as the number of radio channels being available. Hence, the systems quickly run into capacity problems. Waiting lists were developed almost immediately after the introduction of MTS (Young, 1979; Farley, 2005).

In 1947 Bell Labs introduced the concept of cellular communications in order to resolve the capacity constraints of these systems through the geographical reuse of frequencies.[135] To make the concept work, however, the principle of 'switchover' between cells had to be realized – a functionality for which the technology would not be available until

[132] In this chapter, mobile telephony is used as shorthand for a public mobile telephony service. This is a service offered to the general public whereby the mobile network is attached to the public telephone network. It allows communication between customers on the move and all (fixed) public telephone users and it allows communication between customers on the move.

[133] This section builds upon earlier research that has been published in Lemstra, W., Anker, P. and Hayes, V., "*Cognitive Radio: Enabling technology in need of coordination*", Competition and Regulation in Network Industries, Volume 12 (2011), No. 3, pp. 210-235.

[134] AT&T was the mother company of the Bell System, which was comprised of a number of regional wireline telephone companies. AT&T was also referred to as Ma Bell. AT&T also owned the Western Electric Company, a manufacturer of telecommunication equipment, and Bell Telephone Laboratories, its research and development center.

[135] A cellular network is comprised of a network of small geographical areas called cells. Each cell has its own base station. A central switch is used to control the traffic and to redirect traffic from one cell to another. Because the cells use a transmitter with limited power, frequencies can be reused by different cells. See also further down and annex I.

the 1960-1970s (Young, 1979; Davis, 1988). To solve the capacity issue, AT&T had no other means than to ask the FCC for additional frequencies. Hence, AT&T petitioned the FCC to "*allocate a large number of frequencies such that the mobile telephone service could become a mass phenomenon*" (Berresford, 1989: 723).

However, the FCC decided otherwise and allocated only a limited amount of channels for the mobile telephone service, reasoning that other uses of the frequencies would better serve the public interest. The FCC reasoned that "*radio services which are necessary for the safety of life and property deserve more consideration than those services which are more in the nature of convenience or luxury*" (Berresford, 1989: 723).[136]
The FCC took a decision in 1949 to allocate 20 channels in the 152 – 162 MHz band for the newly defined "Domestic Public Land Mobile Radio Service".[137] However, the FCC took also another decision. The FCC introduced competition for this service. Until then, connections to the public telephone network were only permitted by the wireline telephone companies.[138] The FCC gave permission to miscellaneous, or non-telephone company carriers in addition to the wireline common carriers to provide the service.
The available channels were nearly equally split between the wireline carriers and the new miscellaneous common carriers, which are mostly known by the name Radio Common Carrier (RCC). As a result there were only 11 channels available for the wireline carriers (FCC, 1950; Manninen, 2002).

The growth of the Domestic Public Land Mobile Radio Service was considerably impeded by the lack of frequencies. In 1956, 12 additional channels were allocated in the 450 MHz band. The first system that used this frequency range was introduced in the same year (Young, 1979). In 1957, the FCC initiated an inquiry for additional spectrum. As a response to this inquiry, AT&T submitted a proposal to the FCC in 1958 to make available 75 MHz of spectrum for public mobile telephony in the 800 MHz band. However, the FCC determined that the public interest would best be served if these frequencies were allocated to TV broadcast. Thus, the FCC ignored (again) the request for additional channels. Instead, the FCC took the decision to split all available channels (by reducing the channel spacing from 60 kHz to 30 kHz), which roughly doubled the amount of channels available. However, this did not immediately alleviated the frequency shortage, since the new channels formed from channel splitting would not become generally available until November 1, 1963 (FCC, 1958; Davis, 1988; Manninen, 2002).

All systems were in these days still manually operated. Each call to or from a mobile unit was manually connected with the public telephone network by an operator. The mobile unit was based on push-to-talk functionality. Speech was only possible in one direction at the time. An Improved Mobile Telephone System (IMTS) came in operation in 1964. IMTS was based on automatic channel selection, eliminating the need for push-to-talk and making automatic switching to the public telephone network possible based on dialing by the subscriber (Young, 1979).[139]

[136] Most frequencies allocated for the mobile service were designated for private mobile radio, for use by e.g. the police and fire departments.

[137] There were also 24 channels allocated in the 35-44 MHz band for the highway service.

[138] The term wireline telephone company or wireline carrier is used to refer to the total collection of local (wireline) telephone companies. The U.S. local telephone market was dominated by AT&T. The AT&T Bell system consisted of 22 wholly-owned Bell Operating Companies, collectively having about 80% of the local telephone market. The remainder of the market was handled by a collection of smaller telephone companies, plus two companies in which AT&T had a minority interest (Horne, 2009).

[139] The first system, IMTS-MJ operated in the 150 MHz band. In 1969, the same functionality was introduced in the 450 MHz with the introduction of the IMTS-MK.

Although the automatic system made much more efficient use of the available channels, expansion of the service was still severely limited due to the small number of available channels.[140] In March 1964, the FCC made it clear that it definitely gave preference to the broadcasting service and terminated the inquiry for more spectrum for non-broadcasting services, mainly land mobile radio (FCC, 1964). Expansion of the mobile service should come from more efficient use of the available spectrum.

This decision was highly political. The FCC came under increasing pressure from the mobile operators and radio equipment manufacturers to serve the needs of public mobile telephony. In 1968 the FCC reconsidered AT&Ts ten year old request for more spectrum by starting a new inquiry into frequencies for a "truly efficient high capacity" mobile telephone service.[141] The FCC launched the idea to allocate a considerable amount of frequencies for such a service, if it proved to be technically feasible. AT&T responded with the suggestion that a cellular telephone system would be technically feasible (Davis, 1988; Berresford, 1989).

This inquiry was followed in 1970 by a First Report and Order in which the FCC expressed its interest in AT&Ts cellular concept.[142] The order proposed to allocate an additional 75 MHz for common carrier domestic public high-capacity mobile systems and 40 MHz for private mobile radio. Most of this spectrum was taken from broadcasting.[143]
In addition, the FCC asked AT&T as well as others to undertake a comprehensive study of market potentials, optimum system configurations and equipment design for the development and implementation of an effective, high capacity common carrier service in the band 806-881 MHz (FCC, 1970).

In December 1971 AT&T responded to this request with a detailed technical description of a cellular telephone system. This sophisticated mobile system was made possible through advances in technology.[144] The proposed cellular system differed completely from conventional systems. A service area was no longer served by a centrally located single high-powered transmitter on a high tower. Instead, in a cellular system, the service area is divided in small regions, called cells, which are served by a transmitter at relatively low power. This makes it possible to re-use the same frequency over relatively small distances compared to conventional systems. As a vehicle travels from one cell to another, a call in progress is automatically handed-

140 The existing technology could only serve a very limited number of customers per major city. The Bell System in New York could support just twelve simultaneous mobile conversations, the thirteenth caller was blocked. Hence, car telephones became viewed as a status symbol for a few "fatcats" (Berresford, 1989; Gruber, 2005).

141 Docket 18262 "An Inquiry Relative to the Future Use of the Frequency Band 806-960 MHz". Although this docket deals with other services besides cellular, the docket is often referred to as the Cellular Docket (Horne, 2009).

142 Regulations from the FCC are largely created through a rule making process. For each new rule, a docket is opened to act as an electronic file for all the rule making documents issued. Once a docket is opened, a Notice of Proposed Rulemaking (NPRM) can be released, to allow for public comment. Based on the comments, the Commission can then choose to issue a final rule, or Order, a Further Notice of Proposed Rule-making with an amended proposal or a Notice of Inquiry or other Public Notice in support of the Rulemaking Process. See http://www.fcc.gov/encyclopedia/rulemaking-process-fcc.

143 The proposal included the transfer of the upper part of the UHF TV band (channels 70 through 83) from broadcasting to mobile services.

144 Important new technologies were the microprocessor, which made it possible to build electronic switches, and a low cost frequency synthesizer (Young, 1979; Davis, 1988).

over to the next cell. The cellular concept allows to accommodate a large amount of customers with a limited number of frequencies. If the number of customers is rising, the capacity of the system can be further enhanced by splitting the cells into several smaller cells. Because not only the capacity but also the cost of the system increases with the use of smaller cells, it was proposed to use larger cells (with a radius of about 10 miles) at start-up and split the cells as the number of customers increased. In 1971, AT&T reported to the FCC that the system could still function with cells with a radius as low as 1.4 miles (Young, 1979; Davis, 1988; Berresford, 1989).

In 1974 the FCC issued its Second Report and Order. In this Order the FCC clearly stated that it wanted cellular systems to be compatible with one another in order to allow customers to "roam" from one city to another while using their cell phone (Berresford, 1989). The FCC believed that only wireline companies (i.c. AT&T) had the technical expertise to construct and operate such a cellular network. Therefore, the FCC decided that only one cellular system per market (i.e. region) would be allowed and that this spectrum should be licensed to the wireline carriers. At the same time the additional radio spectrum allocation was reduced to 40 MHz (Palmer, 1983).

The decision to give a monopoly to the wireline companies (i.c. AT&T) was not only contested by the non-wireline companies but came also under pressure from other parts of the administration. Both the Department of Justice and the Office of Telecommunication Policy[145] within the Department of Commerce were in favor of competition. This pressure gave rise to a change in the decision of the FCC in 1975. The FCC decided that both wireline and non-wireline carriers were allowed to participate. However, the FCC saw the need for the development of a standardized cellular system to be mandatory in every market area to assure nationwide compatibility (Palmer, 1983; Horne, 2009).

In March 1977 the FCC awarded a license to Illinois Bell to operate a so-called developmental system in Chicago. In this demonstration, AT&T worked together with a Japanese supplier of radio equipment, thereby excluding its former key partner, Motorola. As a result, Motorola joined an effort from the RCCs to demonstrate their own cellular system. Later that year American Radio Telephone Service Inc. (ARTS), an RCC, acquired a license for a developmental system in Baltimore/Washington, using cellular technology from Motorola.[146]

A successful demonstration from ARTS forced the FCC to reconsider its decision. In making its decision, the FCC had to balance between the pressure for the most efficient system against the desire for competition. Both AT&T and Motorola had warned that a split of the available spectrum would result in a less efficient system. The FCC felt that the public benefit of competition would outweigh the benefits of efficiency of a single market for cellular systems. This led ultimately to the final FCC decision in 1982 to grant two licenses per market area, i.e. introducing a duopoly in each market. One license was reserved for the local wireline telephone company and the other open for non-wireline carriers. The radio spectrum was equally split, each licensee would get 20 MHz of additional radio spectrum. A mandatory technical specification was issued by the FCC to assure the compatibility needed to facilitate nationwide

[145] The Office of Telecommunications Policy was established in 1970 to advise the Administration on communications policy. In 1978, the organization was succeeded by the National Telecommunications and Information Administration (NTIA). It is an agency under the Department of Commerce.

[146] Motorola filed a patent for its own cellular system in 1973. Unique in their system was the use of a handheld cellular telephone. Dr. Martin Cooper of Motorola is regarded as the inventor of the handheld cellular phone (Farley, 2005).

roaming.[147] The manufacturers of cellular equipment worked together within the Electronic Industry Association (EIA) to define the standard based on the specifications of the FCC. The standard, which was based on the developmental systems from AT&T and Motorola, became to be known as the Advanced Mobile Phone System (AMPS) (Davis, 1988; Horne, 2009).

Licenses were awarded based on very detailed applications. The selection of the licensee was based on 'comparative hearings', using the information requested as part of the application on marketing, engineering, roll-out plans, cash-flow projections, etc. The applicants included the local wireline telephone operating company for one of the designated licenses, and non-wireline applicants such as MCI, Metromedia, LIN broadcasting and Graphic Scanning for the other license (Lemstra, Anker and Hayes, 2011).

The licenses were issued in a number of rounds for the defined cellular market areas[148], starting with the 30 largest urban markets. The process started in June 1982 when the FCC permitted applications for the first round of 30 designated markets. They received 194 applications for this first round, of which 141 were non-wireline applications, each market attracting two to twelve applicants. The process led to the first commercial license to be granted in 1983. The first analogue cellular service was introduced by Illinois Bell in Chicago in the same year.[149]

The number and size of the applications, in this first round of 30 designated markets, was far more than the administrative structure of the FCC could evaluate within a reasonable amount of time. Hence, the FCC urged the applicants to form joint ventures to consolidate their applications. Which happened on the wireline side, but not on the much more competitive RCC side. The evaluation process was deemed to result in a 'wireline head start' (Calhoun, 1988; Meurling and Jeans, 1994). The FCC also decided to drop the lengthy comparative hearing approach, and to allocate the licenses for the subsequent rounds based on a lottery system among qualified applicants. Under the threat of a non-optimal outcome under a lottery system, the major non-wireline contenders having filed (individual) applications coordinated their efforts and came together under the leadership of Aaron of RAM Broadcasting and Sherwin of Graphic Scanning, the major contenders in several markets, to divide the markets in essentially a game of Monopoly (Calhoun, 1988; Meurling and Jeans, 1994).

The subsequent rounds were opened for applications at intervals of four to five months. Despite the consolidation effort, each subsequent round attracted an increasing number of applicants. The second round of applications for markets 31-60 in November 1982 generated a total of 396 applications.[150]
The third round generated in March 1983 a total of 567 applications. Each application still contained a voluminous set of technical and operational details, which were necessary for the pre-qualification.
It took until February 1986 to sort the application process on the non-wireline side for the top 90 urban markets which covered all the major cities in the US.

147 The official mandatory specification was published by the FCC in OST Bulletin No. 53.

148 There were 734 market areas defined. Out of these 734 market areas, 428 of them were designated as rural area and 306 as urban area. The urban markets were officially known by the acronym MSA (Metropolitan Statistical Area) and the rural markets were officially known by the acronym RSA (Rural Statistical Area) (Horne, 2009).

149 Illinois Bell became part of Ameritech, one of the seven Regional Bell Operating Companies (RBOC) after the AT&T Bell System divestiture. The RBOCs were originally known as Regional Holding Companies (RHCs).

150 Of which 353 were non-wireline applications.

The FCC faced a problem for the next rounds. The number of applications was much higher than expected for the remaining smaller markets. The next round alone, to be held for markets 91-120, generated an average of 500 applications per city. With so many applicants, settlement was impossible in many markets. The FCC took the decision to completely abandon the evaluation of bids. The FCC decided to go for simple lotteries without pre-qualification. Technical and financial commitment was no longer necessary as part of the bids. The result of the decision was exactly the opposite of what the FCC intended. The nature of the applications changed and the opportunity was referred to as a 'speculators dream' (Lemstra, Anker and Hayes, 2011). There was no license fee, the only costs were in the preparation of these simple bids. There were over 92,000 applications for the remaining urban markets and a total of 300,000 applications for the rural areas. Many of the winners were simply speculators with no interest in providing a cellular service. They sold their licenses to experienced carriers at enormous profits. Overall, it took the FCC four years to award the licenses for the remaining urban areas and seven years to finalize the whole process with the award of licenses for the rural areas (Berresford, 1989; Meurling and Jeans, 1994; Garrard, 1998; Horne, 2009).

The first services started in 1983. However, the mobile operators faced a problem with roaming. The FCC decision to make a single standard mandatory did not completely solve all the issues around roaming. The FCC specifications and the AMPS standard only dealt with the air interface. Roaming requires transfer of data between operators and commercial agreements between operators in different cities. Hence, the Cellular Telecommunications Industry Association (CTIA), a trade association represented both wireline and non-wireline carriers, was formed early in 1984. One of the first issues that the CTIA handled was roaming. The CTIA created a committee that set the requirements for the content and format of the data that had to be exchanged for 'roaming' subscribers. These requirements formed the basis for the intersystem standard known as IS-41, which was widely adopted throughout the USA (Davis, 1988; Gruber, 2005).

The wireline carriers were considerably faster with the introduction of the service. There were already 80 wireline carriers operational by the end of 1985. The non-wireline carriers lagged behind with only 15 operational networks. To ease entry for the non-wireline carriers, they were allowed to offer services via the networks owned by wireline carriers. By the end of 1986 most of the 90 largest urban areas had two competing systems operational (Garrard, 1998).

4.1.2 Introduction of mobile telephony in Europe

Sweden is considered by many authors as the first country in Europe to launch a mobile telephony service in 1956. However, already in 1947 plans for a public mobile phone service were developed in the Netherlands, which led to the introduction of the first public mobile telephone service with nationwide coverage in the world as early as 1949. It was an operator assisted service. The service proved its value during the major flooding in 1953, when the wireline infrastructure was out of action (Schuilenga, Tours, Visser and Bruggeman, 1981; Anker, 1995).[151]

In Sweden mobile communications started with a trial system becoming operational in 1950, to be followed by two commercial automatic car-borne systems in 1956, in Stockholm and in Gothenborg (Manninen, 2002).[152] Other European countries

[151] This Openbaar Landelijk Net (OLN) reached its limit in the late seventies with around 2500 subscribers. It remained in service until 1986. The first automatic system, ATF-1, was introduced in 1980 (Anker, 1995).

[152] This MTA system had automatic switching between the four available channels and was connected to the fixed telephone network. However, since the system was based on a single powerful base station, it was a city system with very limited capacity.

followed in the 1960s. With the exception of the Swedish systems, these systems were all manually controlled. In Europe public telephony was provided by governmental owned PTTs and provisioning of mobile telephony was no exception to the case. These early systems had very limited capacity. Most of them worked in the 150 – 170 MHz range where only a small number of frequency channels were available.

The national PTTs in Europe had a long history of cooperation in the field of telecommunications regulation. This cooperation mainly involved interconnection of the national networks and rules for tariffs of cross-border traffic. In 1959 this cooperation became formalized with the establishment of the European Conference of Postal and Telecommunications Administrations (CEPT)[153] by the PTTs in nineteen European countries.[154] In its first year of existence, CEPT expanded the cooperation to the allocation of spectrum. It was decided to allocate the 450-470 MHz band primarily for fixed services and secondary for mobile services. In the 1960s the topic of a common European mobile telephone systems had become an item of discussion in CEPT. However, as the PTTs backed their national telecommunications supplier, no agreement could be reached on the subject on the European level.

At the Teleconference of the Nordic National Telecommunication Administrations[155] in 1969, the Swedish Administration announced its intention to start developing a next-generation automatic cellular mobile telephone system and proposed a joint project.[156] It was decided to form a working party, which became known as the Nordic Mobile Telephone Group which was constituted by Denmark, Finland, Iceland, Norway and Sweden. The NMT Group considered the option of a Pan-European solution but concluded this to be a too ambitious goal. The difference in the use of the 450 MHz band among the Nordic countries were resolved by the NMT Group at the 1971 Teleconference. It was decided to follow the Danish proposal, which was made to align radio spectrum use with neighboring Germany. At the 1971 Teleconference a model of one common system was presented and accepted. In 1975 it was formally decided that the system should be automatic. It should be noted that the NMT Group was not only in charge of defining the specifications, but also involved in the procurement of equipment, its implementation and the further development of the system (Manninen, 2002; Lemstra, Anker and Hayes, 2011).

The NMT Group decided to follow a standardized approach. Signaling, quality of service, numbering and ‘roaming’, were confirmed as essential features at the 1975 Teleconference. The standard was made available to the industry, essentially as an open standard – free of charge. Harmonization was further required with respect to the license for the mobile terminal, which needed to be valid in all countries, irrespective the country of issuance. Also charging principles needed to be harmonized, which ultimately became to be based on the location of the subscriber and the number selected (Meurling and Jeans, 1994; Manninen, 2002; Lemstra, Anker and Hayes, 2011).

153 The official name is *Conférence Européenne des administrations des Postes et Télécommunications.*

154 CEPT membership expanded to 20 countries within the first 10 years of its existence.

155 The Nordic countries already started more formal cooperation as of 1917. At that year they started to hold a bi-annual Teleconference. Nordic cooperation started between Denmark, Norway and Sweden. Finland and Iceland joined the Nordic cooperation in the 1950s (Manninen, 2002).

156 The proposal was based on an internal study commissioned by Televerket on mobile communication. Televerket is the Swedish Telecommunication Administration, a state organization having provided the country with telephone service. In 1993 it would become a state owned stock company called Telia AB.

In 1977 manufacturers had been invited to bid for the supply of the base stations and the mobile switching equipment. In 1978 a trial was successfully concluded. Ericsson became the supplier of choice for the switching part and SRA for the base stations (Meurling and Jeans, 1994; Manninen, 2002).[157] The targeted in-service date of October 1st, 1981 was met, but, the world's first cellular system would be inaugurated one month earlier on September 1st, in the Kingdom of Saudi Arabia (Lemstra, Anker and Hayes, 2011).[158]

With this initial success other countries followed to introduce a cellular mobile telephone service. The NMT standard was adopted in the Nordic countries and some other (smaller) countries within Europe. In the Netherlands the incumbent operator adopted the NMT450 standard, as did the operators in Belgium and Luxemburg. The larger countries all developed their own country-specific analogue system, which was developed by the national telecommunications equipment supplier. The C-450 system was adopted in Germany. The system was developed by Siemens, the dominant national telecommunications equipment supplier in Germany. The system became operational in 1986. France developed the Radiocomm 2000 system (in service in 1986) and in Italy the RTMI/RTMS system was developed (in service in 1985).[159] However, these systems never attracted a large market outside their domestic market (Garrard, 1998).

[157] The mobile switching system MTX was of the AXE type, the first fully digital switch developed by Ellemtel, a joint company of Swedish Telecom and Ericsson. SRA – Svenska Radio Aktiebolaget– was founded in 1919 by ASEA, AGA and Ericsson. In 1982 it would become a fully owned subsidiary of Ericsson (Lemstra and Hayes, 2008).

[158] In 1978 a joint venture between Ericsson and Philips of the Netherlands had been awarded the contract to build a new fixed telephone network for the Kingdom of Saudi Arabia. In 1979 this contract was extended to include a mobile telephone system based on NMT450.

[159] These French and Italian systems are sometimes referred to as "quasi-cellular", because they only had limited possibility for handovers from one cell to another.

In most countries the national PTT was the only company that provided cellular mobile telephony. Sweden was the first European country that introduced competition. In Sweden, a second license was awarded to Comvik which started operation in 1981. However, the competition was very limited. Comvik was given only a very small amount of the available frequency channels (28 of the available 180 channels). It also used a proprietary technology with expensive terminals that were incompatible with any other system (Garrard, 1998).

The UK was the first European country that had a real duopoly. The first license was awarded to Cellnet, a subsidiary of the incumbent operator British Telecommunications (BT). The second license was open to competition and awarded in 1983 to a new entrant, a joint venture of Racal and Milicom (to become Vodafone). The regulator did not prescribe a standard, the only requirement was that they had to use the same compatible system. Consequently, Cellnet and Vodafone had to negotiate the standard to be used, which became known as TACS (Total Access Communication System), a modified version of the US AMPS[160], heavily pushed by Vodafone, intending to leverage the larger US market volume. Motorola would become supplier to Cellnet and Ericsson to Vodafone. The in-service date was January, 1st 1985 (Meurling and Jeans, 1994; Manninen, 2002; Lemstra, Anker and Hayes, 2011).

4.1.3 Second generation mobile telephony in Europe

The success of the analogue cellular systems led in a number of European countries to concerns of (near) future capacity limitations and hence to the exploration of options for expansion of analogue systems in the 900 MHz band, which had been reserved through the CEPT for mobile communications in 1978.

[160] The main difference is the channel spacing: 25 kHz in Europe and 30 kHz in the USA.

The potential of pan-European mobile communications was observed by the French PTT who convened a meeting in Paris with European PTTs in 1981 to explore the plans for the use of the 900 MHz band. The French objective was to start the harmonization of a common system for roll-out by 1985. No agreement was reached, but in 1982 BT also on behalf of France Telecom, invited several administrations to start a project for the implementation of an NMT-based system in the 900 MHz band. Before their scheduled meeting, the Dutch administration proposed a recommendation to be made to the CEPT to start procedures leading to "the construction of a pan-European automatic telephone service in the 900 MHz band"; a proposal that appealed to many European administrations. This resulted in a working party being created within CEPT: the Groupe de travail Spécial pour les service Mobiles (in short: GSM) to develop a specification. The system would have to resolve the capacity shortage of the analogue systems and provide for harmonization of the European market, resolving the incompatibility between the multiple standards being used. The GSM Group started its work in December 1982. To support the standardization of a pan-European system CEPT also took the decision in 1982 to allocate the 862-960 MHz band for international maritime and land-based mobile telephone services. The objective was to realize a European standard, as global coordination through the ITU was considered to be extremely difficult. In 1984 Bellcore[161], revealed its interest to set-up a technical liaison with the GSM Group aimed at compatibility between North American and European systems. Based on technical, institutional and political considerations the invitation was declined by CEPT (Manninen, 2002; Lemstra, Anker and Hayes, 2011).

The developments in the field of mobile telecommunications were observed with interest by the European Commission. The Commission saw the availability of first class telecommunications infrastructure as an essential facilitator to the single European market. However, the European Commission noted that firstly telecommunication infrastructure was based on national markets and therefore too fragmented. Secondly, the European industry was based on "national champions" and lagging behind competitors from the US and Japan. The Commission came to the conclusion that European coordination needed to be strengthened in the development of the next generation of telecommunication infrastructure (CEC, 1983; Sandholtz, 1993).

In September 1983, the Commission came with an action plan containing 6 "lines of action". These lines of action were the starting point for a number of proposals from the Commission. These proposals included collaboration in research and development in order to develop the next generation of telecommunication infrastructure. The proposals were accepted by the member states by the end of 1984 (CEC, 1984).

As part of the strengthening of the coordination, the European Commission endorsed the GSM project in 1984. This endorsement was in 1987 followed by Directive 87/372/EEC 1987 on the frequency bands to be reserved for the coordinated introduction of public pan-European cellular digital land-based mobile communications in the Community, with a target date for the launch of GSM by 1991, with a defined minimum set of services including roaming.

The overall objective for the GSM system was to offer mobile services throughout Europe at low cost, and having enough capacity to serve a mass market. After

161 Following the divestiture of the Bell system, the Regional Bell Operating Companies established Bellcore as a jointly owned R&D facility, as Bell Labs had remained with AT&T, the long-distance and international operator. With the trivestiture in 1996 Bell Labs would remain with Lucent Technologies and AT&T would focus on services related R&D in its AT&T Labs.

initial concerns regarding network capacity had been resolved, the Group embraced the use of hand-held telephones in 1985. In the following year the Group took the decision to go for a digital cellular system. The validation trials held in 1986 with the support of equipment suppliers, such as Nokia, Ericsson and Siemens, led to the decision to adopt Time Division Multiple Access (TDMA) technology. From the following year onward manufacturers were allowed to participate directly in the work of the CEPT GSM Group. Their cooperation was seen as essential to provide the necessary resources in the standardization activities and to meet the implementation timescales. In the same year (1987) operators from thirteen countries signed a Memorandum of Understanding to commit to the network roll-out and cooperation on commercial and operational matters, such as tariff principles (e.g. calling party pays) and accounting (Garrard, 1998; Manninen, 2002; Lemstra, Anker and Hayes, 2011).

In 1988, as a result of a lobby from the European Commission, CEPT decided to create the European Telecommunications Standards Institute (ETSI). All telecommunication standardization activities within CEPT were to be transferred to this newly formed institute, in which manufacturers, operators, administrations and user groups were represented. In 1989 the GSM Group became a Technical Committee within ETSI. A year later Phase 1 of the GSM-900 specifications was released, with open interfaces to foster competition in network deployment. (Manninen, 2002; GSM Association, 2004; Lemstra, Anker and Hayes, 2011).

The formation of ETSI was a result of the need for more direct involvement of manufacturers and other stakeholders in the standardization process and the liberalization that took place in Europe. The main arguments for liberalization were the concern that a persistence of national monopolies would be counter to the principles of the Common Market within the European Union. Telecommunications was one of the first network industries where competition was introduced. The process of liberalization in telecommunications started in 1987 with the publication of the Green Paper on the development of the common market for telecommunications services and equipment (CEC, 1987). The Commission proposed the introduction of more competition, combined with a higher degree of harmonization, in order to maximize the opportunities offered by the Single EU market.[162]

In most European countries in the late 1980s and the early 1990s the national PTTs were split into a telecommunications operator and a postal operator. Subsequently, these new entities were privatized. The policy making and the regulatory part stayed within the government. This ended a period in which the PTTs had a double role as both regulator and operator. These privatized telecommunication operators created the European Telecommunications Network Operators association (ETNO) in May 1992. In the same year, CEPT was reorganized and became a coordination body for policy makers and regulators.

Within CEPT the European Radiocommunications Committee was set up to address all radiocommunication related matters. The prime objective of the ERC was to develop European harmonization measures for the allocation and the use of radio frequencies. At its October 1992 conference in Madrid the ERC introduced a number of proposals to strengthen the cooperation between its members. The ERC decided to introduce more firm agreements ("Decisions") between members to implement policies. In the past, CEPT always worked with

[162] Competition started in the market for equipment with the publication of the Telecommunications Equipment Directive in 1988 (CEC, 1988). The directive introduced competition in the sales of terminal equipment, including mobile telephones. In order to ensure a European market for equipment, directives have been issued to establish the principle of full-recognition of type-approval. Equipment that has been approved in one Member State can freely be sold throughout the European market.

Recommendations. These Recommendations were relatively weak, since administrations were not bound by them. The newly proposed Decisions were considered to be much stronger than Recommendations since administrations commit themselves, in writing, to implement Decisions.[163]

The involvement of CEPT in the European harmonization effort was recognized in the European Union through Council Resolution 90/C 166/02. In this resolution the European Commission gave support to CEPT to set up the European Radio-communications Office (ERO), as a permanent office to support the ERC. The ERO was formally opened on 6 May 1991 and is located in Copenhagen.[164]
The leading role of CEPT in the harmonization of spectrum in the European Union was reiterated in 1992 in Council Resolution 92/C 318/01.

The next step in this liberalization process was the introduction of competition in the field of telecommunications. In most European countries, the introduction of GSM was used to create competition in the market for mobile telephony. In the fall of 1992 GSM was launched in 7 countries by 13 mobile operators. In all EU countries the incumbent who already ran the analogue network obtained one license. The second license was typically issued through an administrative method based on the evaluation of a detailed bid, i.e. a beauty contest or comparative hearing. The bids contained a description of the network roll-out, the offered services, the quality of the offered services and in several cases also an indication of the cash payment to the government for the spectrum use (Gruber, 2005; Anker and Lemstra, 2011).

[163] CEPT was reorganized in 2001. All activities related to electronic communications, including radiocommunications, were transferred to the newly set up Electronic Communications Committee (ECC).

[164] In the reorganization of 2001, the ERO was merged with the European Telecommunications Office, to form the European Communications Office (ECO).

4.1.4 Second generation mobile telephony in the US

Within a few years the success of analogue mobile telephony led to capacity problems in the 800 MHz band. In 1987, the FCC declared that cellular firms could introduce new (digital) cellular technologies at any time without prior regulatory approval, provided that they were backward-compatible with the existing system. In other words, there was no national digital standard but any new system would have to be backward-compatible with AMPS (Gruber, 2005).

As a result in September 1987 a proposal was made to establish an Electronics Industry Association (EIA) Technical Committee (TR 45.3) to focus on future digital systems with the very ambitious goal of service introduction in 1991. In 1988 the US Cellular Telecommunications Industry Association (CTIA) published a set of user requirements for the industry with the objective to increase the capacity of the analogue network tenfold, and in addition improving reliability and quality. AT&T, Motorola and Ericsson set up tests to demonstrate the capabilities of their systems. AT&T and Motorola were promoting FDMA and Ericsson TDMA. Qualcomm used the user requirements of the CTIA to pitch for a new concept, Code Division Multiple Access (CDMA), based on spread spectrum techniques, claiming a theoretical capacity increase of forty times.

The Telecommunication Industry Association (TIA)[165] considered CDMA as being too complex and not a proven concept. Hence, the TIA voted for a TDMA specification as basis for digital cellular systems, although only a threefold capacity increase could be demonstrated with good voice quality (Meurling and Jeans, 1994; Mock, 2005; Lemstra, Anker and Hayes, 2011).

[165] TIA was formed in April 1988 after a merger of the US Telecommunication Supplier Association and the Information and Telecommunications Technologies Group of the Electronics Industry Association.

In 1990, EIA together with TIA released the IS-54 specification for digital cellular systems, also referred to as D-AMPS. The advantage was that TDMA could be positioned as an upgrade of AMPS using the existing base stations, albeit for this evolution dual-mode analogue/digital handsets were required. (Meurling and Jeans, 1994; Mock, 2005; Lemstra, Anker and Hayes, 2011).

Despite this fact, Qualcomm decided to further develop CDMA. Late 1989 Qualcomm, in close cooperation with PacTel, demonstrated a CDMA prototype with a tenfold capacity increase. Field test executed in the fall of 1991 confirmed their claim. Notwithstanding, in 1992 the CTIA reconfirmed its support for TDMA, but also recommended that the TIA set up a forum to discuss a wideband spread spectrum standard. In 1993 the IS-95 CDMA standard was ratified by the TIA. Qualcomm set up a CDMA Development Group (CDG) to promote the system more widely. All major equipment manufacturers joined this group, with the notable exception of Ericsson, which maintained that CDMA would have no advantages over GSM and it did not intend to manufacture any products for this technology (Gruber, 2005).

Mobile operators now had to make a choice for the introduction of digital cellular technology. In spite of the smooth transition to digital technology that was possible with D-AMPS, most of the operators choose for CDMA because of the greater benefits. By 1996, only three operators had chosen to use D-AMPS and eight had decided to use CDMA. However, the largest operator (AT&T Wireless) had chosen to use D-AMPS, thus the population served was nearly equally split between D-AMPS and CDMA. The market was resembling an oligopoly between the two technologies (Garrard, 1998; Gruber, 2005).

4.1.5 Personal Communications

In January 1989 the Department of Trade and Industry (DTI) of the UK issued a discussion document "*Phones on the Move, Personal Communications in the 1990s*". In this document, the UK government posed the assumption that the newly developed GSM would mainly attract the professional market. Therefore, the DTI invited suggestions for a much cheaper mobile telecommunications system suitable for a truly mass market. The system was referred to as a Personal Communications Network (PCN).

This PCN system should operate in the frequency range between 1700 and 2300 MHz. At that time, this frequency range was seen as very high for a mobile service, especially for a system targeted at a mass market. The reason being, that the coverage area of a base station operating in this frequency range is much smaller compared to the lower frequency range of GSM (around 900 MHz). As a consequence, there are much more base stations needed at this higher frequency range than at lower frequencies to cover a particular geographical region. The DTI expected that the new networks would not directly compete with GSM, but would be limited to urban areas or isolated cells without the possibility of roaming from one cell to another. The driving idea was that a mass market needed small, light, hand-portable phone sets, with a long battery life and low prices (Garrard, 1998; Gruber, 2005).

The European Commission was not very pleased with this unilateral action of the UK, while the other European countries were cooperating to develop the new European standard GSM. When the DTI announced the rules for selecting the licenses for PCNs later that year, it ruled that the technology to be used should be based on a European standard.[166] A single standard should be agreed upon after the licenses were awarded. When the DTI announced the names of three winning consortia for PCN licenses, it was still not clear which standard would have to be used and which frequencies would be

[166] At that time, ETSI was not only developing the GSM standard for a digital cellular system but also the DECT standard for cordless telephony.

available. However, the winning consortia had based their bids on GSM technology.

To resolve the issue, the UK came to agreement with ETSI that ETSI would develop a standard for digital cellular communications (DCS) based on GSM. The standard was developed with a minimum-change philosophy to the GSM standard. As a result the standard was already completed in January 1991 just ten months after formal agreement from the ETSI Plenary Assembly to develop the standard. The only significant changes of the DCS standard with respect to the GSM standard were the necessity to operate on a higher frequency with more channels being available and a lower operating power level of the mobile devices targeted at the use of portable handheld devices (Garrard, 1998).

Before the standard could be finalized, a frequency band of operation had to be agreed upon. Within CEPT, it was decided to use the frequency band 1710-1880 MHz. Since this band was internationally allocated for fixed links, this band was proposed to the World Administrative Radio Conference of 1992 (WARC-92) for an allocation to the mobile service. At the WARC-92 the decision was made to make this allocation to the mobile service for operation on a primary basis. This frequency band was harmonized in Europe through CEPT Recommendation T/R 22-07. A more firm ERC Decision (ERC/DEC/(95)03) followed in 1995. The system was given the name DCS1800.[167]

The band started to gain attraction from other European countries as a means to increase competition in the mobile telephony market. Germany and France followed the UK example to increase the competition with the issuing of a DCS1800 license to a third operator, in respectively 1992 and 1994. This course of action was in line with the thinking within the European Commission. The Commission was of the view that the introduction of a second operator was not enough to liberalize the mobile market. In a Green paper, issued in 1994, the European Commission proposed that every country should at least have two GSM operators and one DCS1800 operator. This was followed by Directive 96/2/EC, which instructed Member States to issue licenses for cellular mobile telecommunications services in the 1800 MHz frequency band. The band should be used to enhance competition before 1998. By that time, there were supposed to be at least three firms supplying digital cellular services in each country. Ultimately all EU countries, with the exception of Luxembourg, complied with this objective (Garrard, 1998; Gruber, 2005).

The debate on PCN in the UK was brought to the attention of the FCC in the United States by several industry players. The FCC published a Notice of Inquiry in 1990 on a new service called “Personal Communications Service” (PCS). It took the FCC until 1994 to go through all the bureaucratic procedures and to start the licensing procedure for PCS.

The FCC took the decision to use a slightly higher frequency band than the one used in Europe, because the 1800 MHz band as used in Europe was already in use by military services in the US.[168]
In 1994, the FCC decided to allocate the frequency range 1850-1990 MHz for PCS. Licenses were awarded for different service areas. There were 52 larger Major Trading Areas (MTAs) defined, subdivided in 493 Basic Trading Areas (BTAs). There were two MTA-licenses of 2 x 15 MHz and a BTA-license of 2 x 15 MHz defined as well as three smaller BTA licenses of 2 x 5 MHz. In total, every town in the US should in principle be covered by six PCS licenses. The existing cellular operators were only allowed to acquire a small license within their own service area. These

[167] The DCS1800 specifications were fully merged with the GSM900 specifications in 1991. From then on DCS1800 was called GSM1800.

[168] There was also military usage of the 1800 MHz band in some European countries. However, in Europe eventually the decision was made to move the military out of this band.

smaller licenses could also be acquired by one of the three PCS license holders of the larger licenses. Hence, the level of competition was increased from 2 to at least 5 and a maximum of 8 (Gruber, 2005).

The FCC decided to auction the licenses for PCS. The auctions started in 1994. The FCC did not prescribe a technology. The choice of technology was left to the market. Both the existing standards for digital cellular, IS-136 (D-AMPS) and IS-95 (CDMA), were upgraded to include operating in the PCS band. Most of the larger mobile operators opted for their existing cellular technology. However, most of the new PCS operators chose to use GSM technology. The American National Standards Institute (ANSI) developed in co-operation with ETSI a GSM standard for the US market which became to be known as PCS1900.[169] In October 1996, the GSM MoU group set up a task force to supervise the development of a (tri-band) handheld portable to enable roaming between Europe and the US (Garrard, 1998). As a result, the US market was divided between three technologies for digital mobile communications.

4.1.6 Third generation mobile communications

Concerns on the development of diverging standards for mobile telephony in different regions of the world led already in 1985 within the ITU[170] to the decision to develop a globally harmonized standard for a future mobile system. A Working Party, Interim Working Party 8/13, was established to investigate the scope for a third generation global standard for Future Public Land Mobile Telecommunication Systems (FPLMTS).[171] FPLMTS was envisaged to provide personal telecommunication services through the use of hand-held terminals anywhere world-wide; on land, on sea and in the air. To do so, the system would not only encompass a mobile network to provide access in urban and sub-urban areas, but would also have a satellite component to provide access in remote areas (including in the air and on sea). The system was also envisaged to provide wireless access to the fixed network within buildings (CCIR, 1990).

The FPLMTS discussions were dominated by Europe. Research on a future mobile system started in Europe in late 1985 with a one-year RACE Definition Phase project to evaluate the options for future mobile systems studies within the RACE program.[172] This led to the inclusion of a project in the RACE program in 1988 on a third generation wireless communication system which would be operational in the twenty first century. That project developed the idea of a Universal Mobile Telecommunications System (UMTS) (Evci, 1992; Garrard, 1998).

FPLMTS was put on the agenda of the World Administrative Radio Conference in 1992 (WARC-92). The Conference identified the sub-bands 1885-2025 MHz and 2110-2200 MHz for administrations wishing to implement FPLMTS, including 1980-2010 and 2170-2200 MHz for the mobile satellite component. Europe was the driving force for this identification.[173] This proposal was backed by Japan, which saw FPLMTS as an opportunity for Japanese industry after the internationally limited success of the 1st and 2nd generation of Japanese systems. The main opponent was the United States who wanted to ensure that the spectrum could be used as flexible as possible, and not to be tied to one concept, especially not a European concept (U.S. Congress Office of Technology Assessment, 1993). Agreement could only be reached if it was not a firm

169 Its official ANSI title was IS-661.

170 The decision was taken in CCIR Decision 69.

171 The first meeting of the Interim Working Party 8/13 was held in 1986.

172 RACE (Research and development in Advanced Communications technologies in Europe) was a European Commission sponsored research program, running from 1985-1995.

173 CEPT proposed a lower boundary of 1900 MHz, because the band 1880-1900 was within Europe harmonized for cordless telephony (DECT).

allocation or designation, thus the bands 1885 - 2025 MHz and 2110 - 2200 MHz were "*intended for use on a worldwide basis by administrations wishing to implement FPLMTS*" (ITU, 1994: footnote 764A).[174] Part of the deal with the United States was also the inclusion of an allocation to the mobile satellite service. The development of mobile satellite systems was dominated by the US.

Hence, it was not possible to agree on a single standard within the ITU. Therefore the original objective of one global standard was abandoned. Instead it was decided to develop a framework for 3rd generation mobile communications under the umbrella of IMT-2000, International Mobile Telecommunications for use in the year 2000. Japan and Europe decided to join their effort in the creation of a standard for IMT-2000. In December 1998, a body called the Third Generation Partnership Project (3GPP) was established. Its objective was to 'co-operate in the production of a globally applicable 3rd Generation Mobile System based on evolved GSM core networks'. It was founded by the following regional standardization bodies: ARIB (Japan), ETSI (Europe), ANSI T1 (United States), TTA (Korea), TTC (Japan), and later joined by CWTS, the Chinese standards body. The 3GPP standard became to be known under the name of UMTS (Richardson, 2000).[175]

Subsequent to the establishment of 3GPP, a second body, 3GPP2, was established. This group consisted of the American manufacturers Lucent Technologies, Motorola, Nortel and Qualcomm. It was set up to develop the next generation standard CDMA2000, based on the CDMA system of Qualcomm.

Both the 3GPP and the 3GPP2 standard used CDMA technology. Ericsson and Qualcomm were in a dispute over CDMA patents since the inception of the cdmaOne standard in 1989. This dispute intensified when Ericsson started the development of their proposal for the UMTS air interface. In 1999 the dispute over intellectual property rights was settled. 3GPP and 3GPP2 started a cooperation in order to allow interoperability and interworking between UMTS and CDMA2000 (Richardson, 2000). This made it easier to develop mobile terminals which could use both technologies, allowing worldwide roaming for customers.

In October 2000 the first commercial offering of 3G–services was introduced by SK Telecom in Korea, based on CDMA2000 technology. NTT DoCoMo of Japan followed in October 2001 with the first 3G service based on the W-CDMA technology of 3GPP.[176] All European countries assigned licenses for 3G services in the years 2000-2001. The license assignment procedures varied considerably among the countries, but the majority made use of an auction (Gruber, 2005).

4.1.7 *Assessment of the coordination to develop mobile communications*

The first systems for mobile telephony were very limited in their capacity to offer services to the general public. An efficient and large scale mobile telephone service was only possible with the introduction of a cellular system. Although the concept of cellular technology was already invented in 1947, just one year after the introduction of a mobile telephony service to the general public, the technology to support the concept was not yet available. It took nearly 25 years before the concept

174 The footnote also states that "*such use does not preclude the use of these bands by other services to which these bands are allocated.*"

175 There are a number of names used in relation to the standard as developed by 3GPP. The air interface uses W-CDMA technology. The interface is based on the Japanese Freedom of Mobile Multimedia Access (FOMA) and the European UMTS Terrestrial Radio Access (UTRA). Within the framework of the ITU, the standard is known as IMT-2000 CDMA Direct Spread.

176 The first version of the NTT 3G technology was not compatible with the 3GPP standard. This was resolved in an upgrade of their network.

could be realized and demonstrated in 1971. Since then, it took more than a decade before the first commercial system could be offered to the public in 1981.

This ten years gap can be explained from the fact that it is not enough to have the technology. The institutional arrangements to support this technology had to be developed as well. Although the technology was developed in the United States, it took the US very long to settle the necessary institutional arrangements. As a consequence, the US was not the first to introduce a commercial cellular service. This honor was for Saudi Arabia. They launched a commercial system two years before the United States. The long period needed in the US was due to the debate whether the public objective of an technical efficient system or competition in the market should prevail. Eventually, the public objective of competition in the market for cellular telephony won. Institutional arrangements had to be put in place to issue licenses for both the wireline carriers and the radio common carriers.

This interplay between technology and institutional arrangements can already be observed in the early days of the development of mobile communications. The service was severely limited by the amount of radio spectrum available. The FCC was in full control of the amount of radio spectrum available for mobile communications. Throughout the history of mobile telephony, the FCC had to balance between the need for frequencies for this newly defined service against the vested public interest of broadcasting and of police forces, fire departments and other users of private mobile radio when making decisions on the allocation of frequencies. The FCC gave, at first, a very clear preference to the existing services above the development of this new mobile telephony service. Technological developments, such as channel splitting and automatic channel control, were needed to cope with the capacity constraints.

This preference for the vested interests of the existing services is understandable and explainable. It was a choice between services with a clear public interest against the introduction of a new service which was seen as a luxury for the "fatcats". Moreover, the broadcasting side was unified in their lobby to keep the frequencies. The other side of mobile telephony, was less organized. The main driving force behind mobile telephony was AT&T. Even the RCCs were not wholeheartedly driving for mobile telephony, since they also had an interest in private mobile radio.

The introduction of a cellular service was only possible after the FCC took the decision to set aside additional spectrum for mobile communications, largely at the expense of broadcasting. This decision was made possible after the mobile telephony service proved its value for society.

The development of a large scale cellular service was under tight governmental control, not only in the United States but also in Europe. The development started in Europe within a state firm under managerial control. However, there are some other clear differences in the control of the government on the introduction of a cellular mobile telephony service between the two regions and between the first and second generation of mobile telephony.

These differences in control had their effect on the diffusion of mobile telephony in the United States and Europe. This difference is quite remarkable and concerns both analogue first-generation (1G) and digital second generation (2G) mobile telephony (Koski, 2006; Lemstra and Hayes, 2009).

The FCC was in full control of the development of the mobile telephony service. Not only by allowing access to radio spectrum, but also by determining the size of the market and the number of active operators within each market. The FCC opted for competition in the market for mobile telephony.

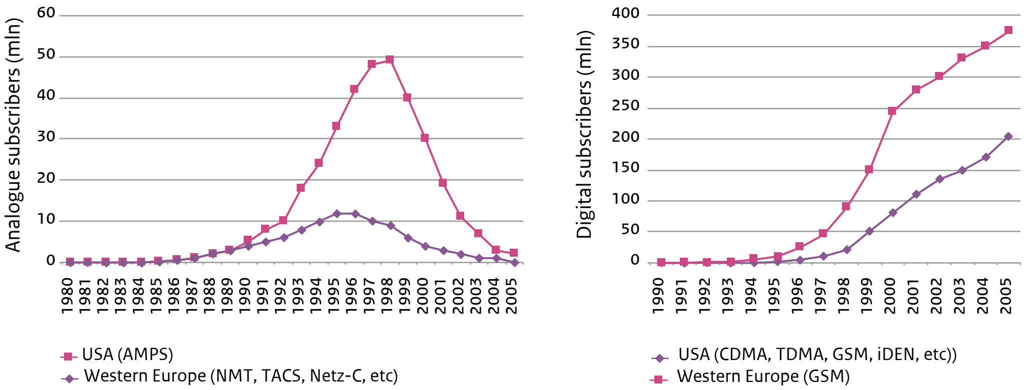

Figure 4-1 Diffusion of analogue and digital mobile telephony in the United States and Europe (Koski, 2006; Lemstra and Hayes, 2009) .

As the amount of frequencies available was very limited, competition was limited to two players.

The market was defined locally. Some coordination in the market was needed to assure the public objective of a nationwide service for the customers. The FCC decided to mandate a technical standard for 1G cellular telephony to force coordination between the various industry players in the market. In contrast, the European industry players decided to develop their own national equipment.
The result was that in Europe there were multiple incompatible standards. All of the larger European countries (the UK, France, Germany and Italy) had their own system made by their national radio manufacturer. Because national industry politics prevailed, the European market for the first generation of mobile telephony was fragmented. The only exceptions were the Nordic countries which developed a common system within the Nordic Mobile Telephone group. This NMT system was also used in some other small markets. However, the size of the combined market was still limited.
It is generally accepted that the combination of a single standard and competition in the market explains the faster uptake of the 1st generation of mobile telephony in the United States compared to the situation in Europe (Koski, 2006).

This situation was reversed for the introduction of the second generation of mobile telephony.
The United States decided to rely on competition between 2G standards, whereas European actors – operators, manufacturers and regulators - decided to coordinate their efforts in the development of a single harmonized standard and operations model, i.c. GSM. The combination of a single standard and the introduction of competition in the market provided good conditions for the diffusion of 2G mobile telephony in Europe. In the United States, the regulator employed a liberal market approach for the introduction of 2G. The operators coordinated the selection of digital cellular technology and their technical specification through the industry organization, TIA, CTIA and EIA. However, they retained individual freedom in the selection of technology and operational model. This resulted in a fragmented market. The technology of choice of the industry organization had not only to compete with another technology (CDMA from Qualcomm), but the fragmented 2G market had also to compete with the uniform market for 1G services. As a result, roaming between operators which employed different 2nd generation digital technology was only possible through the use of an analogue channel. This made use of digital technology less compelling for users in the United States. The situation was the

other way around in Europe. The 2nd generation digital technology developed in Europe (GSM) had for customers some very compelling advantages. It made mobile communications possible in the whole of Europe. This also created economies of scale for the industry in the development of technology and related services. This had for customers the benefit of greater choice in equipment and lower prices. As a result, the diffusion of 2G was much faster in Europe compared to the diffusion in the United States (Koski, 2006; Lemstra, Anker and Hayes, 2011).

From the diffusion of cellular technologies we may conclude that standards play an important role. In the 1st generation in the United States and the 2nd generation in Europe, a standard was imposed to safeguard the public interest of roaming. At the same time this created possibilities for economies of scale for service delivery within the European or United States market.

The importance of a standard to reach economies of scale can already be concluded from the fact that in the smaller European countries cooperation took place in countries with a relatively small market to create a common market whereas in the larger national markets domestic industry politics prevailed. As a consequence, the 1st generation of mobile telephony was dominated by national markets. Whereas in the 2nd generation, the step towards regional markets was made to address a bigger supra national market.

In the development of the 3rd generation the step was made towards a truly global market which would offer worldwide roaming. Although an universal standard appeared to be impossible, the technology had progressed to enable the development of multi-mode mobile telephones.[177] These could be used to roam between regions which had mobile communications based on different standards. Technology could be used to safeguard the public interest of roaming. There was no need to safeguard the public objective of roaming in the development of the institutional arrangements for the 3rd generation. Technology made roaming possible within the 3rd generation while having several competing regional standards.

This regional competition was foremost a competition between the mobile industry in Europe and the industry in the United States. The European standard was the product of cooperation among the leading industry in Europe and joined by Asian partners. Whereas the US standard was strongly focused around a single firm, Qualcomm. The development of CDMA by Qualcomm shows that a single firm with a strong commitment and focus can use its intellectual property rights (IP) portfolio to shield a market from entry by other potential competitors.

This competition had also its repercussion on the allocation of frequencies for mobile communications. Inter-regional and possibly global allocations for mobile communications became an objective for the industry behind the various proposals to widen their market as much as possible. Europe with her history of cooperation was very well prepared for the first debate on the global harmonization of spectrum for the 3rd generation of mobile communications (then still called FPLMTS).

A record of the WARC-92 from the United States even sees the debate that took place at the WARC-92 as "*the rise of regional blocks*". The report states: "*While other regional blocks did not show the cohesiveness and determination of CEPT, some countries of the Asian Pacific and Latin America were able to cooperate on specific issues—indicating their potential emergence as a force to be reckoned with at future conferences.*" (U.S. Congress Office of Technology Assessment, 1993).

177 A multi-mode mobile telephone supports more than one transmission standard.

Since then, regional cooperation in the preparation of WRCs intensified. Within all regions, coordination takes place on the harmonization of the use of the radio spectrum and on the development of common positions for WRCs.[178]
The cooperation in the field of radio spectrum harmonization and utilization is still most intense in Europe (Anker, 2015).

There was not only competition at the level of the industry standard for equipment, but also on the level of the provisioning of services. The United States already introduced competition from the beginning. The wireline carriers had to accept competition on the mobile telephony market from the radio common carriers. In Europe, mobile telephony was introduced in the late 1980s and the early 1990s. At that time a broad consensus in political thinking had emerged in support of deregulation. The introduction of market forces was considered for a number of network industries that had been heavily regulated in the past, including energy, communication, transport, and postal services. Mobile communications was to become one of the leading examples, enabled by a strong growth in demand.

Deregulation changed the set of objectives pursued by the government. One of the new objectives became the creation of a market for mobile communications. The licensing regime had to change to facilitate the introduction of competition. At first comparative hearings were used. However, mobile telephony made use of highly standardized equipment and related services. Hence, the service offering of all the contestants were comparable. This fact made it very hard to define differentiating criteria to compare the various offers. This will make it very difficult for the government to select the winning applicant using comparative criteria.

The institutional change that was already proposed in the late 1950's by Coase perfectly fitted the new public objectives attached to the liberalization of telecommunication infrastructure and the introduction of competition in the market for mobile telephony. This perfect match together with the difficulties with the existing practice (comparative hearing) gradually led countries to the decision to auction the spectrum rights for mobile telephony.

4.2 Wi-Fi: Coordination in unlicensed use of spectrum

In 1942 a new technology was invented: spread spectrum.[179] In that year, a patent was granted to actress Hedy Lamarr and composer George Antheil on a "secret communication system" through the use of a spread spectrum technology called Frequency Hopping. Spread spectrum is a technology whereby the signal is intentionally spread over a much wider bandwidth than strictly necessary. Spreading makes the signal inherently more resistant to interference. Until 1981 this technique remained classified as military technology because a spread spectrum signal is also difficult to intercept and hard to jam. It was not

178 The following regional groups are recognized within the ITU: APT: Asian-Pacific Telecommunity, Arab Group, ATU: African Telecommunications Union, CEPT: European Conference of Postal and Telecommunications Administrations, CITEL: Inter-American Telecommunication Commission, RCC: Regional Commonwealth in the Field of Communications. The RCC is comprised of the Russian Federation and 11 countries of the former U.S.S.R. (Anker, 2015).

179 See Lemstra, Hayes and Groenewegen (2011) and the references in there for more information on the history of spread spectrum.

allowed to be used in civil applications until deregulation happened (Anker and Lemstra, 2011).[180]

4.2.1 Development of Wi-Fi

Commercial application of spread spectrum technology started in 1985. In that year, the FCC decided to allow the public use of spread spectrum for communication purposes in three frequency bands originally designated for Industrial, Scientific and Medical (ISM) applications (FCC, 1985).[181] These bands could be used for communication purposes without the need for a license but applications would have to tolerate interference from other users as well as from ISM applications. This decision followed as a response to pressure from the Carter administration, pushing for deregulation across a broad set of markets. The FCC extended the deregulation spirit to apply to rules on the use of the RF spectrum. Spread spectrum was seen as a communication technology blocked by anachronistic rules (Lemstra and Hayes, 2008).

The MITRE Corporation report, that investigated the potential benefits, cost and risks of spread spectrum prior to the decision, did not identify a strong need from the industry. The report (Scales, 1980: 6-1) concludes that *"many potential spread spectrum applications are likely to be economically unattractive"*. However, the report further concludes that (6-2) *"Other potential spread spectrum applications may be economically feasible, but may make poor use of the spectrum resources that they would require. The commission should then be prepared to determine, on a case-by-case basis, whether the benefits provided by such applications justify their inefficient use of spectrum resources."*

Although the report states that the FCC should determine the benefits on a case-by-case basis, it already provides a case in which the use of spread spectrum technology may be beneficial (6-4). "*Spread spectrum techniques may be able to improve the utilization of the spectrum in cases where use can be made of ISM bands that are relatively unsuitable for applications requiring guaranteed high levels of performance. Indeed, since users of the ISM bands are not nominally protected from interference, it can be argued that any productive use of these bands frees other spectrum resources that are needed by applications requiring protection from interference.*" In other words, spread spectrum technology could be used to make the ISM bands available for low cost applications to free other parts of the radio spectrum for better use.

Based on the report and many comments favoring the proposed authorization, the FCC issued a ruling on the use of spread spectrum in three bands designated for ISM applications: 902 – 928 MHz, 2400 - 2483.5 MHz and 5725 – 5850 MHz. The maximum power was deliberately limited at a rather low level of 1 Watt (FCC, 1985). At this level the radiated power was sufficiently weak and the range short enough to allow sharing of the band with many devices without the risk of intolerable interference.[182]

Now the regulations were set, it was up to the industry to use the opportunity provided and to develop spread spectrum technology into useful

180 The historic case in this section is based on Anker, P., Lemstra, W. and Hayes, V., *Governance of radio spectrum – license-exempt devices,* In W. Lemstra, V. Hayes and J.P.M. Groenewegen (eds), The innovation journey of Wi-Fi – The road to global success, Cambridge, UK: Cambridge University Press, 2011; Lemstra, W., Anker, P. and Hayes, V., *Cognitive Radio: Enabling technology in need of coordination,* Competition and Regulation in Network Industries, Volume 12 (2011), No. 3: 210-235; and Anker, P., Lemstra, W., *Achieving Alignment between Institutions and Technology, the Case of Radio Spectrum,* Competition and Regulation in Network Industries, Volume 14 (2013), No. 2:151-172.

181 In ISM bands, RF emissions are used for Industrial, Scientific and Medical applications other than communications. The RF energy is used for heating, the ionization of gases and the acceleration of charged particles for a large range of purposes. Undoubtedly the best known example is heating with a microwave oven, which operates around 2.45 GHz.

182 The transmission range was expected to be at most 100 – 200 m (Marcus, 1987).

applications. The first civil applications of spread spectrum appeared in 1988 in the form of Wireless Local Area Network and mobile data capturing equipment, such as the Gambatte wireless MIDI digital music interface. This MidiStar Pro system became very popular with top rock bands and other entertainment groups. A derivate of this system was offered to industrial users under the name of Wireless Industrial Data Link (WIDL) products, which became used in nuclear power plants.

A leading role in the development of Wireless LAN technology has been played by NCR Corporation. They saw Wireless LAN as a solution to a nagging issue for their sales force, the lack of 'mobility' in the cash register product portfolio. Among the main client groups for their cash registers were department stores. These stores tended to reconfigure their sales floors on a regular basis. After each reconfiguration, there was a need to rewire the cash registers. The cost of rewiring were significant. To reduce these costs, NCR had already conducted a study which recognized the usefulness of radio technology, if permitted. The new FCC ruling triggered a feasibility study on the application of spread-spectrum technology. This feasibility study was assigned to the R&D group of NCR in the Netherlands, based on the available expertise in both local area networking and radio frequency technology (Lemstra and Hayes, 2008).

The feasibility study came to positive results in the summer of 1987. Subsequently, the System Engineering team in Utrecht The Netherlands set out to create a Wireless LAN with a data rate of 2 Mbit/s, operating in the 900 MHz band. To limit costs and reduce development time the team intended to leverage as much as possible existing protocols and standards.

NCR came to the conclusion that none of the existing IEEE[183] Working Groups responsible for medium access protocols in use for wired networking were willing or able to adapt their protocol for use in a Wireless LAN. Subsequently, under the leadership of NCR the companies interested in establishing a WLAN standard generated the necessary paperwork for the establishment of a new standardization project. July 1990 the IEEE 802[184] Executive Committee approved the request and the IEEE 802.11 Working Group was born. Vic Hayes of NCR was appointed as the chair of the working group. He held the chair for 10 years, the maximum period allowed.

One of the issues the working group had to deal with was related to the modulation technique. The FCC ruling specified two different spread spectrum modulation techniques that could be used: Frequency Hopping (FH) and Direct Sequence (DS). Both of them had their merit, Frequency Hopping was easier to implement and Direct Sequence was more robust and could be used for higher data rates. As neither of the two modes was a clear winner, the working group decided to include both modulation techniques in the standard. In September 1997, IEEE approved the IEEE 802.11 standard, covering

183 The Institute of Electrical and Electronics Engineers (IEEE) is a professional association best known for developing standards for the computer and electronics industry.

184 IEEE 802 is the group within IEEE responsible for the development of standards for local area networks and metropolitan area networks.

Frequency Hopping at a data rate of 1 Mbit/s and Direct Sequence at a data rate of 2 Mbit/s.[185]

In 1990, ahead of the formal approval of the standard, NCR launched its first WaveLAN product. It was in essence a network interface card that could be used in a PC instead of a (wired) network card. The initial sales effort was aimed at the NCR customer base, mainly retail stores.

In 1991 NCR was acquired by AT&T to strengthen its position into the computing business. In 1993, AT&T released the WaveLAN PC adapter for the global market. The customer base was extended to the academic world and enterprises. The product was intended to become a wireless extension of the LAN system of the customers. However, the data rate was too low compared to wired LAN and the price was considered too high to make wireless LAN a mass product.

Meanwhile, the AT&T senior management decided to split the company.[186] The telecommunications equipment division became independent under the name of Lucent Technologies. The WaveLAN activities were transferred to Lucent Technologies. Lucent Technologies was mainly focused on wired and cellular technology and struggled with the positioning of the WaveLAN product.

The breakthrough to the general public came as a result of a strategic collaboration with Apple, which saw wireless LAN as a differentiator for their new iBook. In 1999 Apple launched the wireless LAN card and associated Airport access point. Other PC vendors followed within a year (Lemstra, Hayes and Groenewegen, 2011).

As the IEEE 802.11 standard included the two spread spectrum variants, this could lead to two companies claiming to be compliant while the products would be incompatible. This situation forced the leading Wireless LAN companies to collaborate. As a result, the Wireless Ethernet Compatibility Alliance (WECA) started operation in 1999 as a non-profit organization driving the adoption of a single DS-based world-wide standard for high-speed wireless local area networking. The WECA quickly established an interoperability testing procedure and a seal of compliance, the Wi-Fi logo. In 2002 it changed its name to the Wi-Fi Alliance (Lemstra and Hayes, 2008).

4.2.2 Radio-LAN developments in Europe

Following the decision making by the FCC, an ad-hoc group on Radio-LANs within the CEPT, recommended that the 2.4 GHz band designated for ISM applications be opened for the use of Radio LAN devices. In 1991 the European Radio-communications Committee assigned the 2.4 GHz ISM band for Radio LAN use; on a non-protective and non-interference basis, without the need for an individual end-user license.

In 1992 CEPT identified higher frequency bands (non-ISM bands) for Radio LAN applications. CEPT identified the 5,150 – 5,250 MHz band and the 17.1 to 17.3 GHz band, with a possible extension in the 5,250 – 5,300 MHz band on a national basis. This

[185] The IEEE 802.11 -1997 edition of the standard is still the subject of modifications and extensions. It was extended on December 30, 1999 with IEEE 802.11a to support data rates up to 54 Mbit/s in the 5 GHz band. IEEE 802.11b, an extension of the standard to support data rates up to 11 Mbit/s in the 2.4 GHz band, followed on January 20, 2000. In 2003 the specification for date rates up to 54 Mbit/s in the 2.4 GHz band was released as IEEE 802.11g. Higher data rates of 100 Mbit/s and more making use of antenna diversity with MIMO (Multiple Inputs – Multiple Outputs) technology were approved as IEEE 802.11n on September 11, 2009. IEEE 802.11ac was approved in December 2013. IEEE 802.11ac includes wider channels (80 or 160 MHz versus 40 MHz) in the 5 GHz band, more spatial streams (up to eight versus four), higher-order modulation (up to 256-QAM vs. 64-QAM), and the addition of Multi-User MIMO (MU-MIMO).

[186] AT&T did not only divest the equipment division including Bell Labs under the name of Lucent Technologies, but also the computing business under the name of NCR. AT&T continued as an operator of long distance and international communication services.

spectrum was designated for RLANs adhering to a specific standard, HIPERLAN for High Performance Local Area Networks, yet to be developed. ETSI established a technical committee for the development of the HIPERLAN standard.

HIPERLAN was an European alternative for the (American) IEEE standard. Its aim was to provide a higher data rate of 24 Mbit/s in the 5 GHz band and quality of service aspects that would make voice services possible. Voice was not supported by the original IEEE 802.11 standard.[187] ETSI published the HIPERLAN/1 specification in 1996. A second version was developed to provide data rates up to 54 Mbit/s in the 5 GHz band between portable computing devices and broadband networks, supporting multi-media applications. The HIPERLAN/2 standard was completed in 2004. A HIPERLAN/2 Global Forum was established to support its deployment, supported by e.g. Bosch, Dell, Ericsson, Nokia, Telia and Texas Instruments.

Neither the HIPERLAN/1 nor the HIPERLAN/2 standard have become a success. HIPERLAN was technically superior to IEEE 802.11 and some major firms were involved in product developments, but, HIPERLAN had to compete with a much more commercially matured IEEE 802.11 standard. Nonetheless, the European designation of the 5 GHz band for RLANs attracted the interest of the FCC. On 6 May 1996 the FCC started a rulemaking procedure and decided in a Report and Order of 9 January 1997 to assign RF spectrum for the operation of so-called unlicensed – national information infrastructure (U-NII) devices in the 5,150 – 5,350 MHz and 5,725 to 5,825 MHz bands. The higher U-NII band coincided in part with the already assigned ISM band (Anker and Lemstra, 2011).[188]

The 5 GHz band did not remain uniquely identified for HIPERLANs. The operators of the mobile satellite service detected an oversight, in that they had forgotten to request an uplink frequency during the World Radiocommunication Conference of 1992. In their request they indicated that, in their assessment, the uplink could coexist with HIPERLANs operating in the 5.15 to 5.25 GHz band. Consequently, the 1995 World Radiocommunication Conference decided to allocate on a primary basis a band overlapping with the lower HIPERLAN band, as documented in ERC Decision no. 96/03 (CEPT, 1996). Shortly after this allocation, the satellite operators claimed that, if too many HIPERLANs were deployed in an particular area, they would receive harmful interference. As a result, CEPT was forced to lower the power limit of HIPERLANs from 1 W to 200 mW and to restrict them to indoor use (CEPT, 1999a, 1999b). This decision also included the assignment of an additional 255 MHz (5,470 to 5,725 MHz) for HIPERLANs to allow spreading of the signal power, the inclusion of transmit power control to minimize the aggregate transmitted power in the MSS band, and dynamic frequency selection to prevent the use of frequencies already used by the incumbent users and other HIPERLAN devices.

In December 2000 Project IEEE 802.11h, 'Spectrum and transmit power management extensions in the 5 GHz band in Europe', was approved to cover these modifications. The extension of the standard was approved at the end of 2003. To prevent similar surprises in the future, the European regulators proposed at the World Radio Conference of 2000 an agenda item for the next Conference in 2003. The European proposal was to globally allocate the

187 This lack of support for voice services was also the reason for an industry consortium to develop HomeRF. The HomeRF initiative failed despite the support of major players in the industry (Lemstra and Hayes, 2008).

188 U-NII was intended to provide wireless broadband services, particularly wireless local area networking and broadband access.

HIPERLAN-related frequencies (a total of 455 MHz in the 5 GHz band) on a co-primary basis. At the 2003 World Radiocommunication Conference, the decision was made, with the support of the United States, to allocate the spectrum to the mobile service and to restrict the use to wireless access systems (WASs) including RLANs on a co-primary basis shared with the existing services being satellite in the lower parts of the band and radar systems in the rest of the band. Provisions were set to prevent interference to those services (Anker and Lemstra, 2011).

4.2.3 Case assessment

Although spread spectrum technology was already invented in the 1940s, it took 40 years before it was used in civil applications. The reason for that long delay is remarkably simple: there was no reason to use it. The institutional setting for the use of spectrum was based on exclusive rights. In a regime based on exclusive rights there is no need to use a technology that makes communications more robust to interference at the expense of the use of a wider range of frequencies.[189] This kind of technology is especially useful in an environment where the system has to accept interference. This feature of spread spectrum was useful in the ISM bands, where the system did not only have to share the band with other spread spectrum devices, but also had to tolerate interference from ISM applications.

The institutional arrangements for the use of spread spectrum were made in the light of deregulation. Spread spectrum technology offered a unique possibility of sharing a frequency band between multiple users without requiring the users to coordinate their transmissions in any way. Hence without the need for a licensing process. However, strict rules were necessary to restrict the behavior of the devices to make sharing between a indefinite and theoretically unlimited number of devices possible.

This case shows that the introduction of new technology will also need associated institutional arrangements supportive of this technology.
It further shows that alignment between technology and the institutional arrangements is necessary but is by itself not enough for successful introduction of this new technology. In the institutional arrangements that were set up by the FCC, it is up to the radio equipment manufacturers to coordinate the efficient use of the radio spectrum, including graceful degradation of service levels under increasing load conditions and avoiding interference. The coordination activities necessary to develop new technology to achieve alignment between this new institutional arrangement and technology were shifted from the government to private organizations. These coordination activities took place in a standardization committee. This shift from governmental coordination to private coordination outside the influence of the government could be realized due to the strong leadership of a private actor. NCR Corporation took the leadership because they had a private objective that materialized in a compelling business case. The regulations on spread spectrum triggered NCR Corporation to use this technology for a nagging issue from their sales force: the lack of mobility in the cash register portfolio. The importance of the need of a compelling business case is shown by the failure of HIPERLAN. Although the standard was technically superior, it could not compete with the commercial drive behind the IEEE 802.11 standard and its evolution.

4.3 Privatizing the airwaves in Guatemala

In both the case of mobile communications and the case of Wi-Fi, government took a step back from the command and control regime. In the case of mobile communications, auctions were introduced

[189] The only exception is military usage of the technology. For military applications the distinct characteristics of spread spectrum technology are quite useful as explained in the introduction of section 4.2.

whereby market forces determine who will own the rights to use the spectrum. In the case of Wi-Fi the development of new applications was left to market forces outside the control of the government.

However, government only took a step back in the assignment process. In both cases spectrum is still allocated in a centralized system. Government still determines how the radio spectrum is divided among various radio services taking into account economic, societal and public interest.[190]
The question is what would happen if government takes a further step back and leaves the allocation of radio spectrum to the market? This is not an easy question to answer, but spectrum reforms in Guatemala are an interesting case that can provide some answers to this question.

There are other countries that made a big step in further liberalizing radio spectrum management such as Australia and New Zealand.[191] However, the telecom reform in Guatemala was seen as "*perhaps the most liberal spectrum regulatory policy in the world*" (Hazlett, Ibarguen and Leighton, 2006).[192]

4.3.1 Radio spectrum reform in Guatemala

Guatemala has a long history of dictatorship and internal conflicts. This changed in 1996 with the election of president Arzú. In his first year in office he signed a peace agreement with the guerrilla movement that ended an internal conflict that had lasted around 36 years. The president stood for the task to rebuild the economy. The railroads, electricity, telecommunications and other infrastructures were in terrible shape. In order to strengthen the economy these infrastructures needed to be modernized. This required significant investments which the Guatemala government was lacking. Therefore, investments by private companies would have to finance the modernization of Guatemala's infrastructure.

When president Arzú took office, the fixed telecommunications infrastructure was in the hands of a state owned monopolist, GUATEL. The service was poor and restricted to the capital and a few urban areas. In 1996 the country had only 3.4 telephone lines for every one hundred inhabitants, which was much lower than the average in Latin America of around 10 telephone lines per hundred inhabitants. Since 1989, there was a mobile operator active, COMCEL. This privately owned monopolist had limited coverage and a poor service. COMCEL and GUATEL had a close relationship. COMCEL paid a percentage of its profits to GUATEL. In exchange, GUATEL would not provide a mobile telephony service. In 1996 there were only fifty thousand mobile subscribers on a population of nearly 11 million people.[193]

As in most countries, the government of Guatemala was in control of the allocation and assignment of radio spectrum. Frequencies below 800 MHz were regulated by an office within the ministry of Defence. These frequencies include the bands used for radio and television broadcasting. This gave the ministry of Defence not only a source of income but also control over the "freedom-to-speech". The

190 The Dutch Telecommunications Act uses the phrase "economic, societal and cultural objectives". The notion of the public interest appeared for the first time in the United States in the Radio Act of 1927. In this act the phrase "public interest, convenience and necessity" is used.

191 See Marcus, Nett, Scanlan, Stumpf, Cave and Pogorel (2005) for an overview of spectrum liberalization in various countries, including New Zealand, Australia and Guatemala.

192 The results of the liberalization process in El Salvador are quite comparable with the one in Guatemala. However, the Guatemalan process was the most liberal of the two. Another advantage of Guatemala is that there is more information available on the reforms in Guatemala. See Hazlett et al (2006) for a description of the liberalization process in Guatemala and El Salvador.

193 This equates to 0.4 mobile subscribers per 100 inhabitants, which is low compared to the average of 1.4 in Latin America and 7.2. in the European Union in that year (source: ITU Statistics, http://www.itu.int/ict/statistics; accessed on 29-12-2013).

frequencies above 800 MHz were regulated by the national telephone company GUATEL (Sabino and Leighton, 2013).

Licenses were granted with detailed operational rules on both the type of service to be offered and the type of technology to be used. Foreigners were not allowed to apply for a license. The licenses were awarded in principle free of charge. However, the demand for the licenses far exceeded supply. As a consequence, an illegal market for licenses arose whereby bribes and side payments were necessary to obtain a license (Ibarguen, 2003; Hazlett, Ibarguen and Leighton, 2006).

President Arzú understood that modernization of the telecommunications infrastructure was important to boost the economy. The president started a liberalization program aimed at attracting the private capital required to expand and modernize the telecommunication services. This process was started by the adoption of a new telecommunications law on 17 October 1996, the "*Ley General de Telecomunicaciones*", followed by the privatization of the state-owned operator GUATEL in 1999.

The liberalization objective of this new Telecommunications law was made quite clear in article 1:[194]
"The object of this law is to establish a legal framework to develop telecommunication activities and regulate the use and exploitation of the radio electric spectrum, with the purpose of support and promote the efficient development of telecommunications, stimulate the investments in the group; promote the competition among the different groups or people who offer telecommunication services; protect the rights of the users and the companies that provide telecommunication services, and to support the rational and efficient use of the radio electric spectrum."

The objective of the Law was above all to attract new companies that were able to invest in the delivery of telecommunication services. Competition would serve as a catalyst to rapidly expand service delivery against affordable rates for customers.

To create competition, access to spectrum was made much easier. Decisions about the use of the spectrum was left to the market by the creation of quasi property rights. The Law divided the spectrum in three groups of bands:
1. Reserved for governmental use
2. Reserved for amateurs
3. Regulated ("liberalized") bands

Governmental users and amateurs receive an "autorización de uso de frequencia" (AUF), which can be regarded as an ordinary non-tradable license. Users of the regulated (liberalized) bands receive a "Título de Usufructo de Frecuencia" (TUF). These TUFs are a close approximation of property rights. The owner of a TUF can use the spectrum for whatever he wants. The rights can be rented or transferred in full or in part. TUFs are only subject to minimal technical constraints. A TUF is just one sheet of paper which describes the frequency band, the schedule of operation, the maximum transmission power, the coverage area, the maximum power at the border of the coverage area[195] and the duration of the right. TUFs have a limited duration of 15 years, with the possibility of a renewal for the same period.[196] The back of the TUF contains space for endorsements, to be used

194 An English translation of the Law can be found at the internet site of *Guatemala's* telecommunications regulator SIT: http://www.sit.gob.gt/uploads/docs/laws/TelecommunicationsLaw.pdf

195 Two much sited articles, Ibarguen (2003) and Hazlett et al. (2006) give " maximum power at the border of adjacent frequencies. However, article 57 of the Ley General de Telecomunicaciones of 1996 states "Máxima intensidad de campo eléctrico o potencia máxima admisible en el contorno del área de cobertura." which can be translated as "Maximum electric field strength or maximum allowable power at the border of the coverage area".

196 See article 58 and 59 of the Ley General de Telecomunicaciones.

No. Orden 008738 No. Registro 7549

LA SUPERINTENDENCIA DE TELECOMUNICACIONES DE GUATEMALA

Con base en el Artículo 57 del Decreto 94-96
del Congreso de la República
extiende

Título de Usufructo de Frecuencia

A:

EDGAR AMILCAR MADRID MORALES

Banda o Rango de Frecuencias	:	4.04750 a 4.05750 MHz
Horario de Operación	:	VEINTICUATRO HORAS
Potencia máxima efectiva de radiación	:	55.00dBm
Máxima intensidad de campo eléctrico o potencia máxima admisible en el contorno:		-90.00 dBm
Area geográfica de influencia	:	NACIONAL

Nota: Sujeto a las especificaciones Técnicas contenidas en la Resolución SIT-972-2013

Fecha de Emisión : 08/08/2013

Fecha de Vencimiento: 18/06/2033

Figure 4-2 An example of a Título de Usufructo de Frecuencia. (source: radioverdad.org)

whenever the right is transferred from one owner to another. An example of a TUF is given in Figure 4-2.

The Law stipulated the creation of a new regulator, Superintendencia de Telecomunicaciones (SIT). The role of the regulator was deliberately kept limited. Its main tasks related to spectrum access are the issuing of the rights to use spectrum and resolving cases of interference.

All existing licenses for the use of spectrum held by private companies[197] were changed in TUFs to start the process. A procedure was put in place to grant TUFs for the remaining unoccupied parts of the spectrum.[198] Every party wishing to use unoccupied frequencies was allowed to file a request to the regulator. The application is then evaluated by the regulator. If accepted, the request will be announced to the public. This starts a period in which complaints can be issued. Grounds for complaints are restricted to technical interference. Other parties are allowed to file a competing claim. If there are no competing claims, the TUF will be granted free of charge. If there are competing claims, the regulator will schedule an auction within 35 days of the opposition period (Ibarguen, 2003).

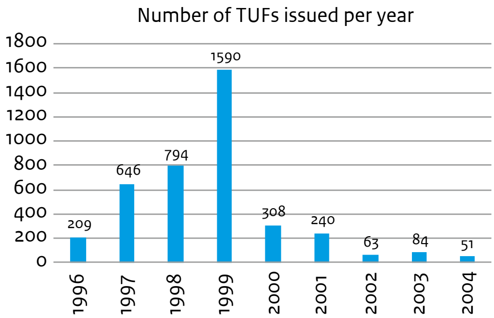

Figure 4-3 Number of TUFs issued per year (Escalante, 2005).

In the first nine years 3985 TUFs were issued to more than 1000 different owners.[199] Of these, 930 were issued to the former state telecommunications monopoly TELGUA, 918 went to other incumbents and 2137 were issued through an auction. As can

197 These were mainly the privatized telecommunications company (Guatel, privatized under the name of Telgua), radio and television broadcasters and ComCel, the only provider of cellular telephony.

198 Article 61 of the Ley General de Telecomunicaciones of 1996.

199 Although the Law states that SIT should hold a publicly available database with the TUFs issued, the database is no longer accessible. The reported number of TUFs issued seems to fluctuate. Ibarguen (2003) quotes a figure of around 5000 TUFs issued in the first 6 years. The difference between the figure quoted by Hazlett, Ibarguen and Leighton (2006) and Ibarguen could be explained by the figure of around 1000 licenses issued for satellite and other use. The figures used here are taken from a presentation given by Escalante in 2005, an employee of SIT. These figures are also used by Hazlett, Ibarguen and Leighton (2006).

be seen in Figure 4-3, most of the TUFs were issued in the first 4 years, with a clear peak in 1999, after the privatization of the former state owned telecommunications company GUATEL, called TELGUA after the privatization.

Since 2000, most of the spectrum has been issued and the acquisition of spectrum rights is mainly based on the secondary market. In 2006, Oscar Chincilla, then head of the SIT, declared that the Guatemalan radio spectrum was saturated, referring specifically to broadcasting bands (Henderson, 2008).

Around 1050 different owners are reported to have gained property rights in radio spectrum. There was a strict procedure to be followed if an owner of a spectrum right suffers from interference. An owner of a TUF who suffers from interference can file a complaint with the regulator. The complaint has to be accompanied by a technical report from a company that is certified to supervise the usage of the radio spectrum. The regulator will then inform the accused party. The accused party has ten days to react with his own technical report. Following this reply, the regulator has ten days to take a decision.[200]

The amount of interference cases formally reported to the regulator from 1996 until June 2005 was 217, representing about 5.5% of the issued TUFs, or 3.7% of all rights issued. Most of these complaints (158 or 72.8%) were related to the FM radio band (Escalante, 2005).

However, the discretionary power of the regulator is limited. Broadcasting operators have set up their own arbitration office. The Cámara de Radio Difusión de Guatemala has its own equipment to monitor the radio spectrum. If an operator encounters interference it can bring the case to the Cámara for arbitration. If private negotiations and arbitration fail the affected party will bring the case to the regulator. If the complaint is accepted, the SIT will first ask the concerned parties to negotiate once more, before forcing a decision (Ibarguen, 2003). However, the amount of reported complaints which were resolved with mediation against the total amount of complaints is limited. In the period from 1996 until June 2005 only 35 (16%) were resolved through mediation of the total of 217 reported complaints (Escalante, 2005).

4.3.2 Case assessment

The spectrum management reform of Guatemala was clearly inspired by the ideas of Coase (Sabino and Leighton, 2013). This reform is seen by Spiller and Cardilli (1999) as *"an experiment"* and by Hazlett, Ibarguen and Leighton (2006: 1) even as *'"proof of concept" for the normative model proposed by Coase'* (quotes used by the authors in the latter text).

As explained in more detail in chapter 1, Coase (1959) suggested that spectrum could be managed the same way as other scarce resources, via property rights and the price mechanism. The market would not only determine who would acquire property rights, but also for which purpose these property rights would be used. The problem of interference could be solved by a clear definition of the rights by the government. It should be possible to change these rights as a result of transactions in the market (Coase, 1959).

The proponents of the ideas of Coase point to the growth of mobile telephony in Guatemala and the lack of interference complaints. Ibarguen (2003), Hazlett, Ibarguen and Leighton (2006) and others clearly show the impact of the spectrum reform on the market for mobile telephony in Guatemala. The growth rate in mobile telephony services was remarkable. Mobile telephony usage grew from 64,197 users at year-end 1997 to 4,510,067 users at year end 2005.[201] The growth rates were among the highest of Latin America. Hazlett, Ibarguen and

[200] Article 53 of the Ley General de Telecomunicaciones.

[201] World Telecommunication/ICT Indicators Database, ITU.

Leighton (2006) made an assessment of the mobile telephony market and came to the conclusion that:
1. more spectrum is used for the provisioning of mobile telephony;
2. the market for mobile telephony is more competitive;
3. prices for mobile telephony are among the lowest in Latin American;

The success of the spectrum reform on mobile telephony is undisputable. However, there are some questions to be raised whether this success offers the '*"proof of concept" for the normative model proposed by Coase*' as claimed by Hazlett et al. (2006).

The first set of questions relates to the functioning of the market for mobile telephony. First of all, the market for mobile communications is becoming less competitive. The market for mobile communications saw a consolidation and is in 2013 dominated by three operators.[202] The former monopolist Tigo Guatemala (formerly ComCel) dominates the market. The other two operators in the market are Claro (formerly Sercom), a property of *America Movil*, and Movistar, which is owned by Telefónica. These two competitors of Tigo are active since the opening of the market for competition.[203] A former fourth active operator (BellSouth) has been acquired by Telefonica. As a consequence, the HHI-index rose from just above 3000 in 2004 to nearly 4000 in 2013. Guatemala 's rank declined from top of the class (5th) to average (9th) among 16 Latin American countries (Hazlett, Ibarguen and Leighton, 2006; GSMA, 2013).

There are several causes that can explain this decline in competitiveness. One of the factors that will play a role is the fact that Guatemala is among the poorest countries within the region and the mobile communications market in Guatemala is still driven by mobile telephony. The market for mobile data communications is very small. Mobile operators in various other countries in Latin America have rolled-out the latest mobile broadband communication technology (LTE). However the existing operators do not have announced any plans to invest in the roll-out of LTE in Guatemala as of 2013 (GSMA, 2013).

Secondly, the amount of spectrum that is used for the provisioning of mobile communication services is no longer among the highest in Latin America. According to a report from 4GAmerica, the amount of spectrum is even slightly below average within the Region (4G Americas, 2013).

The question is whether these observations can be explained by the nature of the mobile communications service or that they are pointing to a weakness in the Coasian model as implemented in Guatemala or are pointing to a fundamental weakness in the model itself. This is not the place to further analyze this question. It is a question that deserves research on its own. However, it indicates that it is too early to state that the performance of the mobile telephony market offers the claimed "proof of concept".

A more fundamental issue is related to the functioning of the rest of the spectrum market. Coase suggested that the market should not only determine who should own the property right but also what services should be provided. Even if the market for mobile telephony is fully functional, it is not possible to claim victory for the Coasian model. Before that can be done, an analysis of the remainder of the radio spectrum market is necessary.

[202] Next to these three mobile operators, RED is active on the market for closed user groups with an iDen network in Guatemala city. A fifth operator, Digicel, acquired spectrum in 2003. However, Digicel was still not active as an operator at the end of 2014.

[203] Both competitors started operations in 1999 after acquiring spectrum in an auction in 1998. The licenses have been renewed in 2011 for a period of 20 years (GSMA, 2014). SIT reported a market share of 48% for Tigo, 31% by Claro and the remaining 21% by Movistar at the end of 2012. No market share has been attributed to the iDEN operator Intelfon, which offers services to business users in Guatemala City

There are a few observations to be made about the functioning of the spectrum market as implemented in Guatemala. The first observation relates to the functioning of the secondary market. Kunigami (2005) came to the conclusion that the secondary market is not functioning optimally. However, Ibarguen (2004) concluded that there is a very lively secondary market pointing to the number of trades made thus far. This dispute points to a weakness in the system as implemented.
The secondary market for usage rights is not very transparent. This lack of information may not only hinder the secondary market, but it also hinders the analysis of the functioning of the secondary market.

To come to a more definitive answer, there is more information needed on the number of trades, which parties are involved in these trades, the timing of these trades and on the usage of spectrum. The number of trades, or a lack thereof, by itself does not provide sufficient evidence for the functioning of the market. A lack of trades may also indicate that the primary assignment of the rights, after the auction, was efficient.

Kunigami (2005) already pointed to the fact that there might be portions of the spectrum under-utilized, not used at all or acquired speculatively. The fact that a fifth operator (DigiCel) acquired spectrum in 2003 and this spectrum is still not used at the end of 2014 seems to support that statement and seems to indicate that the secondary market does not function optimally.

The second observation relates to the limited number of interference complaints. The low number of interference complaints can be explained by the fact that although the TUFs are service and technology neutral, frequency usage is in Guatemala not different from other countries. Guatamala, as a small country, does not develop its own radio technology. Coordination problems related to interference are especially to be dealt with in the definition of the usage right and in transactions in the market if the usage differs between various users.[204] If the various users use a frequency band for the same kind of technology and related service, the coordination needed to tackle interference can largely be dealt with in the standardization of the equipment. Interference in mobile telephony is not an issue because the internationally allocated bands and related standardized technologies are used to provide the mobile telephony service. The coordination needed in association to interference is shifted from the user to the standardization efforts of industry. Interference and the coordination activities to deal with interference are not a big issue, because Guatemala is basically free riding on the standardization efforts of the industry in other countries.

The interference issues that remain are mostly related to FM broadcasting. Illegal use of FM radio is widespread and is generally tolerated by the authorities (Hazlett, 2006). Hazlett, Ibarguen and Leighton (2006) see the problems associated with FM broadcasting as weak enforcement of the property rights. However it seems to be a bit more complicated issue then suggested by Hazlett et al.

The government of Guatemala has been struggling with issues surrounding radio broadcasting, esp. FM radio broadcasting, ever since the reform has started. Many of these illegal FM radio stations are used by indigenous communities for what is called "community radio".[205] The indigenous communities see the use of community radio as their right because *the Acuerdo sobre identidad y derechos de los*

[204] This is the prime reason why services are aligned between countries in the Radio Regulations.

[205] Roughly 40% of the population is indigenous, mainly Maya communities, which have their own language and culture. There are 24 Amerindian languages in use. The *Ley de Idiomas Nacionales* (National Language Law; 2003) obliges the State to recognize, promote and respect these languages. The other 60% of the Guatemalan population is Mestizo (mixed Amerindian-Spanish - in local Spanish called Ladino) or European. The official language is Spanish. (Henderson, 2008; CIA, 2013).

pueblos indígenas (Agreement on Identity and Rights for Indigenous People) promises to implement "necessary reforms in the current radio communications law in order to make frequencies available for indigenous projects"[206] The indigenous communities see this promise as a "freedom-to-speech". The government has been struggling ever since to keep their promise.

In the first years after the reform, the government was reluctant to enforce following the complaints of interference in the FM-radio band. Liu (2005) even claims that the decline in interference complaints is a result of a lack of faith in the government's commitment to enforce rights. Since the start of the reform, various attempts have been made to either intensify the prosecution of illegal use or to come with legalization of community radio.[207]

It is ironical that the problems with a chaos in radio broadcasting is the same problem as the one that triggered Coase to propose the solution that was implemented in Guatemala. It seems that the property rights solution of Coase can cope with the scarcity issue of frequencies (as shown by the uptake of the mobile telephony) but has more difficulties with dealing with the combination of scarcity and a government's inability to realize a public objective, in casu the right of freedom-to-speech. This criticism to the model of Coase was already indicated by Moss and Fein (2003) in their analysis of the model as proposed by Coase in 1959. The Guatemalan experiment seems to validate their (theoretically derived) conclusion.

A third observation is that the system, as implemented, lacks a sound legal basis for the allowance of unlicensed use. The 2.4 GHz and 5 GHz bands that are internationally used for Wi-Fi are part of the reserved bands. This means that in essence a TUF is needed to make use of the band. The use of Wi-Fi was at first not seen as a problem by a representative of the Guatemalan radio communication agency (Velásquez, 2006). TUFs were issued in the bands. These are predominant used for fixed point-to-point links. However, the use of Wi-Fi in the 2.4 GHz band is quite common. Not only by those who have a permission, but also by those without permission (Kunigami, 2005).

This problem of illegal usage by (numerous) low power devices is circumvented in the National Frequency Allocation Table. A footnote to the frequency allocation table (GTM-30) allows in-door use in the 2.4 GHz Wi-Fi band. A TUF is only needed for use in outdoor environments or in large geographic areas. Use of the 5 GHz bands is suspended. This means that it is at the moment not possible to apply for a TUF for these bands. [208]

To allow unlicensed use of Wi-Fi is not in contradiction with the original ideas as put forward by Coase. Property rights are proposed by Coase as a solution in situations where the transaction costs are sufficiently low. In the case of Wi-Fi, with many users, the coordination needed between the users will make the

[206] This Agreement was signed in Mexico in 1995 and is incorporated in the Peace Accords of 1996. However, there is a dispute over the legal status of the Peace Accords. Some claim that the Peace Accords were rejected in a referendum in 1999 and are therefore non-binding.

[207] In 2004, right after the election of president Portillo, the Ministerio Público announced its intention to intensify the prosecution of illegal users of spectrum. In 2010 Bill 4087 was proposed which provides for the legalization of community radio. Since then the Bill has not advanced. However a counter proposal has been made in 2013. Bill 4479 proposes the imprisonment of individual actors and representatives of unlicensed stations, effectively criminalizing community radio with a penalty of up to 10 years in prison. See http://www.culturalsurvival.org/take-action/guatemala-save-indigenous-radio/guatemala-save-indigenous-radio-0 (accessed: 20 august 2014).

[208] Resolución SIT-205-2006. Available at: http://www.sit.gob.gt/index.php/gerencias-sit/gerencia-frecuencias/bandas-de-frecuencias/. See also http://www.sit.gob.gt/index.php/preguntas-frecuentes/preguntas-radio-frecuencias/. Last accessed on 22 August 2014.

transaction costs non-negligible. The solution chosen for this coordination problem is that the coordination is shifted from the government to the technology. Wi-Fi is a technology which uses a protocol to listen if a radio channel is available before transmitting takes place. Due to the listen-before-talk protocol and the low power level of Wi-Fi, there is no need for an individual license. Most of the coordination is now dealt with in the standardization arena, in the development of the technology.[209] Again, Guatemala is free-riding on the coordination efforts of others.

A fourth and final observation is that from the National Frequency Allocation Table, the conclusion can be drawn that the usage of frequencies is more restricted than the TUF itself suggests. Frequencies may only be used for the service as mentioned in the national frequency allocation table (Tabla Nacional de Atribución de Frecuencias). This TNAF largely follows the international frequency allocation table as set by the ITU.

For a number of frequencies it has a very detailed technical subscription of the kind of technology that may be used. To give an example, national footnote GTM-27 restricts the use of the band 88.0 – 108.0 MHz to sound broadcasting for analogue FM radio. The exploitation of the band is calculated according to the National Operational Plan Radio Broadcasting (FM). Thereby, the National Frequency Allocation Table does not only restrict the usage of the band to a certain technology and related service (FM radio sound broadcasting), but the regulation also defines the service areas of the TUFs to be issued.

For spectrum use to be chosen by the user, it is necessary that the right does not describe the service nor the technology, but only defines the usage in terms of the output. This principle is used in the definition of the TUFs, but the National Allocation Table imposes restrictions to the usage of the rights that limits both the transferability of rights and the ability to fragment these rights.

To conclude, the Guatemalan experiment seems to be not too different from the traditional command-and-control system. The government is still in full control of the services that are allowed in a band. There is no real difference in the allocation of the bands between Guatemala and most other countries. The only difference is in the assignment of frequencies to users. The assignment is to a large extend market driven. The main differentiator of the Guatemalan approach seems to be in the timing of the assignment of frequencies that were internationally allocated and standardized for cellular mobile communications at the time of the start of the reform.

The “Guatemalan experiment” did not provide the definitive prove to rebut the statement made by Melody (1980: 396) as referred to by Hazlett, Ibarguen and Leighton (2006: 3):
“The spectrum will continue to be allocated and assigned by means of an administrative process. ... The market cannot be an efficient substitute for the administrative process in achieving either allocational efficiency or the broader objectives of the process.”

The Guatemalan case study shows that there are possibilities to leave the assignment to a greater extend to the market, but that there might still be a need for governmental involvement, especially to safeguard public interest in the allocation of frequency bands.

4.4 Overall assessment

Interference is seen by many as *the* reason for governmental involvement in radio spectrum governance. Coase (1959: 2) explains this by referring to a letter from the Royal Navy to a Senate Committee on Commerce in 1910:

[209] Actual deployment of Wi-Fi may require coordination between neighboring users on the actual frequency channels to be used.

" The Department of the Navy explained that each radio station considers itself independent and claims the right to send forth its electric waves through the ether at any time that it may desire, with the result that there exists in many places a state of chaos."

Further down, in the same introduction, he quoted Naval Commander Hooper explaining possibilities to cope with this "*state of chaos*" *(Coase, 1959: 4)*: *"...radio, by virtue of the interferences, is a natural monopoly; either the government must exercise that monopoly by owing the stations, or it must place the ownership of these stations in the hands of one concern and let the government keep out of it."*

The case studies show that in many cases interference in itself is not the prime motivator for coordination to take place. An overview of issues that were addressed in the various historic cases of chapter 3 and chapter 4 is given in Table 4-1.

As can be concluded from the table, the involvement of government in radio spectrum management can be related to a number of different issues and public interests. The prevention of interference is an interest that is partly dealt with through governmental involvement and partly through private coordination in standardization arenas.

From the assessment of the historic cases it becomes evident that the conflict between the public interest of the government and the private interest of the industry and operators triggers a need for coordination.

The introduction of the first generation mobile telephony was only possible after radio spectrum was made available for this new service. The radio spectrum that was made available had to be weighed against the interest of broadcasting and private mobile radio to use additional spectrum. Hence, government had to balance between two services with the (vested) public objectives of freedom-of-speech and 'safety of life and property' attached to it on one side against the introduction of a new innovative service on the other side. Sufficient spectrum for this new service was only provided after the new service had proven its value for society and the technology was available to offer the service on a sufficiently large scale to the general public.

When making the radio spectrum available for mobile telephony, the US government attached the obligation to provide roaming all over the US. This obligation forced the industry to coordinate the development of the necessary technology. The same kind of industry coordination took place in some (smaller) European countries, notably the Nordic countries, with the coordinated effort to develop the NMT standard. In this case the (Nordic) industry had an incentive for coordination because it enabled to reach the economies-of-scale needed for successful introduction of this new technology. Coordination by the operators facilitated roaming to make a truly international service possible.

In the larger countries of Europe national industry politics prevailed with a fragmented European market as a result. There was no ability to roam across Europe with the exception of the Nordic countries and a few other smaller countries which adopted the NMT standard of the Nordic countries.

Coordination on a single standard (GSM) took place in Europe with the development of the second generation of mobile telephony. This coordination was supported by the European Commission because they saw mobile telecommunications as an essential facilitator to realize a truly European market. This governmental objective coincided with the need for economies-of-scale by European industry to develop the second generation mobile communications for the mass market.

The introduction of the second generation of mobile communications took place in a time period of deregulation and liberalization in sectors thus far characterized by publicly controlled monopolies.

Issue	Dilemma	Solution[210]
Case 1a: Marconi and the bird of Radio[211]		
Refusal of Marconi to interconnect with its competitors made it difficult for competitors to enter the market and deliver messages from a ship to a coastal station or to another ship.	Successful operation of one company (Marconi) against the possibility of firms (from other countries) to enter the market.	Standardized frequencies for telephony. Rules on interconnection.
	Safeguarding of safety-of-life-at-sea across firms.	Standardized frequencies and signal for distress messages. Rules of engagement between the users.
Case 1b: Introduction of other services[211]		
New services seeking access to radio spectrum.	Prevention of interference between incompatible systems seeking access to radio spectrum.	Separating incompatible systems by dividing the resource in multiple smaller resources to accommodate the various services.
		Rules of engagement between the users of a service.
Case 2a1: 1st generation mobile communication in the US		
Introduction of a new service (public mobile telephony).	The allocation of radio spectrum for this new service had to be balanced against the interest of broadcasting with the public interest of freedom-to-speech attached to it and with private mobile radio which was used by emergency services to serve the public interest of safety-of-life-and-property.	At first there was a very limited amount of radio spectrum allocated for this new service. Technology (e.g. splitting cells) had to be used to cater for an increase in demand for this service. Eventually a specific allocation for mobile telephony was made at the expense of the radio spectrum available for private mobile radio and broadcasting.
Assigning spectrum to mobile telephony operators.	Introduction of competition by assigning more than one license or just one license to have the technically most efficient use of radio spectrum.	Economic efficient use prevailed. There were two licenses issued per area to create a duopoly.
Interoperability between the mobile telephony services of different operators.	The right of a mobile operator to choose its own technology against the public interest of nationwide roaming.	Mandatory use of system specification to safeguard national roaming. Cooperation between mobile operators to provide roaming services.
Case 2a2: 1st generation mobile telephony in Europe		
Introduction of a new service	National industry versus economies-of-scale for industry	Cooperation on a single standard in smaller markets by manufacturers. In the bigger countries the national interest prevailed. They had their own national system
	National operators versus an international service (roaming).	Fragmented national markets, with the exception of cooperation between operators of the smaller countries on a harmonized standard which allowed for international roaming and cooperation between the operators to provide the international service.

210 All solutions came from the government unless stated otherwise.

211 This case is described in chapter 3.

Issue	Dilemma	Solution[210]
Case 2b: 2^{nd} generation mobile telephony		
Creation of a mass market for mobile telephony	National industry versus larger economies-of-scale	Cooperation on a single standard in Europe to reach economies-of-scale
	Providing roaming	Adoption of a single standard and cooperation between the mobile operators to provide roaming.
		Solution was left to the market in the US with a fragmented market as a result.
Case 2c: 3^{rd} generation of mobile communications		
Creation of a world-wide market for mobile communications	Protecting regional industry (U.S/ Europe/Japan) versus competition in equipment.	Family of standards. International roaming could be provided through the use of multi-mode and multi-band handsets.
Case 3: Introduction of Wi-Fi		
Introduction of new technology (spread spectrum).	Economies of scale and interoperability of equipment within a deregulated market that is open to all.	Development of an open standard by industry and certification to assure compatibility.
Case 4: Privatizing the airwaves in Guatemala		
Need for private investments in mobile communication infrastructure.	Government versus private control.	Privatization of spectrum rights.

Table 4-1 Coordination issues in the historic case studies.

The institutional change that was already proposed in the late 1950s by Coase perfectly fitted the new public objectives attached to the liberalization of telecommunication infrastructure and the introduction of competition in the market for mobile telephony. Various countries chose to auction the spectrum rights for mobile telephony (Cave, Doyle and Webb, 2007).

The United States choose to introduce competition in the market for the 2^{nd} generation of (digital) mobile telephony and leave the choice of the technology to the market. The result for the 2^{nd} generation was the reverse of the situation in the first generation of mobile telephony; a single European market for digital mobile telephony and a fragmented market in the United States.

The need for a common obligatory standardized technology to enable roaming was no longer necessary in the third generation of mobile communications. Technology eased the issue of roaming. Multi-mode telephones were available to enable roaming without the need for a strict coordination on the use of a single technology. Coordination took place between the administrations of the various regions to come to a worldwide allocation for the third generation of mobile telecommunications. The result was a coordinated effort to develop a family of standards (IMT-2000: International Mobile Telecommunications for the year 2000).

The case of Wi-Fi shows that the introduction of new technology will also need associated institutional arrangements supportive of this technology. It further shows that alignment between technology and the institutional arrangements is necessary but is by itself not enough for successful introduction of this new technology. In the institutional arrangements that were set up by the FCC, it is up to the radio equipment manufacturers to coordinate the efficient use of the radio spectrum, including graceful degradation of service levels under increasing load conditions and avoiding interference. The coordination activities necessary to develop new technology to achieve alignment between this new institutional arrangement and the technology were only realized after a private actor (NCR) had a private objective that materialized in a compelling business case. This private objective of NCR was compatible with the public objectives of the FCC.

The radio spectrum management reform in Guatemala was inspired by Coase´s idea of the large scale introduction of property rights. The case study shows the success of this approach as an instrument to trigger investments in (mobile) telecommunication infrastructure. However, the case study also shows that property rights are not a solution for all aspects of spectrum management. It shows the difficulty of this approach for the use of radio spectrum by short range radio devices such as Wi-Fi.

It further shows the difficulty of the Guatemalan government to deal with the public interest of “freedom-of-speech” related to the broadcasting service, especially the use of FM-radio by the various indigenous communities.

5 Lessons from the past and a framework for the future

The historic case studies in chapter three and four show that the coordination problem in the governance of radio spectrum should not to be reduced to only the phenomenon of interference. The case studies further show that the solutions for the coordination problem are in reality more complex than the dichotomy of government regulations versus privatization (through the introduction of private property rights). Coordination is taking place in various arenas, whereby it is not always necessary for the government to intervene to serve the public interest. To use the words of Elinor Ostrom, there is a need to dig deeper to understand the coordination that takes place and the incentives of the various actors for collective action.[212]

[212] Elinor Ostrom used the title “Doing Institutional Analysis - Digging Deeper Than Markets and Hierarchies” to explain the diverse nature of institutions that exist in society to structure human interaction in the *Handbook of New Institutional Economics* (2005a).

This chapter will further analyze the coordination that took place in the historic cases. It will provide first an overview of the lessons that can be learned from these case studies with regard to the coordination problems in the governance of the radio spectrum. These lessons will be used to reflect on the two alternative approaches for radio spectrum governance that were introduced in chapter 1. These lessons and the reflection will then be used to develop a framework to help to understand the coordination problems and to successfully mitigate these problems.[213]

[213] A first version of this framework was presented at the fifth Annual Conference on Competition and Regulation in Network Industries, Brussels: 30 November 2012. It has been published in the Conference Proceedings under the title “*Cognitive Radio - Aligning the Regulatory Environment with the Technology, a Business Case Perspective*”. The framework is further developed and described in Anker and Lemstra (2013).

“Simplicity does not precede complexity, but follows it”

Alan J. Perlis,
American Computer scientist, 1982

5.1 Lessons from the past: the complexity of spectrum governance

The case studies on the history of radio and the governance of the radio spectrum clearly indicate a need for coordination. This need is related to the attributes of the underlying resource, the radio spectrum, which can be regarded as a common pool resource, as explained in the introduction. In the early days, access to the radio spectrum was open to all. Hardin (1968) explained that open access to a common pool resource faces the risk of the "tragedy of the commons". Hardin recognized two solutions to overcome this "tragedy of the commons". The tragedy of the commons can be prevented by restricting access to the resource, either through government regulation or the introduction of private property rights. However, Ostrom et al. showed that there is a "third way". Ostrom (1990) found that user groups were able to self-organize the management of common-pool resources to mitigate the problems associated with open access, such as congestion, overuse or even destruction of the resource. She found an astounding variety of property rights regimes to restrict access to a common pool resource, including the creation of private property and common property, to restrict access and create the necessary incentives to invest in the resource (Ostrom, 1990; Ostrom, 2005b; Ostrom and Hess, 2007).[214]

Lesson 1

Already in the early development of the resource attempts to restrict access to the radio spectrum can be observed. However, at first it was not government that tried to restrict access. It was a private actor, Marconi, who tried to restrict access to the resource through the use of patents. He built a very successful business case on commercial exploitation of this public resource. Government intervention was triggered by the market power that Marconi deployed against its main competitors. However, the reason for the government to step in was not only based on the behavior of the Marconi company. It was motivated by industry policy, to defend the position of the military in the use of the radio spectrum and to assure safety-of-life at sea. All these reasons can be seen as protection of the public interest. Other cases following the early history confirm this role of government in the governance of the radio spectrum.[215]

> Lesson 1: the primary reason for government to assume a role as prime coordinator in spectrum governance is to safeguard public interests.

Historic cases confirm the assumption made in the introduction that the (historic) role of government to safeguard public interests should be taken into account in the current debate on the best way forward for the governance of the radio spectrum.

Lesson 2

The traditional radio spectrum governance regime that was established in 1927, as a result of early interventions, is often referred to as command-and-control. Analysis of this regime reveals that it is not a regime in which government is in full control. It is a diversified regime in which government is the prime coordinator but part of the coordination is left to private actors themselves, without the involvement of government.

Governments created a system in which the resource was neatly subdivided into multiple sub-resources for the various radio services. The users and user groups of the sub-resources had, and still have, great freedom how to use their part of the radio spectrum. Users organized themselves into user groups to coordinate more detailed operational rules with regard to the use of their part of the resource.

[214] See also chapter 2.

[215] See section 4.4.

The historic cases revealed three sets of action arenas in which this coordination takes place. The first action arena is the allocation arena in which coordination takes place to determine for which purpose the resource will be used.[216] The second arena is the assignment arena where coordination takes place to determine who is allowed to use the resource for the exploitation of the service for which the band is allocated. The third action arena is the arena in which standardization takes place. In this arena coordination takes place on the development of operational rules of how the resource is used. Note that the assignment and standardization arenas can be of a formal or informal nature, and that the operational rules set in a standardization arena can be institutional and technological in nature. The three arenas are depicted in Figure 5-1.

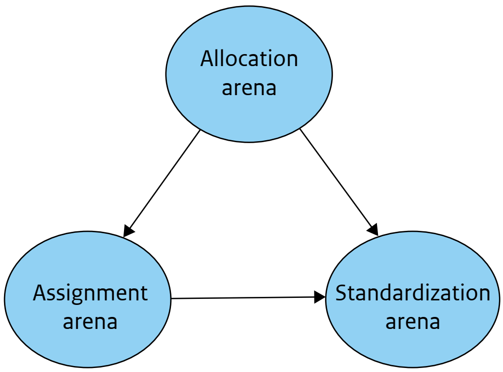

Figure 5-1 Arenas for coordination in spectrum management.

These three action arenas are not independent. The decision on the allocation will determine the freedom for coordination between the relevant actors in the assignment arena and in the standardization arena. A good example of this interdependency can be found in the historic cases of the introduction of the 2nd generation of mobile communications. In the United States the allocation was made for mobile telephony in general. Standardization was left to the private actors with the development of competing systems as a result. In Europe the decision was made to allocate the frequency band not just for mobile telephony but for a specific pan-European digital system, GSM. In this case, standardization was guided by the European governments. The development and use of an alternative (competing) system was blocked through the Directive on the coordinated introduction of GSM.

Decisions on the allocation will restrict also possibilities for coordination in the assignment arena. If a frequency band is specifically allocated for mobile telephony, the candidates for a license will be restricted to (incumbent and potential) mobile telephone operators. Hence, a broader allocation will provide possibilities for coordination among a wider range of (potential) users in both the assignment arena and the standardization arena.

The assignment may also restrict possibilities in the standardization arena. There will be a need to specify conditions of use for the licensee alongside with the assignment. The more general these conditions of use are, the more freedom there will be for the relevant actors to coordinate their use in a standardization arena. Very specific conditions will restrict possibilities for coordination in informal or formal standardization arenas.

[216] Allocation has a very specific meaning in the context of spectrum management. A clear distinction is made between (1) the specific use(s) or class(es) of use for which a frequency band may be used and (2) who is allowed to use the frequency band for the purpose for which it is allocated. The first is called allocation and the second is called assignment. See further Annex I.

Lesson 2: coordination is taking place in three types of interdependent action arenas:

1. Allocation: determination of the specific use of the sub-resource
2. Assignment: determination of who is allowed to use the sub-resource and under which conditions
3. Standardization: development of detailed operational rules on how to use the sub-resource, encoded in technology and related institutions

Lesson 3

The allocation process of the radio spectrum has to deal with the rivalry between the users of various services that want to exploit this resource. In the early days, it was fairly easy to deal with this rivalry among various services by dividing the multi-use common pool resource in a number of single use common pool resources. The maritime community, the aeronautical community, the amateurs, the mobile telephony operators and associated industries, they all were allocated their own part of the radio spectrum. A practice that is still in force today.

Dividing the resource in multiple single-use sub-esources had and still has some major advantages. First of all, it created a governance regime in which services with the same characteristics were grouped together to increase technical efficient use of the radio spectrum and to reduce the phenomenon of interference. Secondly, it assured spectrum access for services with a national or international public interest attached to it, such as safety-of-life at sea and in the air for respectively the maritime service and the aeronautical service and freedom-of-speech for the broadcasting service. The international allocation of radio spectrum created both the necessary interoperability and the economies of scale, two public interests that also need to be assured.[217]

Lesson 3: the allocation has two functions: 1) the prevention of interference between services and 2) assurance of public interests through spectrum access for distinct types of usage.

Lesson 4

In the early days, it was relatively easy to deal with competing demands for radio spectrum from the various existing radio services and for the introduction of new services, as technology made it possible to increase the size of the resource. New services were introduced at higher frequencies than the ones in use for the existing services. At the first radio conference in 1906, frequencies up to around 1 MHz (300 m) were allocated to the only existing service at that time, maritime communications.
In 1927, a frequency allocation table had to be drawn which catered for the demand of a number of new services. This was made possible by advancements in technology that allowed for expansion of the resource up to 23 MHz. The upper frequency boundary was shifted upwards as further progress in technology was made: from 23 MHz to 30 MHz in 1932, to 200 MHz in 1938, to 10,5 GHz in 1947, to 40 GHz in 1959, to 275 GHz in 1971 and to 1000 GHz in 2000. However, going to higher frequencies does not solve all problems related to a rise in demand. The physical properties of the resource are such that not all frequencies are suitable for all types of usage. Each frequency range is optimal suited for a particular kind of usage. Generally speaking lower frequencies travel larger distances and are able to penetrate through dense material like buildings. Higher frequencies travel over shorter distances and have difficulty penetrating

[217] This sub-division of the resource had as a side effect the benefit that it separated the various user groups that wanted access to the resource. This circumvented the rivalry between the various user groups in gaining access to the resource. The separation of the various user groups will be dealt with further down.

buildings. This does not automatically make higher frequencies less attractive, because it also means that interference is a more local problem. Hence higher frequencies can be reused over a shorter distance.[218] The most attractive and most used part of the radio spectrum is the frequency range between roughly 300 MHz and 3 GHz.

The historic case of mobile communications shows the difficulties with this line of action. It was not always possible to go to higher frequencies that were not yet allocated and assigned. Hence, the newly introduced service of mobile telephony had to be introduced in an already allocated band. Thus it had to compete with other services for the use of the resource. This created a clash between the newly defined cellular mobile telephony service and the existing broadcasting service, as well as between cellular mobile telephony and existing private mobile radio services. It was a clash between private parties with diverse and incompatible interests. The government had to balance between the public interests attached to these services, i.e. the vested interest of freedom-of-speech and safety-of life-and-property at one side against the introduction of a new innovative service at the other side. Proponents of mobile telephony could only carry some weight after technology made it possible to turn a luxury service for a few “fat cats” into a cellular service for the mass market.

This example shows the expanding role of government over time in the allocation of radio spectrum to accommodate new services. It is the government who had a central and decisive role in the allocation process, to safeguard the public interest and to make a choice between the conflicting interests of various user groups.

Lesson 4: historically the role of government in the allocation process has been to choose between the conflicting interests of various user groups and to safeguard public interests.

Lesson 5

The institutional arrangements on the radio spectrum assignment strengthen the separation of the user groups. In this action arena coordination takes place regarding the specific users who are allowed to use the particular part of the radio spectrum allocated for the service. Moreover, specific operational rules will be attached to the spectrum usage right. Both the cases of mobile communications and Wi-Fi show that in the assignment of frequencies there are possibilities to shift coordination of who will own the exclusive right or what type of device is allowed to use the radio spectrum and under which conditions (the operational rules) from the government to private organizations.

Auctions were introduced to assign licenses for the 2nd generation of mobile communications. In an auction, it is up to private actors to determine which actor is willing to pay the most for a block of frequencies. The underlying rationale is to achieve an economic efficient allocation of radio spectrum. The private actor that is willing to pay most is the actor who values the radio spectrum most and, by implication, could be expected to use the resource at its highest value, i.e. this private actor is able to make the most (economic) efficient use of the radio spectrum. This institutional change, i.e. the introduction of a market for spectrum usage rights, was already proposed in the late 1950s by Coase. However, his idea was only considered seriously by governments in the early 1990s as this institutional change perfectly matched the new public objectives attached to the liberalization of telecommunication infrastructure and the introduction of competition in the market for mobile telephony.

218 Another advantage of higher frequencies is that there is more bandwidth available. This bandwidth can be used to increase the data rate or the quality of the data to be transported. See also Annex I.

The Wi-Fi case shows that frequency bands can be assigned on a unlicensed basis for generic use of the band. These bands can be used as long as some specific rules (e.g. maximum power level and usage restrictions) are obeyed. This can be regarded as an example of the creation of a spectrum commons in a particular part of the radio spectrum. It is up to the private actors to coordinate their action to come to successful use of the band for a specific application.[219] These unlicensed bands have attracted various new types of applications whereby the communication is short range and the devices are numerous.

In both cases, this shift in coordination is related to the assignment in frequencies. In the case of mobile communications, the assignment is made through the use of market forces and in the case of Wi-Fi the assignment is made general and the intended private actors may coordinate to agree on specific (standardized) use of the frequency band. The latter private coordination typically takes place in a standardization arena. In the latter case, the assignment is not for a specific user but for a specific kind of usage as agreed in the standardization arena.

Lesson 5: in the assignment process a shift in coordination towards the use of market forces (in case of private property rights) and towards standardization (in case of a spectrum commons) has become feasible.

Lesson 6

In 1927, the fundamental decision was made by government to divide the resource into multiple sub-resources. A huge advantage of this division of the resource was that each sub-resource is associated with a rather homogeneous user group with a common interest in the exploitation of the resource. The various user groups became united in their own (formal or informal) standardization arena. User groups came to agreement about detailed arrangements on the operational use of their single-use (sub-)resource. The maritime community, the aeronautical community, the broadcasting community and the amateur community, they all made their own detailed arrangements about how to use the spectrum. In the case of commercial applications, such as mobile telephony and Radio Local Area Networking, these rules were captured in more formal standards. The cases show that patents are used to close the (sub-)resource and keep access to and exploitation of the resource restricted to the members of the community. It is typical behavior that was also noticed by Ostrom (1990) in her field work on common pool resources.

The cases further show the importance of standardization in the shift of coordination from the government to private actors. In mobile telephony, standardization allowed safeguarding of the public objective of wide area service delivery[220] through the private objective of achieving economies of scale. In Wi-Fi standardization allowed shared use of spectrum with an acceptable amount of interference between an unspecified but high number of users. The operational rules to reduce interference to an acceptable level within a shared exploitation of the resource is in this case embedded in the standardization of the technologies to be used.

[219] This can encompass governmental actors, as users of radio applications, but not a governmental actor in the role as a legislator or regulator.

[220] The term wide area service delivery is used here to denote the geographical area in which a mobile telephone could be used, and should not be confused with the actual coverage (within that area). The geographical area was in the 1st generation mobile telephony restricted to one large country (e.g. the United States, France or Germany) or a small number of smaller countries in Europe. In the 2nd generation, it was extended to an entire region (Europe) and in the 3rd generation it was further extended to allow global service delivery. This shift is related to the economies of scale needed to come to successful exploitation of the technology.

Standardization deals with reducing the level of interference to an acceptable level between the users within the (sub-)resource. Problems occur at the boundaries between groups and if a (sub-) resource is shared among various user groups with conflicting interests. At the moment these conflicts are resolved through governmental involvement as part of the allocation that sub-divides the resource and the associated conditions in the use of the radio spectrum.

Lesson 6: in the standardization arena coordination takes place on detailed operational rules, including prevention of interference, for the exploitation of the resource between the users themselves within the boundaries of their resource, outside control of government. Government remains in control of the definition of the boundaries through the allocation and conditions of use.

Lesson 7

The control of interference by technology on the operational level requires coordination on a standard at the collective-choice level by the actors. Olson (1965) already showed that a collective good can be provided when one powerful actor values the good sufficiently. This was certainly the case with the development of Wi-Fi. NCR had a powerful incentive, a Business Case for a nagging issue in their product portfolio, to take the lead in the development of the IEEE 802.11 standard.

Cooperation in the development of the NMT standard started because the governments of the Nordic countries and the manufacturers had a shared interest. The national markets were too small for the development of a national system. The manufacturers and the governments had compatible objectives to come to successful collective action. In the United States, the involvement of the government in the standardization of the first generation mobile telephony, AMPS, was related to the public objective of national roaming. In all these cases, the standardization took place between actors with a shared or compatible interest.

Lesson 7: standardization efforts take place between actors with a shared interest or between actors with compatible interests.

Lesson 8

It is interesting to note that the spectrum governance regime and the advancements that have been made in spectrum governance were triggered by problems with a specific service in this multiple-use common pool resource. Governmental involvement started with regulations to cope with interoperability issues in maritime wireless telegraphy. The tragedy of the commons that arose due to the uptake of broadcasting triggered the creation of the "command and control" regime. Property rights in spectrum were defined with especially the liberalization of mobile communications in mind and unlicensed access (the radio spectrum commons) was introduced to allow access to the radio spectrum for short range devices such as wireless local area network devices.

Private property rights and unlicensed access are focusing on a different kind of coordination which takes place between private actors[221] in another kind of arena, respectively the assignment arena and the standardization arena. In the private property rights approach the government is only dealing with the primary assignment. The coordination activities related to the re-assignment of the resource itself is left to the market. In the case of unlicensed access, the coordination on the usage of the radio spectrum is facilitated through the (standardization of) technology.

221 This may include governmental users of the radio spectrum. See further section 5.4 for the distinction between governmental users and government.

Lesson 8: a shift in coordination to users can take place through a shift of the coordination in an assignment arena or in a standardization arena; government remains in command-and-control of the allocation.

Final lesson

In the case of private property rights, this shift of coordination is made possible by a change in the institutional arrangements, i.e. the introduction of these private property rights. In the unlicensed access approach, standardization of technology allowed a shift in coordination to assure the compatibility between users. As a consequence, both approaches will lead to other results and are applicable in different situations. This is quite well demonstrated by mobile communications that could flourish under a regime of exclusive licenses and Wi-Fi that could develop after new institutional arrangements, based on unlicensed access, were set up.

Final lesson: there is not a simple solution to the radio spectrum governance problem and there is not a single solution that can fit all purposes.

5.2 Reflections on the proposed solutions

As discussed in the introduction, the current debate on radio spectrum governance is largely a discussion on two proposed alternatives next to the traditional "command-and-control" regime: an approach based on private property rights and an approach based on access for all under general authorization rules, usually referred to as a spectrum commons. Considering the historic case studies, what are the implications of the lessons from the past on these alternative regulatory approaches and their appropriateness?

5.2.1 Traditional "command-and-control" regime

The traditional regime, as introduced in 1927 and (largely) still in force today, is described in the current debate as a regime in which the spectrum management authority is in complete command-and-control. However, the analysis of the historic cases shows that this is not correct. In this traditional regime, the services with the same characteristics are grouped together. An associated legal framework of rules is used to regulate these services. By doing so, the radio spectrum is not only subdivided between the various services, but also the associated user groups are separated. Each user group is entitled to use its own part of the radio spectrum resource. These sub-resources were in most cases exclusively allocated to the service related to that user group. The multiple use resource of radio frequency spectrum is effectively subdivided in a number of single-use resources for a restricted and dedicated group of users. The analysis shows that these user groups have a large degree of freedom to coordinate their use of the radio spectrum through formal and informal standardization activities.

In the traditional radio spectrum management regime four interrelated tasks can be identified (Hatfield, 2003; Anker, 2013a):

1. *Allocation of the correct amount of spectrum to certain uses or classes of uses, e.g. mobile communications, broadcasting or navigation.*
2. *Assignment of specific usage rights to certain users or groups of users, e.g. a mobile operator, the police or air traffic control.*
3. *Developing rules and regulations governing the use of the radio spectrum within the band (e.g. maximum transmitter power).*
4. *Adjustment of the established allocation, assignment and associated rules as technology, markets and public interests evolve over time.*

In the traditional "command-and-control" regime, government has assumed responsibility for all these tasks. However, analysis of the historic cases shows that parts of the coordination, related to the assignment (task 2) and a part of task 3 (standardization), can be shifted to private actors.

The debate about the appropriate spectrum governance regime started from the weaknesses of this traditional "command-and-control" regime: (1) some of the portions of the assigned spectrum are hardly used, and (2) the regime is slow in responding to changes in market and technology.

The solutions as proposed by the two alternative approaches is focused on an economic efficient assignment (task 2). However, the first weakness is strongly related to the allocation (task 1) which sub-divides the radio spectrum in a large number of sub-resources and the second weakness is strongly related to the ability to make adjustments to a given distribution (task 4). Allocations are made to satisfy the market demand with the given technological capabilities in mind at the moment in time that the decision of the allocation is made. Assignments are made within these given allocated bands. However, the correct amount of radio spectrum for a particular service is not static. It will change due to changes in market demand and changes in technology. This point is clearly shown by the historic case of mobile communications. As the demand for mobile communications was rising rapidly and advancements in new (digital) technology were made, there was a need to enlarge the allocations for mobile communications.

5.2.3 Private property rights

As explained in the introduction, a private property rights approach first of all requires well defined spectrum rights. These rights will have to be put in the market through a primary assignment, generally an auction. Once these property rights are distributed, these rights can be transferred in an open market. Trading is expected to take place if these rights can be used more profitably by another user. Trading is expected to ensure that the rights will be possessed by the user who values these rights most, i.e. the rights will be used most efficient from an economic perspective. The owner of these rights should be free in its use of these rights. Interference is resolved by a clear definition of the rights. After an initial definition of those rights by government, it should be possible to change these rights as a result of coordination in the market.

The goal of this approach is not to minimize interference, but to maximize output. Coordination will not lead to a situation in which there is no interference, but to a situation where there is an "optimal" amount of interference. "*What has to be insured is that the gain from interference more than offsets the harm it produces*" (Coase, 1959: 27).

The exchange of rights in a market is only feasible if the transaction costs are sufficiently low. This is e.g. the case in mobile telephony or broadcasting whereby the number of spectrum rights holders is limited and use is made of comparable technology (in terms of transmission power and network topology) for their transmissions. The various users will be limited in the amount of differentiation in the use of their technology. However, if one user wants to increase the transmit power to a level that is much higher than the transmit power of the other users in a band, the high power user will be faced with a large increase of the number of transactions and a large increase in the associated transaction costs. Coase (1959) acknowledges that there may be a need for special regulations in cases where the market is too costly to operate.

This approach entails an institutional solution to ease coordination associated with the assignment of spectrum rights through a market for spectrum usage rights. This alternative focuses on economic efficient use for the delivery of typically commercial services by a limited number of users. Radio spectrum is thereby regarded as an input for the production of these services. There seems to be a fit for situations in which frequencies are used to deliver infrastructure-based services, such as mobile communications or broadcasting, which require a large upfront investment. The service provider is only willing to pay for this investment if it can be sure that there is a proper return on investment. Exclusive property rights with a sufficiently long (or infinite) duration will ensure that the owner can have access to the radio spectrum for a period of time long enough to recoup the investments and make a return on his investments. This point is clearly demonstrated by the historic case of Guatemala, where privatization of spectrum rights accelerated the introduction of mobile telephony.

Nonetheless, there remains a role for government in a property rights approach. First of all, government should define and enforce well defined private property rights. These rights should then be auctioned in a primary distribution of these rights. However, Coase is not very clear on the boundaries of governmental involvement in the definition of these rights. Coase states (1959: 34):
"How far this delimitation of rights should come about as a result of a strict regulation and how far as a result of transactions on the market is a question that can be answered only on the basis of practical experience."

The historic cases show some practical experience in the coordination with regard to the delimitation of usage rights. However, as opposed to the proposition of Coase, the historic cases on mobile communications show that this coordination on the delimitation of the rights does not take place bilaterally between the individual users affected. Most of the coordination takes places in a standardization arena as part of a larger standardization effort, within a larger group of users and equipment manufacturers. Their primary incentive to participate in a coordination effort in a larger group is not to control interference, but to reach economies-of-scale. Bilateral coordination between the owners of spectrum usage rights seems to be focused on the particular assignment itself.

The possibility for coordination in a private property rights regime provides for some flexibility to users. They have some flexibility in the use of technology to cope with changes and they have some flexibility in the amount of radio spectrum used individually. However, this flexibility is restricted by the total amount of radio spectrum allocated to the service.

5.2.3 Unlicensed access

The essence of the unlicensed access (or a spectrum commons) approach is that anyone can have access to the radio spectrum as long as radios are used with built-in techniques and rules to limit interference between users. In this regime, technology is used to coordinate access to spectrum between radio devices while limiting the interference between those devices. This approach is built on the believe that: "*technological developments made obsolete the whole idea of defining discrete channels for exclusive control and then allocating and assigning them, whether by regulation or prices*" (Benkler, 2012: 82).

In other words, the approach is built on the assumption that the radio spectrum in itself is not scarce, only access to the radio spectrum is scarce. Although this might be true in general, it is not true if one takes into account that specific services need to have access to certain parts of the radio spectrum. This means that this approach is also not capable of handling all types of services. Some services need a very specific frequency or range of frequencies in which they have to operate. Good examples are weather radar systems and radio astronomy. It is also not very clear how to deal with social and public services in this regime.

Different suggestions have been made about who should develop the rules necessary to avoid the tragedy of the commons. Benkler (1998, 2002) suggests either government should develop the rules or a non-governmental body that is open to anybody, along the lines of the W3C[222] or IEEE. Buck (2002) suggests to leave the management of the spectrum commons to localized spectrum groups. Government should only allocate the radio spectrum and formulate the guiding principles needed to set up these groups.

Both proposals have in common that the boundaries of the spectrum commons are to be defined by the government through the allocation of one or more bands. The coordination on the actual usage of the band can be left to the users of the band. This is quite similar to the actual coordination process that took place after the FCC decision to allocate radio spectrum for the civil application of spread spectrum technology.

This approach seems to focus on the creation of a market for equipment that can be used for certain applications whereby the interference to other users is limited, i.e. in relatively high frequency bands and for applications with a limited amount of power. The question what the incentives of the actors are to participate in the standardization activity is not addressed in the literature. The Wi-Fi case indicates that a strong incentive can be found in an attractive business case, as shown by NCR.

5.2.4 Concluding remarks

The lessons from the past show that the reality is complex and cannot be simplified to a debate on the best of two alternatives. The debate over the best way forward is too much focused on the theoretical if not ideological merits of these two alternatives. Most of the discussion is very polarized and takes almost religious proportions. However, as demonstrated neither of the alternative approaches can deal with all aspects of radio spectrum management. The two approaches are each optimally suited for a different situation. In other words, the debate on the merits of both approaches focusses on only certain aspect of the spectrum governance problem and only provides

[222] The World Wide Web Consortium (W3C) is an international consortium where Member organizations, a full-time staff, and the public work together to develop Web standards.

	Radio spectrum management approach		
Management task	**Traditional regime Command-and-control**	**Private property rights**	**Unlicensed access (spectrum commons)**
1) Allocation	Governments in control	Governments define the boundaries Specific usage of service/ technology emerges in the market	Governments define the boundaries User groups define the specific applications
2) Assignment	Government in control	Primary assignment by auction Secondary assignment in the market	Everybody can have access as long as strict rules are followed
3) Rules	Specific rules defined by government	Governments define the boundaries	Governments define the boundaries
	Detailed operational rules defined by private actors in a standardization arena		
4) Adaptability	Slow in response to changes in market and technology	Can cope with changes in market demand for services and technology	Can cope with changes in market for applications
Remarks		Optimal for infrastructure based services	Optimal for device centric applications

Table 5-1 A comparison of the three different spectrum management approaches.

a partial solution. Table 5-1 provides an overview of the three different approaches and their applicability to the various tasks in spectrum management.

Both alternative approaches have in common that they provide for more flexibility. However, they both take interference as a starting point for coordination. The historic cases reveal that interference is an important factor in spectrum governance, but it is by no means the only factor to be taken into account. The other factors are related to the interests of both private and public actors. Examples of other factors that have to be taken into account are: economies-of-scale, interconnection, interoperability, roaming, safety-of-life-at-sea, freedom-of-speech. These private and public interests cannot be provided in all cases with the alternative approaches.

The coordination in the alternative approaches is centered around the assignment. Coordination on spectrum usage takes place in the market between users or as part of smart technology to determine who (or what device) is allowed to access radio spectrum. The allocation of radio spectrum and the role of standardization are largely disregarded in the debate on the alternative approaches. The alternative approaches offer only a solution to deal with interference within the boundaries of the (sub)resource and the assignment of spectrum usage within the (sub)resource.

The alternative solutions cannot deal always with the public interests attached to the provisioning of some applications and services and both alternative approaches can be used and they are applicable in different situations for another kind of services or applications.[223] Hence, it is not a matter of choosing the best (alternative) regime. It will be a mixed approach in which there remains a need for the traditional command-and-control regime in some circumstances. Both approaches enrich the toolkit of the spectrum management authority. Various authors also refer to various hybrids and intermediate regimes. Freyens (2009) provides some additional advantages and disadvantages of the two alternative regimes and a more detailed sketch of possible hybrid and intermediate regimes.[224]

In both alternative spectrum governance approaches there is still a need for governmental involvement. Government will have to clearly define the boundaries for the property rights and will also have to define the boundaries for the spectrum commons. Government remains responsible for dispute resolution and enforcement of these boundaries (Goodman, 2004). The assignment of the spectrum rights can then be left to market forces and access to the spectrum commons can be addressed and resolved within a standardization arena by user groups and/or manufacturers.

At this time, virtually all (usable) radio spectrum is allocated and assigned. There are no opportunities left for frequency bands that could easily be cleared nor are there possibilities to make unoccupied higher frequency bands available. Hence, there is need for a regime in which both approaches are gradually introduced in parts of the radio spectrum. A gradual approach has the added value that there is a possibility for the actors to learn from past actions.

223 The proponents of the private property rights often argue that private property rights will lead to the economic most effective use. However, investigations in (regulated) common property rights regimes seem to indicate that if (1) information is perfect and (2) transaction costs are negligible, both regimes will lead to a Pareto-optimal equilibrium (Baland and Platteau, 1996).

224 A much cited advantage of a commons approach is the reduced lead time from innovation to market. If that really is the case remains to be seen. The development of Wi-Fi started in 1985 with the spread spectrum decision of the FCC. This led to a standard for Wi-Fi in 1999. This is comparable to the introduction of the 3rd generation of mobile communications. The development started in 1985 with the identification of spectrum for FPLMTS. The first 3rd generation service was offered in 2000.

The question in which parts of the radio spectrum a particular approach should be introduced, and what the remaining role of government should be is not addressed in the current literature on the spectrum governance debate. Hence, there is a need to dig deeper to provide answers. Can the lessons from the past combined with the lessons from Elinor Ostrom on the governance of common pool resources shed some light on the process to come to a more flexible spectrum governance regime and on the determination of the remaining role of government? These questions are addressed in the following section.

5.3 A framework to tackle this complexity

Elinor Ostrom taught us two enduring lessons, a substantive lesson and a methodological lesson. The first lesson is to embrace complexity and context – or simply, *reality*; to avoid distortion from reductionism, and overstated gains from simple models. The second lesson taught us how to deal with this complexity, through the use of a robust analytical framework. She developed the Institutional Analysis and Development (IAD) framework to systematically research reality in order to analyze and understand institutional diversity (Frischmann, 2013).

The IAD framework posits that the behavior of actors in the action arena where coordination takes place is influenced by three sets of external variables: (1) the physical and material conditions, of which the characteristics of the resource, the products and services that are provided and the technology used to provide these products and services are important elements; (2) the characteristics of the formal and informal institutions; and (3) the characteristics of the (groups of) actors that are involved.

The historic cases show that the coordination in spectrum governance takes place in three interrelated types of action arenas: (1) the allocation arena, (2) the assignment arena and (3) the standardization arena. The coordination between actors does not take place in a static environment. If this were the case, the institutional arrangements as set in 1927 would have been sufficient. Coordination is triggered by the need to adjust to changes in one or more of the external variables. The biggest challenge for spectrum management is not in the allocation, the assignment, or in the control of interference as such, but in the need to adjust to changes. Control of interference is only one aspect to be considered.

This change can be of a technical nature, e.g. development of a new technology; or it can be of an economic nature, e.g. to adapt to changes in the demand for services; or it can be of a political nature, e.g. a change in the public objectives. The traditional regime is generally regarded as being too slow in responding to changes (Anker, 2010b). The notions above combined with the lessons from the historic cases suggest that the debate on the spectrum governance regime should not be about the choice for the optimal regime to cope with interference, but about the development of a process to cope with changes.

The IAD framework posits that if a change in the external environment occurs, coordination will take place to adapt to the new situation. Adaptation of the institutional environment to cope with this change, may require a coordination activity at the next higher level, e.g. coordination at the collective choice level may be needed to change the institutional arrangements at the operational level. In the case of spectrum governance, a coordination activity may not only lead to changes in the institutional setting (for the lower level), but may also lead to a technological solution, or to a mix of institutional change and technological change. This role of technology as an outcome of coordination is largely neglected in the current literature on the IAD framework. This alternative of a technological solution instead of a institutional solution for the coordination problem deserves attention.

In this respect, the exploitation of the radio frequency spectrum for the provisioning of products and services can be regarded as a complex sociotechnical system. Such systems involve multiple actors, contain technological subsystems and components central to its performance and have societal, political and economic relevance and impact. They are dynamic in the sense that they are constantly changing and adapting. Technology and institutions are strongly interwoven in these systems (Hughes, 1987). The application of new technology may require a need for changes in the institutions. In turn, the institutions that are in place may influence investment decisions that determine the path of future innovation and technology adoption.

This linkage between institutions and technology is captured in the concept of co-evolution. With co-evolution is meant that technology and institutions have a significant causal impact on each other (Murmann, 2003). Nelson (1994), von Tunzelmann (2003) and others have clearly shown this linkage between changes in technology and the need for changes in institutions as a result, and vice versa. In other words, if technology changes there is a need to adjust the institutions to become compatible with and supportive of the new technology. The institutions suitable for an earlier set of fundamental technologies may be quite inappropriate for the new set of technologies (Nelson, 1994). On the other hand, if institutions change there may be a need for changes in technology to adapt to the new institutional arrangements. Indeed, history is full of examples where existing institutional structures pose an obstacle to the success of new technologies and related industries which "*require institutional reform if they are to develop effectively*" (Nelson, 1994: 58).

Examples of the linkage between institutions and technology can be clearly found in the historic cases of chapter 3 and 4. A good example is spread spectrum technology. The technology was already invented in 1942. At that time the usage of radio spectrum was based on exclusive rights. Hence, there was no need to use technology that made communications more robust for interference. This is an characteristic that is only useful in a frequency band that is shared with other users. The use of spread spectrum for commercial applications was only useful after an institutional change was made in the 1980s.[225]

The historic cases also show that for certain problems there are solutions to be found in either a change of the institutional arrangements or a change in the technology. An example of the latter is the uptake of mobile telephony. There was not enough radio spectrum allocated to mobile telephony to accommodate the market demand for this new service. However, the FCC refused an institutional solution, because it gave preference to the vested interests of private mobile radio and broadcasting. Therefore, a solution had to be found in technology. The technology of channel splitting was introduced to use the available radio spectrum more efficiently.

Another example of the linkage between institutions and technology can be found in the principle of listen-before-talk. This principle was part of the institutional arrangements for the maritime service and other services in the early days of radio communication. The radio-telegraphist had to listen into the channel to observe that there was no activity before using it. Nowadays, it is possible to

[225] Usage of spread spectrum technology was in the years before the 1980s restricted to military applications. See further chapter 4.

implement listen-before-talk in technology as part of the medium access protocol.[226]

The concept of co-evolution between institutions and technology explains the need for changes in institutions if technology changes and vice versa, but this co-evolution perspective does not shed any light on the characteristics of the institutions appropriate to a particular technology (Saviotti, 2005). Let alone how institutions should be changed as a consequence of changes in technology. Finger, Groenewegen and Künneke (2005) brought this concept of co-evolution one step further. They posit that the economic, social and technical performance of complex technical systems is dependent on the degree of "coherence between the technical and the institutional coordination". In other words, there is a need for alignment between technology and institutions for these systems to perform satisfactorily, in economic, societal and technical terms (Finger, Groenewegen and Künneke, 2005; Finger, Crettenand, Laperrouza and Künneke, 2010). Performance will be negatively affected if institutions and technologies are not sufficiently aligned.[227]

The concept of coherence highlights the need for alignment between institutions and technologies when institutional and/or technical changes are made to the system. However, also this concept does not provide an answer to the question how institutions should be changed in response to changes in technology and vice versa. It is a concept that can be used to analyze the (mis)match between a given technology and the institutional arrangement surrounding it in a static comparative approach.

In an effort to try to answer the question how alignment between technology and institutions could be achieved, there is a need to take a closer

[226] Listen before talk is used in Wi-Fi and other short range devices to share the band between numerous devices and it is used in mobile terminals to be sure it only transmits if it is attached to a mobile network.

[227] Finger, Groenewegen and Künneke (2005) identified four technical functions that need to be performed satisfactorily for a given infrastructure to function properly: interoperability, interconnection, capacity management and system management.

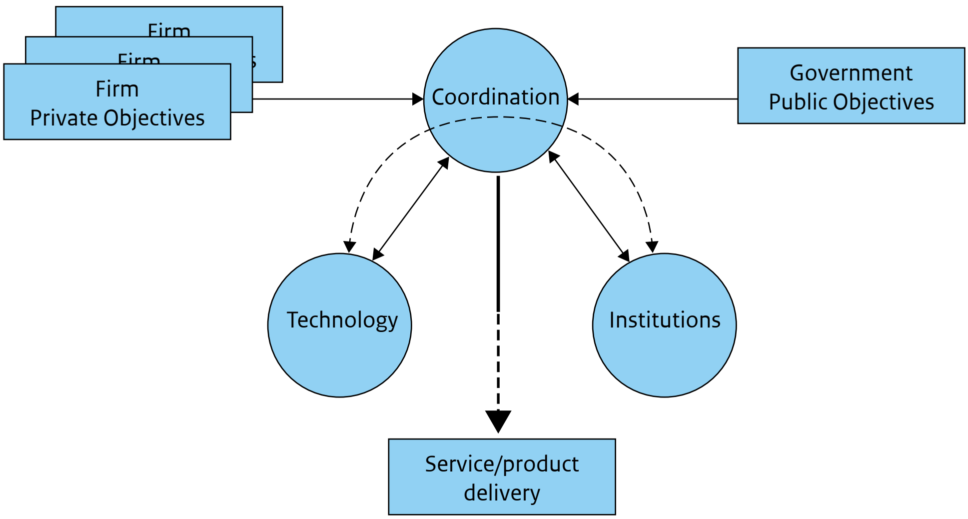

Figure 5-2 Two levels of alignment in the interaction between actors to achieve alignment between institutions and technology.

look at the relationship between technology and institutions. This relationship is not direct, technologies do not shape institutions and institutions do not craft technology. It is through the interaction between actors that technology will have an influence on institutions and vice versa.[228]

The setting in which actors coordinate to try to align the technology with the institutions and vice versa is shown in Figure 5-2.

In the interaction to achieve their objectives actors are guided by the structure, being both institutions and technology. They will try to influence and change the structure if this contributes to the realization of their objectives. In the interaction among actors there is not necessary an overall goal. Each actor has its own reasons to participate and is performing behavior in order to pursue its own interests which might be partially conflicting with the interests of other actors (Economides, 1996; Scharpf, 1997). This coordination effort will be successful if the outcome is mutually beneficial to all actors (Ostrom, 2005b), in other words, if actors participating in this coordination activity can all realize their objective to a satisfactory degree. This means that there is not only a need to align institutions with technology, but that this alignment can only lead to a successful outcome if there is alignment possible between the objectives of the various participants in this coordination activity.

The actors involved can be broadly classified in two distinctive groups. First, there are private actors (further denoted by the simplified term firms) that have capabilities to innovate and develop new technologies, new products and new services. By doing so, they force other actors to react. These are private firms such as equipment manufacturers and service providers. On the other hand, there are actors who are capable to shape the institutions under which all actors have to act. These are public actors (further denoted by the simplified term government), including political authorities, public administrations and regulators (Finger, Crettenand, Laperrouza and Künneke, 2010).

These two classes of actors have different sets of objectives. In a somewhat simplistic view of the world, governments have objectives to protect the public interests. Since the liberalization[229], governments have above all an objective of economic efficient use of complex technical systems. This is accompanied by societal objectives, such as universal service delivery, and in some cases also by economic objectives as part of industry politics. Today, governments rely on an appropriate market design and associated regulations to serve this mixture of economic and societal objectives. In the case of mobile communications, radio spectrum policy is used to create a market for mobile telephony. Specific auction rules may be used to allow new entrants and to influence the number of players in the market. Specific obligations may be attached to the licenses to serve societal objectives, e.g. a coverage obligation.

On the other hand, firms have completely different objectives. Important (private) objectives are maximization of profit and shareholder value. Firms invest in (new) technology and the development of new innovative products and services. However, in general firms will only decide to invest in the development of new products and/or services if they can expect a future return. These investment decisions are driven by three major considerations: (1) the prospective demand and willingness to pay for new products and/or services; (2) the magnitude of the investments required; and (3) the degree of risk or uncertainty involved.

228 See further chapter 2.

229 Liberalization refers to the introduction of competition in sectors that were characterized by publicly owned monopolies or regulated private monopolies in the past. These reforms involved mainly institutional changes.

The profile of the business case, in terms of depth of investment and the recovery period required, will influence the ability to obtain the necessary (external) funding. As such the business case is especially challenging for service provisioning that requires a huge upfront investment, e.g. an infrastructure roll-out to provide mobile telephony. In these cases the right to exploit the radio spectrum, or any other infrastructure which requires substantial up front investments, over a significant period of time and on an exclusive basis will contribute to the willingness of entrepreneurs to invest, as it may make the business case more viable (Lemstra, Anker and Hayes, 2011).

Firms will not always have (private) objectives that are fully in line with each other. This is most apparent in cases where the private firms have a completely different business case, such as a mobile operator compared to a broadcaster. However, differences in objectives can also be noticed in cases of actors with a more comparable business case, e.g. the wireline carriers versus the radio common carriers in the development of mobile telephony as discussed in chapter 4.

Although the respective objectives of firms and government are completely different, they are highly interdependent in the realization of their objectives. The institutional arrangements that are set up will have to provide the certainty to entrepreneurial firms to invest in new technology and the exploitation thereof. If as a result of considerations of profitability firms decide not to use the system as intended, government fails in realizing its objectives.

This alignment of the private and public objectives is illustrated by the case of the development of GSM. The European manufacturers needed economies of scale to develop the next generation of mobile communications and to compete with Japanese and American manufacturers. This objective was in alignment with the objectives of the European Commission on the development of a competitive single European market. The European Commission regarded telecommunications as an essential facilitator in the creation of the European internal market while advanced telecommunication infrastructures were regarded as a source of competitive advantage for European firms.
A European coordinated standardization effort was regarded necessary for the European mobile telecommunication industry to be competitive on the worldwide market. This resulted in the endorsement of the GSM project by the European Commission and eventually to the creation of ETSI in 1988 in order to develop harmonized European telecommunication standards including GSM.

In setting up the institutional arrangements, governments will steer technology and possible business cases into a certain direction. Ostrom (1990) showed that the specificities of the entry and authority rules will favor certain types of usage over other types of use.[230] This is also true the other way around, certain types of perceived usage will require particular entry and authority rules.

Hence, decisions made by governments on the market design and associated regulations will have an influence on the viability of possible business cases. For example, decisions made in radio spectrum policy on the amount of radio spectrum allocated, whether a license is required or the radio spectrum is made available on a unlicensed basis, the number of licenses issued, the roll-out and other obligations attached to the licenses and the award mechanism for the licenses (e.g. an auction or a beauty contest) will all influence the required

230 Ostrom made this observation in the investigation of common pool resources. Künneke and Finger (2009) show that the problems associated to infrastructures are quite similar. They argue that infrastructures (including energy, communication, transport, and postal services) can be perceived as common pool resources providing essential services to society.

investments and the possibilities to exploit a certain business case. This is quite well demonstrated by the 2nd generation of mobile communications (GSM) that could flourish in Europe under a strict licensing regime.

Governments will need to be very well informed to make the right decision in order to let the intended business cases flourish. Lessons learned from the past seem to suggest that a too "pushy" approach from governments may be counterproductive and retard or stall technological development (Haug, 2002). There are a number of examples where the (European) governments pushed for a single European harmonized standard that was not successful. Well known examples are the Enhanced Radio MEssaging System (ERMES), the Terrestrial Flight Telecommunications System (TFTS) and the European HIPERLAN standard.[231]

In order for the radio spectrum governance system to be as flexible as possible, government should restrict access to radio spectrum not more than absolutely necessary to fulfil the general public interest of efficient radio spectrum use and the specific public interests to allow access to radio spectrum for social goods and services and for public services. Much of the coordination on the use of the radio spectrum can be left to private actors. They can coordinate their use of the radio spectrum in for instance a standardization arena to fulfil their own private interest, e.g. to reach the necessary economies of scale.

The main role of government will be what Ostrom describes as a facilitator state. A facilitator state allows considerable local autonomy to individuals and groups but provides a supportive framework, including the provision of specialized information, dispute resolution and the capacity to enforce institutional rules. The emphasis here is on individuals and groups providing their own institutional arrangements to solve collective action problems with the state acting to support them in this particular role (Ostrom, 1990; Pennington, 2013).[232] The role of government will be more prominent to assure the delivery of societal and public services.[233]

In all circumstances, government should be very clear in the public objectives they want to pursue and they may even have to prioritize between various public and societal objectives. Moreover, government should be aware that the public objectives may be realized through private actors. Governments should then shape the institutional setting such that the public objectives are aligned with the private objectives and the institutional setting is in alignment with the technology. Last but not least, government should monitor the coordination efforts and facilitate the market if and when necessary. Public provisioning remains as a 'last resort' if all else fails.

5.4 Concluding remarks

The lessons derived from the historic cases revealed that the core objective of spectrum governance is not to prevent interference between the users of the resource. They clearly demonstrate that the core of radio spectrum governance is the need for coordination to adjust the institutional setting and associated technology to cater for changes in market, technology and/or public objectives. Until now the role of actors involved in the coordination has been

231 ERMES was a European standard for messaging. TFTS was a European standard for a system to permit the placement of telephone calls by passengers on commercial aircraft directly to ground stations. HIPERLAN was a European standard for wireless Local Area Networking, discussed in chapter 4.

232 Ostrom distinguishes between the role of facilitator and the role of controller. A controller state is a state in which the state itself manages the resource.

233 This role of government is further elaborated in chapter 7.

largely disregarded. However, the objectives of the participating actors are key to come to successful outcome of coordination. This outcome will only be successful if the public and private actors can come to mutual beneficial outcomes. Hence, all participants should be able to realize their objectives to a sufficient degree. As a consequence, there is a need to align the objectives of the public and private actors with one another and with the institutions and technology to be used.

In this chapter, a framework is proposed that can be used to analyze the alignment of the objectives of the private and public actors. This alignment framework can be used for the design of an approach towards the introduction of more effective decentralized coordination in the radio spectrum governance regime and more efficient use of this valuable resource.

However, the historic cases do not reveal how this alignment can be realized. This will be explored in the next two chapters. In these chapters, the alignment framework will be operationalized. Chapter 6, will operationalize the framework for the forward looking specific case of the introduction of new cognitive radio technology in the United States, a fundamental change in technology to access radio spectrum. The alignment framework will be used to analyze the process in which this introduction took place. This is followed by a discussion and a proposal on how the process could be shaped to come to successful introduction of this new technology whereby not only the institutions are in alignment with the technology, but the objectives of the actors are also aligned. In this discussion, use will be made of experiences in the Netherlands in shaping the process. The next chapter (Chapter 7) will operationalize the framework for the generic case of radio spectrum governance. A revised spectrum governance process is proposed that takes the alignment of the objectives of the government with the objectives of the private actors as the starting point, whereby policy is produced in a governance process based on multi-actor structures. Government is considered as one of the actors in the process, an important one, but government is no longer in control of the whole process. Its role is shifting to a facilitator of the process. Recent experience in the Netherlands with this new approach is summarized in this chapter.

6

The alignment framework in practice: introduction of cognitive radio technology

This chapter provides an example of how the alignment framework could be used in the development of institutional arrangements for cognitive radio technology. The chapter starts with a brief introduction of cognitive radio technology followed by a description and analysis of the recent experience in the United States to develop the institutional arrangements for the introduction of cognitive radio technology. The chapter continues with a discussion on the need for coordination in the development of this new technology. A proposal is made to explore Use Cases within a Community of Practice as the way forward to realize the necessary coordination between the actors to facilitate the successful deployment of cognitive radio and to realize – at the same time – the goal of improved utilisation of the radio frequency spectrum. It is argued that government is in a good position to take the lead in the establishment of such a platform for coordination. This is followed by a discussion of the experience in the Netherlands with coordination in a Community of Practice. The chapter ends with some recommendations for the next steps in this coordination activity.

6.1 Cognitive Radio: the need for coordination

In 1999, already more than 15 years ago, the concept of cognitive radio was proposed by Mitola and Maguire as a promising technology to deliver personalized services to the user through the most efficient use of available radio resources. They described a cognitive radio as a device that can match its own capabilities to external observations (in terms of available radio resources, prevailing spectrum rules, user needs and preferences, operational costs of a service, etc.). The device would use knowledge from these observations to adapt itself to provide wireless services most appropriate to the user needs and preferences. The radio would be able to learn

"To me, error analysis is the sweet spot for improvement."

Donald A. Norman,
American designer

from its past actions and experience and incorporate this knowledge in future decisions. It was a vision of a highly intelligent wireless personal digital assistant with which users travel. Wherever a user goes, the cognitive radio device would adapt to the new environment to offer personalized services that satisfy the user's needs (Mitola and Maguire, 1999).

In their view cognitive radio is a research goal towards which a software defined radio platform evolves. This type of cognitive radio is often referred to as full cognitive radio or Mitola radio. Shukla (2007) concluded that due to the given technological challenges, it is unlikely that a full cognitive radio will be achieved in the foreseeable future.[234]

Today, the focus of most research towards the use of cognitive radio is much more narrow. Cognitive radio technology has been proposed as a means to increase efficient use of spectrum. This focus on efficient use of spectrum was introduced by Haykin. He redefined a cognitive radio as (2005: 201-202): *"an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind:*

- *highly reliable communications whenever and wherever needed;*
- *efficient utilization of the radio spectrum."*

Since then the concept of cognitive radio has been further explored and the importance of cognitive radio as an enabler to increase efficient use of the radio spectrum has gained momentum (Anker, 2010b; RSPG, 2011).

The key feature of such a cognitive radio is its ability to recognize and use parts of the radio spectrum that are assigned to a conventional user but are actually not used by this user. A cognitive radio is able to adapt its communication strategy to use these parts while minimizing the interference that it causes to the conventional users. This capability of cognitive radio technology is considered as highly valuable for the introduction of new radio communication services, as essentially all (usable) radio spectrum has been allocated and assigned, but some portions of the spectrum are hardly used. Various measurements have shown that at particular geographical locations large portions of the spectrum are not continuously used or even not used at all (FCC, 2002b; SSC, 2005; Wellens, Wu and Mahonen, 2007). Although, the qualification when spectrum is not used is debatable, the measurements clearly show that there is ample room for more intensive use of the radio spectrum.[235]

Significant efforts are put into the development of cognitive radio technology that is able to identify so-called 'white spaces', i.e., unused parts of the radio spectrum, and to use those white spaces for additional use of the radio spectrum. The technology is very promising as a solution to enhance spectrum sharing. However, commercial exploitation of cognitive radio technology is still very limited. It is

[234] To be more precise, Shukla predicted that a full cognitive radio will not be achieved in the next 20 years. However, he made this prediction in 2007.

[235] Detection of spectrum usage is a non-trivial technical problem. The "hidden node" problem is a fundamental challenge for detection of spectrum usage. The "hidden node" problem occurs when the detection device due to a physical obstacle, cannot sense radio transmissions, and therefore assumes that the radio spectrum is available. Another problem is that it may be very difficult or even impossible to detect receive-only users such as passive radio astronomy and other scientific uses or broadcasting users. Other usage such as short range communication may be difficult to detect due to the low emitted power level, while satellite communication may be difficult to detect due to the very low power levels of the signal at the surface of the earth. Even when a satellite downlink is detected it does not mean that the satellite service is actually used by receiving earth stations in that particular area (RSPG, 2010).

mainly confined to experiments and field trials There are some trials with commercial use of cognitive radio on-going. Most of these are focused on the exploitation of white spaces in the TV broadcasting bands (Pawelczak, Nolan, Doyle, Oh and Cabric, 2011; Medeisis and Minervini, 2013; Marrero, Villalonga, Inguanzo and Gómez, 2016).

One of the main reasons for this lack of practical and commercial use of cognitive radio technology is considered to be uncertainty about the institutional arrangements. Although there are possibilities to use cognitive radio under the current radio spectrum management regime, the current institutional environment is not compatible with dynamic forms of radio spectrum access made possible by cognitive technology. Regulatory provisions are needed to align the institutional arrangements with the new capabilities of cognitive radio technology. This uncertainty on the institutional arrangements associated with cognitive radio technology will have to be mitigated before successful, large scale deployment may be expected and the potential economic and social value related to dynamic and more efficient use of the radio spectrum can be realized (Anker, 2010b).

In the development of cognitive technologies there is a need to make choices about some of the more fundamental features of the technology, such as the technology to be used to make a cognitive radio aware of its radio environment and the band(s) in which the cognitive radio is allowed to operate. In making these choices there is a need to match the regulatory environment with a specific set of capabilities related to cognitive radio technology. These choices will need to be made well informed as these choices play a pivotal role in the business models of the entrepreneurs. The way governments allocate the use of radio spectrum to particular radio communication services on the (inter) national level and assign the rights to use the radio spectrum on the national level is determining the viability of the business case for particular radio communication products and services.

In this respect there is the issue of 'the chicken and the egg': certain types of radio spectrum rights assignment facilitate certain types of usage, while certain types of perceived usage will require a particular type of assignment. In other words, entrepreneurs are reluctant to invest in new products and/or services based on cognitive radio technology because of the degree of regulatory uncertainty and regulators are not in a position to provide this certainty because it is uncertain if their choices will support a viable business case. Hence there is a clear need for coordination to align the institutional environment with the technology, such that both government and entrepreneurs can realize their objective in order to come to successful introduction of cognitive radio technology.

6.2 The introduction of white space devices in the TV band in the United States

As already noted in the introduction, there are many parts of the radio spectrum that are exclusively assigned to a particular service, whereas a lot of this assigned radio spectrum is not used in any instance or at every location. Recent developments in (cognitive) radio technology made it possible to develop a cognitive radio that is able to recognize unused parts of radio spectrum assigned to conventional users and adapt its communication strategy to use these unused parts while minimizing the interference that it causes to the conventional users.

The first band that got attention of the spectrum management authorities for the introduction of this type of cognitive radio technology was the television broadcasting band. The reason for this attention was that the planning of broadcast stations in the television band is such that there is white space available in any given location at any time. As television broadcast stations make use of high power transmitters, there is a need for a large geographical separation between stations that use the same television channel and for a frequency separation between broadcast stations in the same geographical area, to avoid interference between broadcast stations. It is not possible to use the adjacent television channel in the same geographical area. As a result of this geographical separation and frequency separation there are typically unused television channels in any given area.

A transmitter that uses a low power level compared to the (high power) TV broadcast stations would not need a separation distance as large as another high power broadcast station for co-channel and adjacent channel operation. This creates possibilities for the introduction of additional usage of the TV broadcast band, albeit for low power transmitters. The actual channels that are available for additional usage will depend on the location.

Part of the white space is already used in the TV band for wireless microphones, an application that is closely related to broadcasting, as wireless microphones are used to support the production of content that is distributed via television. Any other additional (cognitive radio) transmitter that is introduced in this band will need to be aware of the authorized usage in the band, being not only TV stations but also these wireless microphones.

Spectrum management authorities in a number of countries developed rules to permit usage of these white space devices in the TV bands. The first spectrum management authority to do so was the FCC of the United States.[236] The activities from the FCC started with the publication of a Notice of Inquiry (NOI) in December 2002. In that inquiry, the FCC requested comments from industry on the unlicensed use of portions of the TV band at locations and times when the spectrum is not being used by authorized services. Allowing unlicensed devices to operate on unused TV channels would lead to more efficient use of the spectrum (FCC, 2002a).

After a review of the comments, the FCC published in 2004 a Notice of Proposed Rulemaking (NPRM). In this NPRM, the FCC concluded "*that there are technical options now available that make it feasible for new types of unlicensed equipment to share spectrum in the TV bands without causing harmful interference to TV broadcast or other licensed services operating within these bands*". Based on this conclusion, the FCC provided possible rules to permit unlicensed spectrum access to white spaces in the TV bands.

The FCC differentiates between two categories of unlicensed devices in its proposal to allow access to white spaces in the TV band: (1) lower power "personal/portable" unlicensed devices, such as Wi-Fi like cards in laptop computers or wireless in-home LANs, and, (2) higher power "fixed access" unlicensed devices that are generally operated from a fixed location and may be used to provide a commercial service such as wireless broadband internet access.

Fixed devices should either use geo-location technology such as GPS incorporated within the device to determine its location, or alternatively, the location of the device could be determined at installation by a professional installer. The location is used to consult a database with information on the availability of TV channels per area. Portable devices would receive this information transmitted by an external source such as a broadcast station or another unlicensed transmitter indicating which channels are available at its geographic location. Furthermore, the FCC was seeking information whether unlicensed devices could incorporate sensing capabilities to detect if other transmitters (TV broadcasting stations and wireless microphones) are operating in the area (FCC, 2004).

[236] See Anker (2013b) and the references in there for a description of the activities in various other countries.

In response to this notice the IEEE created the IEEE 802.22 Wireless Regional Area Network (WRAN) working group with an aim to develop a standard for unlicensed operation in the TV bands. The standard intends to provide fixed wireless broadband access in rural and remote areas. In first instance, the standard should incorporate sensing to find and choose unoccupied frequencies in the television bands (FCC, 2006).

In its First Report and Order and Further Notice of Proposed Rule Making in October 2006, the FCC came to the conclusion that there are possibilities for fixed low power devices to use these white spaces. Accordingly, the FCC made the initial decision to permit fixed low power devices to operate in the TV white spaces. However, the FCC was of the opinion that there is a need for more information before the final rules on the use of white spaces could be set. Therefore, the FCC requested additional comments on whether the operation of personal/portable devices should be allowed and on the means that white space devices, both fixed and personal/portable, should use to determine the availability of unused frequencies in the TV bands and the technical features and parameters of such capability to prevent interference to authorized services. The FCC was especially seeking comments on whether spectrum sensing could be used by these white space devices to determine if TV channels are unused. Based on the information gathered, the FCC would set the final rules and the FCC would consider whether appropriate provisions are to be developed to permit low power personal/portable devices to operate in the TV white spaces (FCC, 2006).

The FCC recognized that tests were necessary to determine the effectiveness of the interference avoidance approaches. The FCC invited interested parties to submit prototype devices for testing at the FCC Laboratory. Two prototypes were received by the FCC. The conclusion of these initial tests was that these prototypes do not consistently sense or detect TV broadcast or wireless microphone signals. The tests also concluded that the transmitter in the prototype device could cause interference to TV broadcasting and wireless microphones (FCC, 2007).

Rules to allow TV white space devices were adopted in a Second Report and Order in 2008. Both fixed and portable unlicensed devices were permitted to operate in the TV band at locations where that part of the radio spectrum is not being used by licensed services. All devices were required to consult a database to obtain a list of the permitted channels in their geographic location before they are allowed to transmit. The only exception to that rule is that portable devices are allowed to work in a client mode under control of another fixed or portable device which has access to the database. In addition, all devices must also have a capability to sense TV broadcast and low power auxiliary service station signals. Other requirements include the transmission of identifying information to ease enforcement in case of interference and the requirement for all devices to be certified by the FCC laboratory.

The FCC also allowed white space devices that do not access a database, but completely rely on spectrum sensing. The maximum transmit power is more limited for these devices and the devices will have to undergo rigorous testing to "*fully ensure that such devices meet a 'Proof of Performance' standard that they will not cause harmful interference*" (FCC, 2008).

In its Second Memorandum Opinion and Order of 2010 the FCC removed the requirement to include sensing technology to detect the signals of TV stations and low-power auxiliary service stations for white space devices that incorporate geo-location and database access. The white space devices may rely solely on geolocation database access to get information on the availability of white spaces in the area (FCC, 2010).

Subsequently the FCC issued a call for proposals for geolocation database providers. After evaluating the responses received from the interested parties, it conditionally designated nine entities as TV band database administrator in January 2011. The FCC granted preliminary approval to two entities to actually exploit a database, SpectrumBridge Inc. and Telcordia Technologies[237], in the first half of 2012. As of October 2014 there are five certified white space database administrators.[238] All white space database administrators have permission to offer database services for a period of five years.

The rules were further refined in a Third Memorandum Opinion and Order. The rules were changed in order to decrease the operating costs for fixed TV band devices and to allow them to provide greater coverage, thus increasing the availability of wireless broadband services in rural and underserved areas without increasing the risk of interference to incumbent services (FCC, 2012a).

Since the FCC made its first decision, there have been a number of experiments and small scale service offerings. However, white space usage never reached the scale as originally expected and is not expected that it will do so in the United States. The use of white spaces in the television bands is now shifted towards the provisioning of rural internet connectivity in rural areas in Africa (Standefort, 2015).

6.3 Analysis of the FCC process

Already from the beginning the FCC made it clear that it was seeking rules for unlicensed use of the TV band by white space devices. The proposed rules in the Notice of Proposed Rulemaking were an amendment of Part 15 of the FCC Rules.[239] Part 15 provides for the operation of unlicensed radio transmitters. This starting point makes the whole discussion on the rules to allow access to these TV white spaces device centric. This is also reflected in the original objectives of the FCC when proposing those rules (FCC, 2004: 2):
"the proposals set forth herein would provide for more efficient and effective use of the TV spectrum and would have significant benefits for the public by allowing the development of new and innovative types of unlicensed broadband devices and services for businesses and consumers."

The device centric focus of the FCC is an explanation for the FCC's prolonged interest in sensing. A device that solely uses sensing as a source of information to identify white spaces makes this judgment completely on its own without a need for contact with the outside world. All other sources of information that are proposed (a geolocation database or a pilot channel) make the device part of a network. In that case there will be a need to build infrastructure that has to be supported by the business case. Building of infrastructure would require an upfront investment. These investments will only be made if these can be recouped over a larger timeframe. This is easier if access to radio spectrum is on an exclusive basis through licensing.[240]

Notwithstanding that the FCC proposed unlicensed use of the TV white spaces in the Notice of Proposed Rulemaking in 2004, the FCC addressed the issue of licensed versus unlicensed operation and sought comments on the issue in the First Report and Order of 2006. In the Second Report and Order, the FCC

[237] Telcordia Technologies became active as a white space database administrator under the name of iconectiv

[238] See http://www.fcc.gov/encyclopedia/white-space-database-administrators-guide for a full list of white space database administrators.

[239] All rules and regulations from the FCC are contained in Title 47 of the Code of Federal Regulations. Title 47 is subdivided in a number of Parts of which Part 15 contains all rules on unlicensed use of radio transmitters.

[240] See further Anker (2013b) for a more extensive discussion on the influence of cognitive radio technologies on business opportunities.

came to the conclusion to proceed with unlicensed operation and not to license access to white spaces. However, this issue was dealt with from an institutional perspective. The FCC argued that a licensed approach is not practical. The FCC concluded: "*that attributes supporting the successful use of licensing would be difficult to accomplish here, particularly if we want to maintain our stated goal of not affecting the interference protection status of existing services*" (FCC, 2008: 19). The FCC deals with the main reason for licensing, creation of an incentive for investments, from the same perspective: "*With regard to the argument that a licensing regime would encourage investment in the provision of services using wireless spectrum, we observe the stability normally provided by exclusive licensing would be difficult to achieve for TV band device operation*" (FCC, 2008: 20). The FCC does not really address the question on the effect of that decision on the business opportunities for the exploitation of white spaces.

The FCC is crafting the rules in a process in which it tries to align the institutions with the technology. The process itself as followed by the FCC reflects a cautious step-by-step approach. After each step, private actors are invited to comment on the step taken. The received comments are reflected in the document in which the next step is taken. This is a transparent approach in which each actor is able to provide information on its interest. However, it is also an approach in which government (the FCC) is in full control of the process.

All decisions that are taken are part of this alignment between the institutions and the technology. The FCC is aware of this as is clearly shown in the Notice of Proposed Rulemaking. In its opening statement on the discussions about the proposed rules, the FCC asks comments on the proposed rules the FCC in the following way (FCC, 2004: 4):
"*We request comment on our tentative conclusions and proposals as set forth below. In particular, we seek comment and technical analyses relating to methods for avoiding interference to authorized services.*"

The FCC does not ask the question if private actors see a business opportunity in making TV white spaces available. The FCC is mainly interested in comments on the technology that can make these white spaces available within the given institutional setting of unlicensed use.

This focus of the FCC on the technology can not only be observed in the general discussion, but also in the more detailed discussions on the institutional setting. In the original ruling, the FCC proposed rules based on spectrum sensing. The FCC does extensive testing to see whether the technology is able to comply to those rules. If sensing does not seem to work, it is abandoned and a preference is given to other technology. This decision has great impact on the business opportunities. All remaining methods to identify white spaces make the device part of a network. In other words, a clear shift is made from device centric business opportunities to service centric opportunities. This effect of the decision on the intended business opportunities is not addressed by the FCC.

So, the question remains whether there is alignment between the objectives of the public actor (in casu the FCC) and the private actors. Since the public interest will have to be served by the intended business opportunities, the question then is if the business opportunities that are made possible by the rules to access white spaces can support the public objectives as defined by the FCC.

Already from the beginning, the FCC made it clear that the public objective was first of all more efficient and effective spectrum usage. However, the FCC goes one step further by defining the rules around two intended business opportunities. The intention was to make the TV band available for (1) white space devices to provide access for Wi-Fi like equipment, but more importantly also for (2) the provisioning of broadband internet access services in rural areas. Its intended use is above all to

provide more affordable wireless broadband access services (FCC, 2004: 2):[241]
"*allowing unlicensed operation in the TV bands could benefit wireless internet service providers (WISPs) by improving the service range of their existing operations, thereby allowing WISPs to reach new customers*"

This is also the first service for which standardization activities were started. The IEEE 802.22 wireless regional area network (WRAN) working group was formed in 2004. IEEE 802.22 was specifically formed to standardize technology based on the rules proposed by the FCC. The IEEE 802.22 WRAN standard aimed at using cognitive radio techniques to allow sharing of geographically unused spectrum allocated to the television broadcast service, to bring broadband access to hard-to-reach low-population-density areas typical of rural environments (Cordeiro, Challapali, Birru and Sai Shankar, 2005; FCC, 2006; Stevenson, Chouinard, Lei, Hu, Shellhammer and Caldwell, 2009).

The first question one has to ask on this business opportunity for rural broadband access is: Why is there no service provided at the moment? The main reason is not a lack of radio spectrum. The main reason is that the costs to provide the wireless service are too high in relation to the willingness to pay for the provided service. Under the FCC white space ruling, rural broadband access is made more feasible due to the fact that a lower frequency range is made available, which extends the coverage area of a base station compared to the existing alternatives to provide the service. However, the business case is only viable if the cost reduction is bigger than the additional costs associated with the new cognitive technology.

[241] The emphasis on the ability to provide affordable broadband wireless internet access services in rural areas is also to be observed in the statements of Commissioners that is attached to the NPRM and can also be observed in the subsequent FCC documentation.

Wireless internet services can also be provided by the existing mobile operators. Existing mobile networks operate at frequencies that are just above the television band. This means that the gains of using a lower frequency are limited. Therefore the business case must be based on a network deployment that is cheaper than that of a mobile network. Hence deployment of a wide area network based on white space access that covers the whole rural area remains questionable. It is much more likely that white space access will be used to provide localized access to the Internet at specific nodes. This is a business case that is comparable to Wi-Fi hot spot access, although over larger distances.

Typically, it is a service which is delivered by a so-called wireless internet service provider (WISP). A WISP provides a broadband internet service with a network based on wireless technology. WISPs are predominantly active in rural and remote areas where fixed internet access is not available.

Usually, the WISP brings an expensive (fixed) internet connection to a central point in the serving area. From that point, the connection to the customers is made through one or more base stations. Each base station has an antenna on an elevated point from which it is able to serve a number of customers. The customers have a router connected to a small antenna on a fixed position that is pointed to the nearest antenna site of the WISP. This connection serves as an (wireless) alternative for a fixed cable or ADSL connection. There are also possibilities to provide the broadband connection directly to the consumer devices. However, in that case the service area of an antenna site will be smaller and hence, there are more antenna sites needed to serve the same geographical area.

The next question is whether the capacity that can be supported by white space access is high enough to support the demand of the users. In areas where the required demand for capacity is bigger, the coverage area of the base station may have to be made smaller. This conflicts with the reason to make these lower frequencies available. This means that the business case will be restricted to areas with a population density below a certain limit. On the other hand, the population density may not be too low, because there must be enough customers in the service area of the base station to make a profitable business case. The limit will be lower if the demand per customer is higher. In sum, the business opportunities will be limited to areas where the population density is not too low, because there must be enough (potential) customers in the area, but the population density may also be not too high, because this will increase the cost of the network and will reduce the usefulness of these lower frequencies. A related point is, whether the assigned band will have enough white space capacity available for the intended application – broadband internet access – to support a successful business case. Moreover, the already limited capacity that is available for white space access is under pressure, because the FCC decided in 2012 to auction off part of the TV-band (the so-called 600 MHz band) for use by public mobile operators, based on a preceding incentive auction for TV licensees to give up their licenses (FCC, 2012b).[242] This will limit the available white space capacity even further.

The final question is if there are private actors (WISPs) that are willing to provide the intended service. When the FCC proposed to make use of a geo-location database instead of relying on sensing, a shift was made from a device oriented business case towards a business case where there is a need to invest in infrastructure to build the database and to provide the end user devices access to this database. Notwithstanding, the FCC retained the institutional setting of unlicensed access to white spaces. Moreover, there is limited white space capacity available and there are no guarantees to spectrum access in an unlicensed access regime. These factors will reduce incentives for private actors to invest in the infrastructure. This would explain why the intended service providers are relatively absent in the standardization activities and other discussions around white space access in the UHF TV-band and why the number of TV white space devices deployed as of the end of 2014 is still limited although the FCC has allowed access to TV white spaces since February 2009 (FCC, 2008).[243] Real commercial services were made possible in 2012 after the FCC permitted white space database administration to provide the necessary database services. In the same year, the FCC made some changes to the rules mainly to lower the cost for WISPs to provide broadband access in rural areas. However, the white spaces don't seem to attract WISPs to provide their service in rural areas. Moreover, in this institutional setting it is also not very clear what the business model for commercial operation of the database should be.

To conclude, there seems to be alignment between the institutional arrangements and the technology. The FCC took a very careful step by step approach to implement institutional arrangements that are aligned with the current state of technology. However, whether there is alignment between the public objective of the FCC to provide broadband access in rural areas with the objectives of the private actors remains to be seen. It is highly questionable whether the intended social objective will materialize in a viable business opportunity to provide wireless broadband access in rural areas and for the exploitation of the associated database.

Since the institutional setting is device centric, the technology may be more successful in the delivery of wireless (Wi-Fi) access within an in-house

[242] The incentive auction was proposed as part of the Federal government's plan to meet President Obama's mandate to free up 500 MHz of new spectrum for wireless services by 2020 (NTIA, 2010).

[243] The first (trial) white space network to provide rural broadband was launched in Claudville, Virginia in October 2009.

network. With the existing bands used to provide in-house Wi-Fi (2.4 GHz and 5 GHz) it is difficult to reach parts of the home as the range in these higher frequency bands is limited. It is in this lower frequency band much easier to achieve wireless connection in the entire house with transmitted power levels similar to what Wi-Fi uses today. This has the added advantage that the in-house network is already attached to the internet, which will make it easy for the white space device to connect to the database.[244] However, also in this case, the added value of using lower frequencies remains to be seen for a number of reasons. First of all, the device still has to connect to a database, whereas the business case for the exploitation of the database remains questionable. Second, the increased range will lead to a reduction in the throughput of the in-house network compared to an ordinary Wi-Fi device.[245] Last but not least, the market for Wi-Fi devices is a mass market with a huge existing installed base. The white space devices will be more expensive than an ordinary Wi-Fi device. It will depend on the availability of devices and on the price difference if customers are willing to pay for a white space device.

An alternative is to use cognitive radio technology to 'automate' the already existing opportunistic access to the band for wireless microphones. The use of cognitive radio technology will make the wireless microphone more expensive. The question is whether the added value of the technology is high enough to make this a viable business case? There are indications that this might be the case. When these microphones are used, it is already standing practice to make use of a type of sensing to find an available frequency channel. Currently, this sensing is based on a manual scan. This scan is time consuming and is performed before the microphone is used. If a cognitive radio device automatically performs a scan of available frequency channels, the costs associated with a manual scan falls away. In a number of scenarios the time to do an extensive manual search is not available, e.g. when the wireless microphones are used to provide a live report of an unannounced news event. In these cases, automatic scanning will give a better sharing of the white spaces among the wireless microphones with a lower probability of interference between these microphones.

Another much cited option, is the use of white spaces for machine-to-machine communications. If the M2M communications is restricted to fixed applications it is not very expensive to use a geo-location database for access. The location of the sensor can be programmed in the sensor. However, in order to allow for mobility there is need to include sensing, which restricts the communications to a rather low power level. The addition of sensing will make the device more expensive and raises the power consumption. This makes it less attractive for low cost M2M applications with cheap sensors and a need for an extended battery lifetime. Since there are no guarantees to spectrum access, M2M communications is restricted to applications which tolerate a rather high latency, such as meter reading. For such applications there is most likely enough capacity in the TV white spaces available to support the underlying business case.

6.4 A platform for coordination

The case of the FCC clearly shows the need for coordination to come to successful introduction of cognitive radio technology. The goal of the coordination activity will be to make the choices about the institutional arrangements and the cognitive radio technology such that there is alignment on two levels as demonstrated in

244 IEEE 802.11 published the IEEE 802.11af amendment to the standard in order to provide support for operation in unused TV channels through the use of a geolocation database in February 2014.

245 Due to the increased range there will be higher probability of overlap between messages from the various devices within the local network and hence a lower throughput.

chapter 5. First of all, there is a need for alignment between the institutions and the technology. Secondly, the specific choices on the institutional arrangement and the technology should be such that there is alignment between the objectives of both the entrepreneurial firm and government. If these objectives are aligned, these choices will enable viable business opportunities for the firm to realize its own private objectives and for government to serve the public objectives.

The dilemma that governments are now facing is that, since the liberalization, prevailing policy suggest a technology neutral assignment of radio spectrum, while enabling the deployment of a specific technology, i.c. cognitive radio technology, is of public interest to enable viable business opportunities needed to achieve more efficient utilization of the radio spectrum. It appears that in this light, regulation to allow deployment of a specific type of cognitive radio technology in parts of the radio spectrum that would otherwise be underutilized or not used at all is justified (Lemstra, Anker and Hayes, 2011).

Early involvement of government in the development of new technology can be observed in the historic episodes of chapter 4. In all episodes coordination through a standardization process started with an initial business opportunity in mind. In most episodes this business opportunity was related to the allocation of radio spectrum for a specific service. This is most clearly demonstrated in the case of the development of Wi-Fi. This process was started with the FCC decision in 1985 to allow spread spectrum technologies to be deployed for data communication in the ISM bands. Private coordination on useful exploitation of the band started after a firm –NCR– had a perceived solution for its customers' needs using the technology for which the radio spectrum was allocated.

There are several reasons why government could take the first step in this coordination effort. First of all, as stated, the government has a clear objective in mind for the use of cognitive radio technology: enhancing efficient spectrum use. However, for the realization of this objective it is dependent on the industry and service providers. Secondly, government has a greater degree of freedom. Government can directly influence both developments that are taking place in technology as well as developments in the market through institutional arrangements and industry policy. Thirdly, regulation is about giving certainty. Not only by restricting usage, but also by enabling and facilitating innovative use (Baldwin and Cave, 1999; Anker, 2010).

Government can facilitate this coordination activity through the initiation of a platform for coordination in which the equipment industry, the service providers and the government closely cooperate with the aim to find potential product-market combinations where cognitive radio functionality provides a 'value add' and determine whether these cases are attractive enough to be taken up by the industry as first applications of cognitive radio. This product-market "sweet spot" serves as a catalyst to both the private sector and government: for the private sector to develop products and services based on cognitive technology and for government to realize the ultimate objective of more efficient (shared) use of spectrum.

This platform can be considered as a Community of Practice. A Community of Practice is a platform where all interested stakeholders can share knowledge, information and practical experience (Wenger, 1998).[246] Such a Community of Practice can be regarded as a process of social learning that occurs when people who have a common interest in a subject or area collaborate over an extended

[246] Wenger (1998) describes a Community of Practice as a group of people whose members have a common interest in a subject, problem or goal; through collaboration and sharing of ideas, practices and knowledge, they improve their skills in a particular common domain.

period of time, sharing ideas and strategies, determine solutions, and build innovations (Lave and Wenger, 1991; Wenger and Snyder, 2000).

This Community of Practice can be used to explore Use Cases and to find a "sweet spot". The objective of this exploration is to determine whether these Use Cases are attractive enough to be taken up by the industry as first applications of cognitive radio, as first steps on the road toward broader deployment of cognitive radio technology.

There will be actors involved in this platform that have a different and possibly conflicting interests. Face-to-face communication in a platform can help the group of actors to gain a sense of "solidarity" and build trust between the members of the group. Group learning through information sharing, doing things together and having shared successes can over time take precedence over the differences within the group. Even among heterogeneous groups with significant differences in culture, ethnicity, wealth, and economic and political power, communication can increase identity and solidarity. Face-to-face communication can create at a minimum the shared perception of a consensus in favor of cooperation, and can in fact lead to actual commitments to cooperate (Ostrom, 2007a; Ostrom, 2010; Hoffman and Ireland, 2013). In these contexts, the initial role of government is to provide a collective action arena to facilitate face-to-face communication, group learning and cooperation.

6.5 Experience with a platform in the Netherlands

There is already some experience with a Community of Practice in the Netherlands. A Community of Practice related to cognitive radio (CRplatform.NL) has been established to facilitate coordination by the actors, being both private actors and the government. This initiative evolved from discussions on cognitive radio in two special sessions of the NFO (Nationaal Frequentie Overleg) in 2009 and early 2010. The NFO is the regular platform of the Ministry of Economic Affairs for interaction with the radio spectrum users and industry about radio spectrum policy. During the discussions it became apparent that the industry, the academic community and the government were all involved in activities surrounding the development of cognitive radio. However, it was noted that the participants were not aware of the activities of each other. There was a common understanding among the participants that the development of cognitive radio could benefit from information sharing and coordination of activities.

During the second NFO Special of January 2010, various forms and formats for a potential competence center were discussed. They ranged from a very light version of a knowledge portal on the internet to much more embedded and staffed variants. The participants had a clear preference for a format which included meetings with possibilities for face-to-face communication and discussion. To get started, the lighter format of a platform was chosen.

Based on these conclusions representatives of the ministry of Economic Affairs, the academic research community and the industry decided to initiate the CRPlatform.NL.[247] It was decided that the Delft University of Technology would chair the platform and accommodate the secretariat. The reason being that the University would be a neutral host without a specific interest in the development of cognitive radio.

The aim of the Community of Practice is to identify the uncertainties surrounding potential deployment areas of cognitive radio and to find ways and means

[247] The platform was initiated by representatives of the University of Technology Delft (TUDelft), Department Technology, Policy and Management, Section Economics of Infrastructures (W. Lemstra), the Ministry of Economic Affairs (P. Anker) and Marketing4B2B (K. Mioulet).

of addressing and reducing these uncertainties through discussions among stakeholders; thereby facilitating the successful deployment of cognitive radio based products and services. More specifically, the objectives of the Community of Practice are (Lemstra and Hayes, 2010):

- Sharing information regarding research, development and deployment of cognitive radio,
- Identifying the uncertainties surrounding the deployment of cognitive radio,
- Discussing ways and means of addressing and reducing these uncertainties,
- Advising the regulator regarding the needs of cognitive radio,
- Contribute to the successful deployment of cognitive radio based products and services.

The platform organizes meetings and workshops and has a repository on the internet with information considered useful for the participants. The main focus of the workshops is to explore potential application areas of cognitive radio, so-called Use Cases. Some of the workshops are dedicated to the state-of-the-art of the technology and to the theoretical framing of sharing spectrum through cognitive radio technology. Each workshop brought together potential users, industry, service providers, policy makers and regulators, as well as academic researchers.

The workshops on the Use Cases take the perspective of the user itself. The Use Case is introduced by the case owner. A presentation is given of the Use Case centered around the communication needs. The discussion that follows is centered around solutions to these communication needs and the question whether the use of cognitive radio has added value. The following application areas have been among the topics of a Use Case Workshop during the first two years: Container Terminals in the Rotterdam harbor; Special Events captured by broadcasting organizations; Public safety communications by the police force; High intensity communications at airports; and domotica. Moreover, manufacturers of cognitive radio and related shared access products and technology have had an opportunity to present their solutions, such as hybrid radio, professional wireless audio equipment and high-density Wi-Fi solutions.[248]

In these explorations, one of the first questions to be asked is what the added value is from the use of the new cognitive radio technology, and are these gains high enough to cover the increased cost of the use of this technology compared to the alternatives? The Use Cases as discussed suggest that cognitive radio functionality adds most value in situations that are typically niche applications or are a small segment of the overall market for wireless technologies. One of the reasons is the fact that cognitive radio technology is basically a technology to (more efficiently) share the radio spectrum. As cognitive radio provides additional functionality compared to current radio technology this will come at increased costs, at least initially. Situations of temporarily or local high-intensity demand are expected to provide the highest willingness-to-pay by the end-users.

The fact that the added value of cognitive radio is most promising in Use Case targeted at a specific market segment, or even a market niche will lead to a (relatively) low to moderate potential market volumes. This impacts the viability of the cognitive radio business case. Nonetheless, the Use Cases also show similarities, in particular if cognitive radio based solutions are considered as variants of a more generic cognitive radio platform solution. Especially the combined business case of the communication needs of the public safety services in case of an emergency and the registration of this emergency by news gathering organizations seems to be logical and promising. This became apparent during the Use Case Workshop on Special Events, as during (ad-hoc) events the needs of public safety and broadcasting

[248] A full list of workshops can be found at CRplatform.NL

converge at the same place and time. The type of communication needs show a strong parallel. Hence, pursuing solutions for one group of actors (broadcasters) should best be done cognizant of the needs of the other group of actors (public safety).

This example shows that finding a sweet spot for cognitive radio might be easier if the solutions for one group are similar to the solutions for the other group, at least on the technology platform level. This increases the addressable market and hence the viability of the business case. Investigations on the possibilities for a combined platform for public safety and broadcasting are ongoing. The unresolved issue is the very localized capacity needs during (ad-hoc) events. What remains to be better understood is the capacity issue and a perspective whether under the circumstances of the Use Case there are enough 'white spaces' that may be exploited.

One of the workshops on the exploration of the development of cognitive radio technology further disclosed hybrid or reconfigurable radio as a logical first step towards full cognition in the roll-out of new products and services. Experimentation with hybrid radio in the Rotterdam harbor area revealed that a hybrid radio that senses which mobile networks have coverage at the specific location and automatically selects an available network can greatly increase the availability of mobile services. The experiment revealed that the availability of mobile services can be increased to 99% as opposed to an availability of only 85% if a single mobile network is used. The availability can reach virtually 100% if the hybrid radio also includes satellite radio for locations where no mobile network has coverage (Ende, Brouwer, Borgonjen and Anker, 2010).

The small addressable market for the Use Cases further shows that a viable business case for cognitive radio will require other ways to realize economies of scale. This can be done by development of a combined cognitive radio platform for niche applications with comparable characteristics. However, it remains a market for niche applications. This extends the need for coordination to the European level, if not to the global level. Such coordination may still be left to be organized by the industry actors. However, the use case experience suggests that lacking a very compelling business case the likelihood that industry actors will take the lead is expected to be low. This ties in with the fact that discussions within the Community of Practice confirmed the role of government to facilitate this search for a product-market sweet spot.

6.6 How to proceed?

The experience within the Community of Practice in the Netherlands was focused on the exploration of Use Cases. This exploration revealed that there are uses cases in which cognitive radio can have added value. Hence there are possibilities to align the objectives of the private actors with the objectives of government.

The next step to take is to select a promising business opportunity for a more in depth analysis. This analysis will require a few additional steps to take. The first step is to find the objectives of the private actors willing to invest in this new technology. The questions to be posed are: "What is the added value of using cognitive radio technology?" and "Is the intended business case attractive enough to recoup the necessary investments in this new technology?" If there is an added value, the next step is about the relation between the use of the new technology and the institutional environment. This requires possible implications of the intended use of this new technology on the institutional arrangements and the other way around. Are there any barriers in the existing institutional arrangements to use this new technology? Has the new technology an effect on existing usage of the radio spectrum? In other words, how can the proper functioning of incumbent systems be assured if this new technology is introduced? This last question, is not just a question of institutional arrangements versus technology. The sharing of radio spectrum of an incumbent owner with cognitive radio technology may have an impact on the use of the radio spectrum by the incumbent. This means that it may also affect the private objectives of the incumbent and possibly related public objectives.

If the business opportunity is explored, the question is whether there are any requirements to the new institutional arrangements imposed by the intended business case, e.g. a need to have assurances about a time span over which the intended service can be provided that is long enough to recover necessary upfront investments? When the "sweet spot" is analyzed, the government should set up the associated institutional arrangements to enable it. These institutional arrangements encompass regulations on the frequency bands in which the new technology may be used, the possible need for a license and the conditions under which access to spectrum is allowed.

This in-depth analysis of a promising business opportunity will require a shift in the Community of Practice. The Community of Practice will have to shift from a broad platform to a more focused platform dedicated to the business opportunity. This will require the participation of interested partners involved in this particular business opportunity.

The Dutch experience revealed that there might be a need to scale the Community of Practice to the European level to reach economies of scale. The RSPG (Radio Spectrum Policy Group) has already recommended creating a platform to allow researchers, academia, manufacturers, operators, service providers and regulators to coordinate research activities in the field of cognitive radio. According to the RSPG, this platform could build upon already existing platforms with comparable purposes, notably COST-TERRA (RSPG, 2011).

This notion of the RSPG on COST-TERRA is quite relevant. The discussions within COST-TERRA were very fruitful. However, the COST-TERRA platform was rather academic in nature.

As the discussion within COST-TERRA was too academic, discussions will benefit from an extension of the platform to a Community of Practice that involves all stakeholders. In order to do so, the participation should be widened in two directions. Firstly, participation should be extended to service providers and users of spectrum. This may strengthen the discussions on the incentives for both the incumbent users and cognitive radio users and the impact of possible business cases of cognitive radio on the incentives of incumbent users. Secondly, participation should be widened to industry players to incorporate the ideas and solutions in the development of new technology and technology standards. In this platform all participants should work together with the national spectrum regulators to find and enable a sweet spot. The regulators can enable this sweet spot on a European level by specifying the necessary and specific regulatory regime in a European decision and/or European recommendation.

6.7 Business opportunities for cognitive radio

Both the institutional arrangements and the specific cognitive radio technology will influence possibilities for certain business opportunities and at the same time will pose limitations on other business opportunities for cognitive radio and dynamic access to spectrum. There is a need for alignment between the institutional arrangements and the specific cognitive radio technology to enable a business opportunity. The framework of chapter 5 poses that this alignment is necessary but not sufficient. There is also a need for alignment between the objectives of the private and public actors. This alignment will enable business opportunities that can serve the objectives of both the public and private actors.

Part of the problem with the white space regulations in the TV bands, is that is very hard to get alignment between the incumbent users and the secondary cognitive users. If the incumbent users of the band and the new cognitive radio users cannot come to an agreement about the use of the band it will be extremely difficult to introduce white space devices in this band. These rules will have to be set by the regulator in such a way that (a) the rules are strict enough to keep the interference to the incumbent user(s) below an acceptable level, but (b) these rules are not too tight in order to enable opportunities to use white spaces to communicate. Finding the right balance will be extremely difficult. Even if this balance is found, the use of the white spaces will remain difficult. It remains to be seen whether this band will have enough capacity for the application - broadband internet access - to be successful, as explained earlier.

Studies performed on the use of the UHF broadcasting bands for cognitive radio in Europe showed that the amount of white space available in Europe is even more limited than the amount of white spaces available in the United States. The reason is that the digital broadcast planning is more tight in Europe. Moreover, the TV band is in Europe already heavily used “opportunistically” for Program Making and Special Event services, especially wireless microphones. Furthermore, the upper part of the band has been made available as a harmonized sub-band for mobile use (ECC, 2008b). Hence, the amount of available spectrum for white space devices is far less than in the United States (ECC, 2008b; Beek and Riihijarvi, 2011). This amount is even further reduced in Europe through the decision of the World Radio Conference 2012 to extend the possibility of the use of the TV band for mobile services to the 694-790 MHz band.[249].

The problem to align the objectives of the cognitive radio user and the incumbent user may be easier to address in an environment whereby the cognitive radio users are licensed. Cooperation between a licensed incumbent user and known cognitive radio users will make the required coordination easier. Restricted access may increase the level of trust for the incumbent user and may make them more willing to share their white spaces with a known and trusted white space user. Restriction of access to white spaces to a specific user group provides the possibility for active coordination between the incumbent user and the secondary (white space) user about the sharing rules, i.e. the likelihood of interference and guarantees about access to spectrum. This will give the incumbent more control over the environment (Anker, 2010b, 2013b).

This type of sharing could be used to broaden the amount of accessible spectrum for users who need a guaranteed Quality of Service although only temporarily. This makes this type of sharing a perfect fit for e.g. Electronic News Gathering and other Programme Making and Special Events services. Electronic News Gathering only requires spectrum for short periods of time and for a restricted local area but it requires guaranteed access during the operation.

Another service that needs guaranteed access to spectrum but only in a very local area and for a short period of time is public safety. Public safety organizations have their own network for day-to-day operations. However during an emergency situation they have a huge demand for communications on the spot (Pawelczak, Prasad et al., 2005). A public safety organization might make an agreement to alleviate their urgent local needs with other frequency users.

[249] At the WRC-2012 there was only a preliminary decision made. This decision was made definitive at the WRC-015

In the agreement sharing arrangements are covered but the actual spectrum usage can be based on the local conditions and spectrum sensing of the local use of the incumbent user.

A good opportunity to start this form of sharing is in bands of the military. The military already have a longstanding practice of sharing with both the Electronic News Gathering community and public safety organizations. This may raise the level of trust to a level that is high enough to start an experiment (Anker, 2013b).

Eventually cognitive radio can help to create a spectrum commons in which the spectrum is dynamically and fairly distributed among all devices. Discussions within the proposed Community of Practice may help to find a specific type of application to focus standardization efforts and may help to develop a promising business opportunity.

These devices will opportunistically share the spectrum. A device will sense its environment before starting to communicate. Opportunistic spectrum access based on sensing will always have a likelihood of interference and there are no guarantees that an device can find an opportunity to communicate. The likelihood to find an opportunity will depend on the amount of devices and their communication needs in relation to the amount of capacity available. This sets limitations to the use and on the types of applications that can be supported. Since there is no need to build infrastructure there is a match with a device oriented open access regime of a commons. Opportunistic spectrum access based on sensing is expected to be restricted to low-end applications involving low power devices.

Opportunistic spectrum access can not only be used among devices itself but it can also be used to share bands between incumbent licensed users and unlicensed short-range devices in bands that were difficult in the classic scenario. Examples of this are the TV white space devices as discussed earlier in this chapter and the use of the 5 GHz band by radio local area networks (RLANs). RLANs use sensing to detect and avoid incumbent radar systems.

Sensing is also of interest to military users but for a completely different reason. A true sensing device acts solitary without the need for coordination with the outside world. This makes it possible to communicate without making the whereabouts and communication needs of the military radios known to others. This will make their communications less vulnerable.

A possibility to ease the problem of the (un) reliability of sensing is to start the introduction in a focused area. In other words to focus sensing for a specific application in a band that is not too-wide. The regulator should pinpoint a band for opportunistic spectrum access in cooperation with industry. To reach economies of scale this band could be designated on a regional level, for example on a European level (Anker, 2010b).

A very promising application for a true spectrum commons whereby unlicensed devices pool their spectrum is in-house networking. An in-house network is an ad-hoc network by its very nature. No two in-house networks are exactly alike and devices are turned on and off during the day, new devices are brought in, devices leave the house and the neighboring houses have the same ad-hoc way of working. The number of wireless devices in a household is rising while the users want to have new equipment that is “plug and play”. A new device that is put into service should be able to find its own possibilities to communicate within the in-house network. Opportunistic spectrum access can be used to realize this goal. A new opportunistic spectrum device senses its environment and coordinates its use within the local in-house network. A possible band to start is e.g. the 60 GHz band (Anker, 2010b, 2013b).

A second example of ad-hoc networking is the radio network between vehicles as part of Intelligent Transportation Systems (ITS). Restricting access to the pool for certain applications with a polite cognitive protocol, may alleviate the tragedy of the commons. If the number of devices becomes too large with respect to the available radio spectrum, the radio spectrum becomes of no use to all. However, even if a polite cognitive protocol is used and the band is restricted to a certain type of applications, the amount of radio spectrum that is made available must be enough to cater for the intended business case (Anker, 2013b).

As a next step cognitive radio can be used to make the market for spectrum more fluid. In a true property rights regime dynamic access to spectrum is obtained through buying, leasing or renting access rights from the owners of the spectrum. This regime provides the possibility for active coordination between the incumbent user and the cognitive user about the likelihood of interference, and on guarantees about access to radio spectrum. If the barriers to instant trading are removed, the opportunity to buy and sell rights to access spectrum can be based on the actual demand for spectrum. This creates the opportunity to use cognitive radio technology for higher valued services, such as mobile telephony, and for a spot market to be introduced. A spot market is a perfect means to acquire or sell rights to spectrum access based on the actual demand at any given moment in time (Anker, 2010b; Anker, 2010a).

This property rights regime can be used among operators to pool the spectrum in such a way that the rights to spectrum access are based on the actual demand for spectrum by their respective users. One of the suggested implementation scenarios is that mobile operators use a part of their spectrum to provide the basic services to their respective customers and pool the rest of their spectrum to facilitate temporarily high demands for spectrum. However, cooperation between mobile operators that are in direct competition to each other is not likely to happen (Bourse, Agusti et al., 2007). The private incentives of direct competitors will be very difficult to align.

This kind of sharing spectrum might be a more viable option for implementation in border areas to ease the problem of border coordination. Nowadays the use of spectrum in border areas is based on an equal split of the use of spectrum between neighboring countries through the definition of preferential rights. However, there is no relationship with the actual demand for spectrum at either side of the border. Cognitive radio technology may be used to split the available spectrum resources at the border based on actual demand. A prerequisite is that the spectrum market is introduced at both sides of the border or in a region, e.g., the European Union (Anker, 2010b).

Pooling radio spectrum between different services that are not in direct competition to each other might be a more promising approach. A property rights regime can help to make licensed spectrum that is not fully used available to others users.
In this case access to spectrum is based on an negotiable acceptable level of interference, instead of the worst case scenarios based on harmful interference that are used by regulators to introduce a new service in an already used band. This may open bands for alternative use which might otherwise be kept closed. The incumbent licensee may now have an incentive to open its spectrum for other, secondary, users. The incumbent licensee is in full control because it can earn money with unused spectrum, whilst the access to its spectrum of the secondary user is set by the incumbent itself based on its own conditions (Anker, 2010b).

Licensed owners of radio spectrum can also grant access to parts of their spectrum that they do not need in a certain geographic area and/or for a certain period of time to secondary devices. These devices can get access to this spectrum after an explicit request for permission to the owner of the spectrum. The owner will need a mechanism to facilitate requests from secondary devices for permission to use spectrum. Cellular operators can use their existing infrastructure to handle these requests. E.g. a mobile operator can set aside a mobile channel for this purpose. The owner of the spectrum and the secondary user can negotiate their own terms under which the secondary user may have access to spectrum. This provides possibilities for active coordination between the incumbent and the secondary user about the acceptable level of interference and guarantees to access spectrum (Anker, 2010b).

A spectrum market can only function if information about the actual ownership of the spectrum property rights is readily available to facilitate trading. The regulator is ideally positioned to perform the task to keep a record of the ownership of these rights. Inclusion of monitoring information about actual usage of spectrum can further facilitate trading by giving more insights in the possibilities for secondary usage (Anker, 2010a).

A second incentive might be to introduce easements in spectrum property rights. In other words, if a spectrum owner is in possession of spectrum that (s)he actually does not use, everybody is entitled to use this spectrum in an opportunistic way as long as the transmissions of the rightful owner are not subject to interference from this opportunistic spectrum access. This is an incentive which might prevent market players from hoarding spectrum (Anker, 2010a).

A special case of licensed spectrum pooling is pooling whereby a single operator who is the exclusive owner of the spectrum uses cognitive radio technology to perform a flexible redistribution of resources among different radio access technologies within its own licensed frequency bands to maximize the overall traffic by an optimum use of spatial and temporal variations of the demand. This could be used by mobile operators to realize a flexible spectrum allocation to the various radio access technologies in use or to have an optimal distribution of spectrum between the different hierarchical layers of the network. E.g. to realize an optimal allocation of spectrum to femto cells that takes account of the actual user demand without affecting the macro network. The prime requisite for such a scenario is that the license from the operator is flexible enough and technology neutral (Anker, 2013b).

6.8 Concluding remarks

To realize successful exploitation of cognitive radio technology there is a need for cooperation between public and private actors. Analysis of the recent introduction of cognitive radio in the US shows that radio spectrum management is too much focused on the alignment between institutions and technology such that (harmful) interference is prevented. It fails to address how government can realize its public objectives. Hence, there is a need for a radio spectrum governance process such that both government and the private actors can realize their respective objectives.

Exploring Use Cases can be a good instrument to bring all interested parties together and in an explorative modus to find and enable a “sweet spot” for the use of new technology to share spectrum. A “sweet spot” is enabled if the institutional arrangements and the specific cognitive radio technology are aligned in such a way that an intended business opportunity that serves the public interest can be realized. This exploration can take place in a Community of Practice. The national spectrum management authority is in a perfect position to initiate and facilitate such an exploration in a Community of Practice.

An initial exploration of possible business cases in a Community of Practice in the Netherlands revealed that the type of cognitive radio technology to be used and the appropriate institutional arrangement to support it depends on the specifics of the intended business case and the specifics of the users with which the bands will be shared. When a viable combination is found, the national spectrum regulator should set up the specific regulations to facilitate the CR deployment and thereby make an important step towards a more efficient utilization of the radio spectrum.

It is recommended to introduce this Community of Practice for Cognitive Radio on a European level. Such a Community could make use of, and build upon the experience acquired with the COST-TERRA platform. In order to encompass all interested stakeholders, this platform should be extended with representatives of service providers, user communities and industry players.

Experience in the Netherlands also found that lacking a very compelling business case the likelihood that industry actors will take the lead is expected to be low. The discussions within the Community of Practice confirmed the role of government to facilitate this search for a sweet spot.

7 Redefining the radio spectrum governance process

The lessons from the past and the alignment framework as introduced in chapter 5 suggest to shift the role of government from a controller of the spectrum management process to a facilitator of a decentralized spectrum governance process. Governance is thereby understood as a process by which policy is produced within multi-actor structures.[250] Government is considered as one of the actors in the process, an important one, but government is no longer in "command-and-control".

This chapter describes the consequences of this shift from a government controlled spectrum management process to a multi-actor spectrum governance process. A redefined spectrum governance process is proposed to implement this shift in the role of government. This redefined spectrum governance process is based on insights obtained from and builds on the institutional analysis and design framework of Ostrom et al. combined with insights from competitive market theory and uses the alignment framework of chapter 5. The central element of this proposed process is the alignment of the objectives of government with the objectives of the private actors.

Before this new process is expounded, this chapter will start with a reassessment of the radio spectrum management process and an assessment of the role of government. After the redefined radio spectrum governance process is explained, the consequences of this redefined process for the existing international spectrum management coordination arenas will be discussed. This is followed by case

[250] See chapter 2.

> "Opposition brings concord. Out of discord comes the fairest harmony"
>
> Heraclitus
> Greek philosopher, 535 – 475 BC

descriptions covering recent experiences with this shift in the role of government in the Netherlands. One of the cases describes the process used by the Dutch government to develop radio spectrum policy in multiple rounds of interaction between stakeholders, including operators, manufacturers, users (private, business and governmental) and academia facilitated. The chapter concludes with observations on the implementation of this redefined process.[251]

7.1 Reassessing the radio spectrum management process

As explained in chapter 3, historical developments have led to a situation in which government has assumed a central role in the management of the radio frequency spectrum. In the resulting command and control regime government makes all the key decisions: on the allocation – which parts of the radio spectrum may be used for a particular purpose – and on the assignment – who may use these parts and under what conditions. The regime is based on the separation of the various radio services to avoid interference and hence on technical efficient use of the resource.

However, as concluded in chapter 5, the two alternative spectrum management approaches that have been proposed to cope with the weaknesses of the current regime, do not address and resolve all functions of spectrum management. The alternative approaches only deal with a shift in control from government to private actors in the assignment of frequencies. They take the allocation of spectrum and the definition of the boundaries of the (sub) resource as a given. Separation of the various services is still the basis of the radio regulations and the alternative approaches are implemented within this underlying structure. Hence, the introduction of property rights led to separate markets for specific services. The market for rights of use of the spectrum for broadcasting services, a market for rights of use related to mobile communication services, a market for rights of use for private mobile radio services, etc. government remains in command-and-control of the types of services that may be provided.

This is clearly demonstrated by the provisions for trading in the U.K. Trading has been made possible in the U.K. in 2004. Trading is limited to six different license classes (Akalu, 2014): business radio, spectrum access, concurrent spectrum access, broadband fixed wireless access - scanning telemetry, fixed services and public wireless networks. Trading is allowed, but the usage of the right is restricted to the strictly defined license class. trading has not been as successful as desired. The number of trades is rather limited relative to the number of potentially tradable licenses (Lemstra, Groenewegen, De Vries and Akalu, 2015). Professor Martin Cave, the chief architect of spectrum trading in the UK has been quoted as being “disappointed” by the number of trades (Akalu, 2010).

However, the number of trades in itself is not of relevance. The question is if trading, as implemented by Ofcom, serves its objective. Trading was in the U.K. proposed by Martin Cave to give incentives to firms to “*husband the nation's resources and direct it into the most profitable uses. Where demand grows for a service which utilizes spectrum, spectrum will increasingly be deployed for that purpose. Firms that do not utilize, or underutilize, spectrum will have an incentive to lease or sell it.*” (Cave, 2002: iv). In other words, trading was supposed to shift not only the decision about who uses the spectrum (the assignment), but also the decision about for what purpose (the allocation) from the government to private actors.

Most of the license classes are so narrowly defined that there is no possibility to change the utilization

[251] An adapted and abridged version of this chapter has been published as Anker, P. (2017) “From spectrum management to spectrum governance”, Telecommunications Policy. (https://doi.org/10.1016/j.telpol.2017.01.010)

of the resource to direct it to its most profitable use. Hence, the use restrictions of the license prevent realization of the stated objective. Due to these use restrictions, the license can be regarded as an integral part of the business case. As a consequence, most trading is to facilitate a change in the spectrum user rather than in the spectrum usage (Akalu and Arias, 2012). The experience with trading in the Netherlands is not much different from the situation in the UK. The number of trades of licenses is quite low and is typically part of the transfer of an undertaking. The only exception is that trading has been used as a correction mechanism after a primary assignment of spectrum rights for mobile communications (Anker, 2013c).

The same kind of observation can be made for the way in which the spectrum commons (unlicensed access) approach is implemented in Europe. The European legislation is very specific and based on the separate treatment of various applications. The Short Range Devices (SRD) Decision[252] of the European Commission is based on 14 harmonized categories of SRDs, of which 11 categories restrict the kind of usage, e.g. Radio Frequency Identification (RFID), (electricity, gas and water) metering devices and social alarm systems (EC, 2006, 2013). The SRD Decision covers 81 definitions for the use of a subband of which 43 definitions deal with a relatively small part of the spectrum between 27 MHz and 2500 MHz. The definitions identify specific applications, with associated power levels and mitigation techniques, many of which apply to the same frequencies. The specific regulations severely restrict change of use of the spectrum for new (innovative) applications (Kruys, Anker and Schiphorst, 2016).

[252] Decision 2006/771/EC on harmonization of the radio spectrum for use by short-range devices and its later amendments are commonly referred to as the SRD Decision.

Hence, both the implementation of exclusive spectrum usage rights and unlicensed access regulations severely restrict possibilities to optimize the use of the radio spectrum to changes in demand and technology. The implementation of both alternative approaches is such that coordination on the best use of the radio spectrum is not left to private initiatives, but is still within the remit of the government's command-and-control approach. As far as coordination on the type of usage takes place, this coordination is taking place in a very time consuming and non-transparent allocation process under control of government(s). It is at best coordination for the market instead of coordination in the market.

While the property rights approach and the unlicensed access approach are intended to introduce decentralized coordination in the radio spectrum management regime, the overall process is still a top-down process centered around the separation of services with the government in control. This leads to a situation in which the implementation of the alternative approaches is not satisfactory with regard to the objectives of government.

7.2 The current radio spectrum management process in the Netherlands

That the current spectrum management process is still a top-down approach can be illustrated by the spectrum management process in the Netherlands. Figure 7-1 gives an stylistic overview of this process.[253] The international allocations (1) and the transposition to the national allocations (2) are

[253] This stylistic overview is published in the Radio Spectrum Memorandum 2005. This Memorandum has been replaced by an new Memorandum in 2016 (Ministerie van Economische Zaken, 2016). This new Memorandum redefines the objectives of the Dutch government in radio spectrum management. The overall process, described above, is not fundamentally changed.

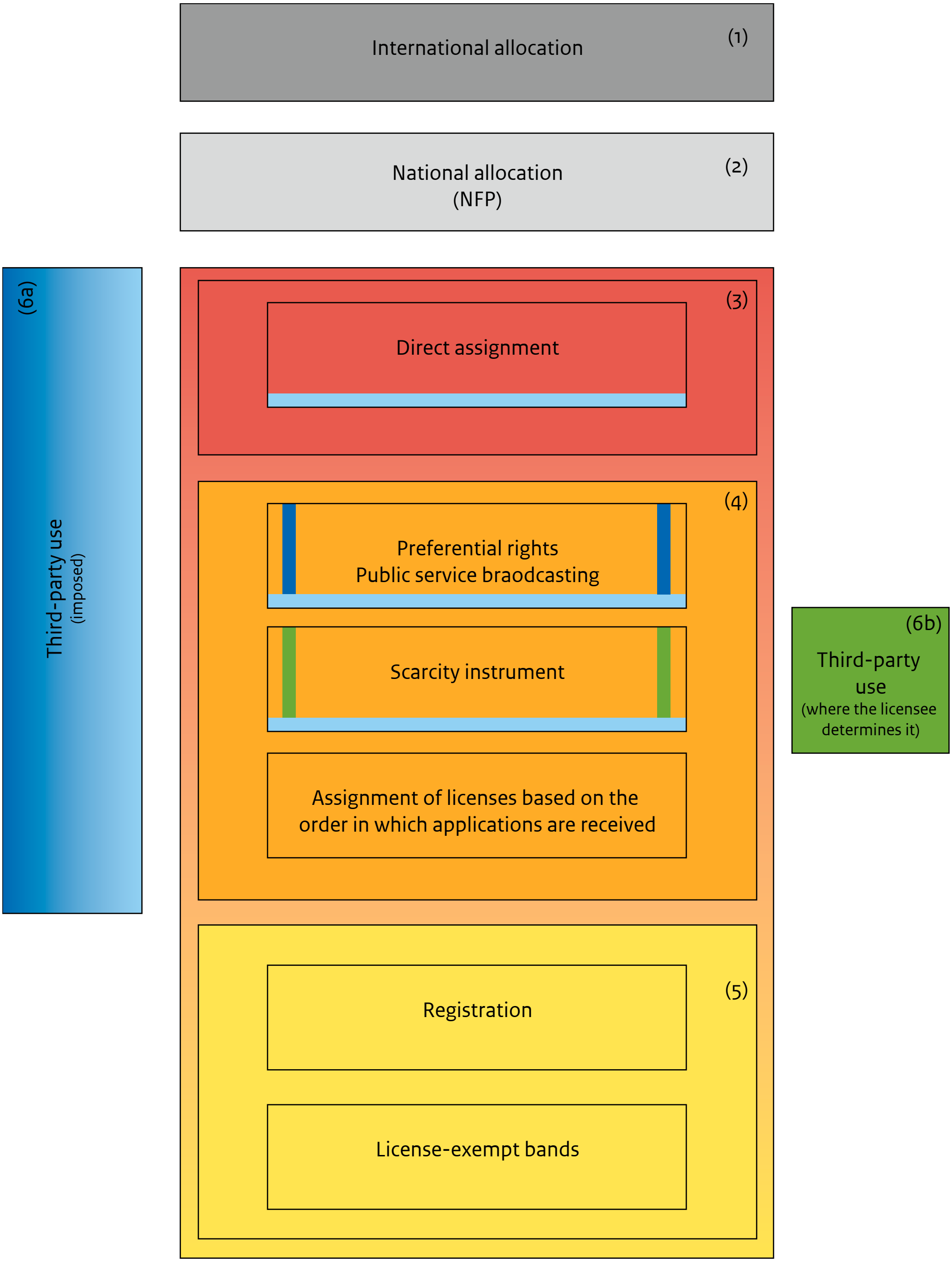

Figure 7-1 The spectrum management process in the Netherlands.

largely taken as a given.[254] The process starts with ensuring access to spectrum for services that serve the public interest. It encompasses services and applications concerning the country's safety and security, such as defence, emergency services, the police, air traffic management and vessel traffic control. In addition, it includes all other services and applications considered essential from a societal or cultural perspective, such as public service broadcasting or the use of the frequency spectrum for scientific purposes, including meteorology and radio astronomy.

The assignment of frequencies for public interest tasks is based on a needs justification plan (*behoefteonderbouwingsplan* or *BOP*). The radio spectrum assigned for public interest tasks will not always be fully used all of the time. This means that third-party use will be possible (6a). On the basis of the needs justification plan, it will be examined, in mutual consultation between the ministries involved, whether third-party use is possible and arrangements will be made about the conditions to be attached to third-party use.

The remainder of the frequency spectrum can be used for economic activities in a licensed domain (4) or in the license-exempt domain (5) (Ministry of Economic Affairs, 2006).

From this overview, the conclusion can be drawn that the spectrum management process is centrally managed under control of the government. The assignment of frequencies for commercial services and applications is embedded in a system in which first the allocation is made and second radio frequencies are set aside for public services. If this process is compared to the overall objective of economic efficient use in a decentralized market economy, the conclusion can be drawn that the process starts from the wrong end. It starts with the commanding and controlling role of government instead of the functioning of the market.

7.3 Redefining the role of government

From the above, as well as from the historic cases, the conclusion can be drawn that the overall radio spectrum management process is still a top-down process centered around the separation of services with government in control. It's a process in which the focus of government is on the definition of an institutional environment that is in alignment with specific technology and related services or applications such that (harmful) interference is prevented. The case of implementation of new cognitive radio technology in the United States as discussed in chapter 6 exemplifies this focus of government on the alignment between institutional environment and the technology.

The framework of chapter 5 suggest that although the alignment between the institutional environment and the technology is important, it is not enough. The outcome of coordination can only be successful if there is alignment between the objectives of the government and those of the private actors involved in the coordination activities with regard to spectrum governance. Hence, the starting point for a redefinition of the role of government has to be the objectives of government in this spectrum management process.

In that respect, it is not a coincidence that the debate on both alternative approaches for spectrum governance only got traction after the liberalization of the telecom sector started in the 1980s. Liberalization added the objective of economic efficient use to the set of objectives pursued by governments. It started a process in which free competition was preferred relative to a centralized

[254] The Dutch administration is actively involved in the international arenas on radio spectrum allocations. However, this aspect is hardly addressed in the Memorandum. The international allocations are taken as a given for the formulation of national spectrum policy.

organization of markets. Competition is thereby seen as an instrument to reach this added objective by encouraging industrial efficiency, an optimal allocation of resources, technical progress and the flexibility to adjust to a changing environment (Motta, 2004). Since then, proper functioning of the market became part of the public interests to be safeguarded. Governments rely on a market design and associated regulations to serve a mixture of economic and public objectives. Public objectives are supposed to be realized by the private actors.

The case study on mobile communications in chapter 4 provides a good example of this shift of governments towards this added objective of economic efficient use. One of the new objectives pertaining to mobile communications became the creation of a competitive market for mobile communication services. Auctions were introduced in several countries, whereby market forces determine who will own the rights to use the spectrum. The institutional change towards a system with private property rights as already proposed in the late 1950's by Coase perfectly fitted with this new objective for mobile communication services (Anker and Lemstra, 2013).

Decentralized coordination in the market is supposed to provide a solution to both weaknesses of the current "command-and-control" approach. Decentralized coordination is supposed to lead to more efficient use of the radio spectrum and the market is regarded as more adaptive to changes in demand as well as to changes in technology.
This ties in with the literature on the governance of common-pool resources. This literature provides evidence that a governance approach in which government is in "command-and-control" is not the most effective approach and may lead to economically inefficient exploitation of the resource. The main reason being that government lacks knowledge of the exploitation of the resource to be successful as the central coordinator in the governance of the resource (Ostrom, 1990; Baland and Platteau, 1996; Dietz, Ostrom and Stern, 2003).

Experience in the governance of common pool resources suggests that there are possibilities to devise decentralized coordination based on self-organization to govern the use of a common pool resource. However, this is based on field studies on local resources which produce a single, valuable resource-unit with a high level of predictability known to all participants. In that case, it is possible to devise marketable rights or other simple, allocation rules that enable individuals to make efficient long-term use of the resource (McGinnis and Ostrom, 1996).

In these single-use resources, participants share a common interest in the exploitation of the resource. The participants have a collective incentive to sustain the resource. Yet as many scholars have cautioned, local organization alone is no panacea. The survival and operation of self-governing local organizations are usually nested within, and conditioned by, a broader institutional setting (E. Ostrom, 1992; Tang, 1992; Lam,1994).
The literature suggests that this is especially the case for large and complex resources with multiple-use. Large and complex resources require more formal rules through government involvement (McGinnis and Ostrom, 1996; Libecap, 2005). One of the reasons for governmental involvement is the inhomogeneous use of the resource with a conflict of interest by users as a result.[255] This is illustrated in the historic case of chapter 3. Governments created single-use sub-resources within this multiple-use use complex resource of radio spectrum. This sub-

[255] Another reason for governmental involvement in a complex resource with inhomogeneous use, is that information about the exploitation of the resource is not shared among all users. See (McGinnis and Ostrom, 1996) and (Stern, 2011) for the difference between the governance of (single-use) local commons and multi-use complex global commons.

division of the resource into multiple single-use resources led to successful private coordination between the homogeneous users of the sub-resources which had a shared interest.

However, this sub-division of the resource leads to a suboptimal solution in which the coordination on the allocation of the sub-resources is in the hands of government as the prime coordinator of the spectrum resource. In the past, this sub-optimal solution in the exploitation of the resource was acceptable. Moreover, as discussed in the introduction, the regime is nowadays regarded as being too slow to cater for the rapid growing demand. There is a lack of accessible spectrum in the current spectrum management regime. In an economic sense, there appears to be a paradox. The available radio spectrum is fully allocated and assigned, while significant parts of radio spectrum remain unused in practice when considered on a time or geographical basis. There is a need for more intensive use of existing bands, by increasing possibilities to share bands among various services. Sharing of a band fundamentally changes the characteristic of the coordination problem. The resource is no longer subdivided in multiple single-use resources. In a multiple use resource coordination will become more difficult. In such cases government can facilitate decentralized coordination by providing a supportive institutional framework that includes dispute resolution, the capacity to enforce institutional rules and the provisioning of specialized information, with a mixed approach involving elements of individual property, common property and public regulations as a result (Ostrom, 1990; Pennington, 2013).

This continued need for government involvement is also affirmed by the proponents of alternative radio spectrum managements approaches in which (part of) the coordination is shifted towards private initiatives. However, the proponents are not completely clear in what this role should be. Both acknowledge that there is a need for formal, government defined, rules on the boundaries for the private or common property rights. This is a role that is related to the general role of government in modern society. Government provides a legal framework in which private coordination can take place and the government provides the means for the enforcements of these formal rules. However, the historic cases revealed another, more explicit, role for governmental involvement.

They revealed that the prime role of government in spectrum management is related to safeguarding the public interest. The public interest is not only related to economic efficient use of the resource but is also related to a specific interest attached to a service or application that uses spectrum, such as the use of a radio onboard an aircraft or a ship to safeguard safety-of-life in the air or at sea. The existence of a public interest in itself does not mean that there is always a need for the government to intervene with specific rules and obligations. Intervention will not be needed if the public objectives of the government aligns with the objectives of the private actors. In that case, the business opportunities of the private actors will serve the public interest and the role of the government can be confined to the provision of the legal framework and the enforcement thereof. This means that the role of the government in the coordination activities related to spectrum management will depend on the public objective(s) related to the service or application to be provided by the private actor.

In that respect, services and applications can be broadly classified as (1) Commercial goods and services, e.g. mobile telephony and radio local area network devices; (2) Social (non-market) goods and services that are beneficial to the society at large, of which scientific use and social alarm systems are clear examples and (3) Public goods and services, such as services for national security and safety. The set of public objectives attached to these three different classes of services and applications is distinctively different. This will influence the role of

	Public services	Societal services and applications	Commercial / private services and applications
Examples	Defence, emergency services, air traffic control	Radio astronomy, social alarm systems	Mobile telephony, fixed links, wireless connectivity
Governmental involvement	High Strict control	Medium Control of certain aspects	Low General functioning of the market
Governmental rules and obligations	Access to spectrum for public services or specific obligations attached to a license to guarantee public service delivery	Obligations attached to a license or in the allocation to the use of spectrum to assure provision of social goods and services	Competition rules
	Prevention of interference		

Table 7-1 A classification of goods and services and the role of government.

the government in setting up the institutional arrangements for these service classes. An overview of these classes is given in Table 7-1.

For commercial applications and commercial services, the role of government will be very limited and of a more general nature. The institutional arrangements will be related to efficient use of the resource and the prevention of interference. Efficient use of the radio spectrum is guaranteed by general rules on the correct functioning of private coordination in the market.

In case of societal services and applications the role of government will be more specific. The provisioning of the societal services and applications will have to be assured by a restriction in the allocation or by obligations in the rights of use. In case of public services the role of government will be even more strict to guarantee access to spectrum by these public services or by putting severe obligations in spectrum usage rights to guarantee public service delivery.

Some authors argue that both public services and societal services can be treated in the same way as commercial services in a private property rights approach.[256] They argue that radio frequencies are an input to the production function. This input can be acquired in the market, just like other inputs such as land and labor. However, this presupposes that there is a functional market for spectrum property rights. Since this is not the case at present, there will be a need for governmental involvement. However, this is not to say that public services and societal services will always need their own spectrum. There might be other institutional arrangements to guarantee public and societal service delivery, e.g. with obligation in a license for a commercial service. Government should be very clear and transparent in their objectives and why there is a need for specific obligations to guarantee the provision of these societal services and public services. The solution chosen for the provision of public services will depend from country to country as part of the political system within which government acts. This will be further discussed in section 7.8.

Hence, there are reasons for the continued need for government involvement in the governance of the spectrum resource. Government's role in this coordination effort is associated with three different

[256] See Cave, Doyle and Webb (2007) for a discussion on this subject.

categories of rules in the institutional arrangements: (1) to set the rules to enable market exchange, including the definition of the rights; (2) to preserve correct functioning of the market, including control of interference, and, (3) to realize societal or public objective(s). The first set of rules are the rules that allow appropriate functioning of the market, including the definition of the rights of use. The second category of rules are the rules to prevent market imperfections and to make actors behave conform the market rules. These rules will guarantee equality among the actors, will prevent abuse of power and will preserve correct functioning of the market. Most of these rules are the rules of fair competition embedded in competition policy. However, there will be a need for some formal and informal rules and regulations specific to spectrum governance. It may also include the provisioning of information, e.g. on the ownership of rights of use and the actual use of the radio spectrum to facilitate trading. The third category of rules are needed to adjust the market with specific regulations, to realize the governmental objectives if they are not an outcome of the decentralized market process. They contain rules that constrain market players by making very specific allocations or by attaching specific obligations to a license.

7.4 The case for a redesigned radio spectrum governance process

The governmental objective of safeguarding the public interests is not taken into account in the alternative approaches – neither in the property rights approach nor in the spectrum commons approach. The alternative solutions focus on coordination in the market or the use of smart technology to determine who (or what device) is allowed to access radio spectrum. They take interference as the core of the problem and provide an institutional solution (private property rights) or a technical solution (smart technology) to determine who (or what device) is allowed to access the radio spectrum without creating harmful interference. Although the alternative approaches were supposed to enable the market to direct radio spectrum use to its most profitable usage, this is virtually impossible due to the strict separation of radio services that is still in place to safeguard the public objectives. The safeguarding of public objectives through radio spectrum allocations have resulted in the current mixed regime that is way too rigid, as explained in the introduction of this chapter.

However, changes in technology make it possible to safeguard the public interests through other means than a strict separation of services. This solution, with a strict separation of services, was developed in a time that each radio service used a particular and dedicated technology. Hence there was a one-to-one relationship between the technology used and the service to be offered.

The main reason for this separation was that these radio services had different characteristics. This strict separation of services is associated with rules to define the boundaries between incompatible services to control interference between those services. It is a vertically integrated system in which every service had its own exclusive allocation.
This way of allocating radio spectrum made perfect sense in a time when technology made it possible to increase the size of the resource. New services where introduced in higher parts of the spectrum than in use for the existing services. However, this way of working has come to an end. New services can no longer be allocated in radio spectrum in even higher frequencies. New services will have to compete with existing services for radio spectrum.

This strict separation of the various radio services is not only undesirable, it is also no longer necessary. Nowadays, there is technology available that can be used to offer various services. A good example is the convergence of mobile communications and broadcasting. Current technology can provide both mobile communications services and broadcasting services over the same network. This convergence can be noted in both broadcasting technology as well as in mobile communications technology. Evolved Multimedia Broadcast/Multicast Service (eMBMS) has been introduced in 3GPP specifications to enable multimedia delivery, including delivery of TV broadcasting services over a mobile network (Lecompte and Gabin, 2012). On the other hand, specifications for digital TV broadcast (DVB-T2) provide possibilities to offload services, especially live video, from cellular networks over the broadcasting network (Gómez-Barquero, 2013; Rother, Ilsen et al., 2014).

A second example can be found in the convergence of some applications within the fixed service and the mobile service, such as fixed wireless access whose architecture has more in common with the architecture of a mobile network than with the architecture of point-to-point links. A third example is the ability of new mobile communications technology, especially LTE and 5G technology, to deliver a versatile and flexible mix of services that is tailored to the needs of a specific user group or a specific kind of usage. This includes the possibility to deliver public and societal services and applications that currently are provided through the use of dedicated spectrum allocations, such as public safety services (Public Protection and Disaster Relief) and services related to transport and traffic management (Intelligent Transport Systems).

Hence, this one-to-one relationship between service offering and technology is no longer valid. Nonetheless, the control of interference by the grouping of comparable technology in the frequency domain still is. The allocation could be broadened, based on the behavior of the technology in the frequency domain instead of the current practice of a separation based on a service offering. Broadly defined allocations create the possibility for the market to assure the economically best use of the spectrum without the need for a (lengthy) re-allocation process. In such an environment, application of the alternative approaches (property rights and a spectrum commons) leads to a situation in which some but not all public objectives pursued by the government can be realized. It is then the role of government to design the market such that the public interests are protected and its own objectives are realized.

7.5 Redesigning the radio spectrum governance process

In making decisions on the market design, governments will make decisions to protect the public interest and to realize their own (public) objectives. However, the government will need to take decisions, that make it possible for private firms to realize their objectives as well, as explained in chapter 5 and illustrated in chapter 6. It is through the actions of private firms, individually and collectively, that the governmental objectives will be realized. The institutional arrangements that are set up will have to provide the certainty to firms to invest in new technology and the exploitation thereof. If as a result of considerations of profitability firms decide not to use the system as intended, government fails in realizing its objectives. Hence the starting point for a redesign of the spectrum governance should be the objectives of the actors.

Since the liberalization of the telecom sector in the 1990s, governments rely on a market design and associated regulations to serve a mixture of economic and societal objectives. The public objectives are to be realized by the private actors. In the case of mobile communications, radio spectrum policy is used to create a market for mobile telephony and mobile internet access. Specific obligations may be attached to the licenses to serve public objectives, e.g. a coverage obligation.

The market is supposed to provide a solution to both weaknesses of the current command-and-control regime. Decentralized coordination in the market is supposed to lead to more efficient use of the resource and the market is regarded as more adaptive to change. This requires a shift in the role of government that can be regarded as a next step in the liberalization process which has not been recognized yet.

The role of government shifts from a government in control of a centrally managed spectrum management process to a facilitator of decentralized coordination in the market in a (multi-actor) spectrum governance process. The first role of government in this decentralized governance process is to design a market in which decentralized coordination can take place.

Government has to provide the legal framework and the enforcement thereof to create and structure a market such that decentralized coordination can take place and correct functioning of the market is preserved. Efficient use of the spectrum is guaranteed by private coordination in the market. Both property rights and unlicensed access are useful in this market design as they are applicable in different situations for particular types of services and applications.[257]

In the property rights approach spectrum is regarded as an input for the delivery of typically commercial services by a limited number of users, such as mobile communications or broadcasting, which require a large upfront investment. The provider of the service is only willing to pay for this investment if it can be sure that there is a proper return on investment. Exclusive usage rights will ensure that the owner can have access to spectrum for a period of time long enough to recoup the investments and make a return on his investments. The exchange of rights in a market is only feasible if the transaction costs are low. If the number of users becomes too high, the transaction costs may become prohibitive.

The spectrum commons approach is especially useful for device centric applications, where due to the unrestricted amount of potential users the transaction costs can become prohibitive. In this case, a general authorization will provide rules to restrict the behavior of the transmitter to prevent interference. Every manufacturer should be able to put devices on the market as long as the devices adhere to the regulations in the general authorization.

However, the alternative approaches cannot deal with the public interest attached to some usage.[258] Coase (1959) admits that there may be a need for special regulations in cases where the market is too costly to operate. Hence, it is not a matter of choosing the best (alternative) approach. It will be a mixed approach involving individual spectrum usage rights, unlicensed access and public regulations (Cave, Doyle et al., 2007; Freyens, 2009).

Starting point for this new approach will be a market design involving both property rights and unlicensed access, in which decentralized coordination can take place. Government can improve the functioning of the market by providing specialized information or by facilitating the market. Government may need to correct the market, with specific regulations, to realize public objectives if they are not an outcome of the decentralized market process. This shift in role of government with a greater reliance on market forces to realize the public interest may require an expanded role of monitoring to ascertain that the public interests is indeed served by the market (Groenewegen, Spithoven and Berg, 2010).

[257] See chapter 5 for a more detailed explanation of the applicability of both alternative approaches.

[258] Clear examples are air traffic control and applications which have to make use of very specific frequencies, such as weather radar radio astronomy and other scientific services.

7.5.1 Spectrum usage rights

The spectrum rights will have to be based on broadly defined allocations to assure that the market can steer spectrum usage to its economically most efficient usage. A broadly defined allocation shifts the boundaries for coordination to the definition of usage rights and rules to share spectrum between various technologies. The creation of the market requires careful attention to the definition of the rights, or to put it more precisely, defining the amount of interference that may be caused to other users within the band and to neighboring users in adjacent bands.

These spectrum usage rights are exclusive rights to use the spectrum. They can be regarded as (quasi) property rights. The difference is that the spectrum usage rights can either be revoked by the government or have a limited usage period in order to allow the government to enhance the functioning of the market if needed. These rights will be introduced and distributed to the market participants through a primary assignment of these rights, usually an auction. The auction rules should be carefully crafted in order to meet the objectives of the allocation and the objectives related to the spectrum usage rights. Clear and well formulated objective(s) are needed to come to a well-chosen auction design that fits these objective(s). In general, the main objective will be an economically efficient assignment. To reach that objective, auction rules will be needed to encourage price discovery and to prevent strategic behavior and collusion (Klemperer, 2002; Cramton, 2009). However, government may impose a spectrum cap or reserve spectrum for a newcomer, if this is needed to enhance the functioning of the market.

The central tenet of these individual usage rights is that trading will take place if this right can be used more efficiently by a new user than by the owner of the right. In order for decentralized decision making on the economically most efficient use to take place there is, as argued, a need for broadly defined allocations and clearly defined spectrum usage rights. In most cases trading requires prior approval from the authorities before trading may take place. If this barrier to instant trading is removed it will provide possibilities to develop a spot market. A spot market is a perfect means to acquire and sell rights to spectrum access based on the actual demand at any given moment in time (Anker, 2010a).

These (broadly defined) rights will also increase possibilities to share spectrum between the owner of the right and a secondary user who rents or leases spectrum in geographical locations or time periods for which spectrum is not needed by the primary user.

Historically, the technical conditions attached to the spectrum usage right were based on a particular technology and related service. This enabled government to optimize technical efficient use of the spectrum. However, this approach does not provide for any flexibility in the use of technology by the private actors and hence will limit possibilities for the transfer of rights in the market. Decentralized coordination on the usage can only take place if technical conditions are described in a “technology neutral” manner, e.g. by defining a spectrum mask which gives the boundaries for the transmission in the band and at the edge of the specified band.

Some efforts have been made in the past to come to a more neutral definition of spectrum usage rights rights to encompass the notion of technical neutrality.[259] Spectrum usage rights are nowadays defined through the use of a Block Edge Mask

[259] There have been several theoretical attempts to define spectrum property rights, however, none of them was adopted in practice (Cave and Webb, 2012).

(BEM).[260] The intention of the concept is to ensure that the spectrum right contains the least restrictive technical conditions. The spectrum usage rights are as far as possible independent of particular technology(ies) and of the service(s) to be provided. It should be noted, however, that the definition of the BEM is not completely independent of a particular technology and the service to be provided. The definition of the right is based on the service to which the band is allocated and related network deployment of a given technology. This will optimize the use of the spectrum right for a given technology and related applications. Other technologies may be used as long as the BEM is respected (ECC, 2008a). This concept of a BEM can be used as a basis for coordination in more broadly defined allocations. The actual choice of technology or technologies is left to the market participants, whereby coordination in the standardization arena will have to resolve any potential incompatibilities between the technologies proposed to be used.

The historic cases show that private coordination does not take place bilaterally between the individual affected users. Coordination takes place in a standardization arena, within a larger group of users and equipment manufacturers. Their primary incentive to participate in this coordination effort is to reach economies-of-scale. Standardization primarily deals with the (prevention of) interference between the users of the group, i.e. it only deals with the prevention of interference within the band itself. Hence, the main focus of government in the definition of spectrum usage rights should be on the rules to protect the surrounding users in the neighboring bands. If the owners of these rights are allowed to negotiate between themselves to adjust the boundaries of their spectrum rights, this would create as much flexibility as possible for the owners of spectrum rights.

Coordination on the type of usage should be left as much as possible to private coordination, e.g. in a standardization arena. Close cooperation between the government and private actors will be needed to come to a BEM that on one hand provides the flexibility needed to direct its use to the economic most efficient use but is stringent enough to protect users in the surrounding bands. In order to define the spectrum rights on the latest state-of-technology (of both the transmitter and the receiver) this cooperation will involve both potential operators for various services, as well as manufacturers and academic experts. This may lead to a situation whereby there are competing standards that can be used within the band, that comply with the spectrum usage rights.

Despite the effort, the current definition of rights is still very much controlled by government. A good example can be found in the European Decision on the harmonization of the 694-790 MHz frequency band for terrestrial systems (EU, 2016). This decision provides harmonized technical conditions for the use of the 700 MHz band for wireless broadband as well as conditions for the use of the duplex gap and guard bands which should provide for flexibility in the national usage of the duplex gap and the guard bands. However, the technical conditions are provided for a very limited set of services: wireless audio, public security services and Machine to Machine communications. The Decision is supposed to give the least restrictive technical conditions, but confines the use of these gaps to certain very specific services. Although the same conditions could be used to offer other kind of services (e.g. broadband private mobile radio, wireless cameras), these services are not allowed in the band. The decision gives only some flexibility on the national level to choose between a few specific services to be offered.

[260] Usually, a so-called block edge mask (BEM) is formulated. A BEM is an emission mask that is defined as a function of frequency relative to the edge of a block of spectrum for which rights of use are granted to an operator. It consists of in-block and out-of-block components which specify the permitted emission levels over frequencies inside and outside the licensed block of spectrum, respectively. See also Annex I.

It is does not provide for coordination in the market to direct the usage to its most economic usage. It is a clear example of a command-and-control regime at the European level.

The coordination effort to come to the least restrictive technical conditions should be widened. The type of usage should be left as much as possible to private coordination, e.g. in a standardization arena. Close cooperation between government and private actors will be needed to come to a BEM that on one hand provides the flexibility needed to direct its use to the economic most efficient use but is stringent enough to protect users in the surrounding bands. In order to define the spectrum rights based on the latest state-of-technology (of both the transmitter and the receiver) this cooperation will involve both potential operators for various services, as well as manufacturers and academic experts. This may lead to a situation whereby there are competing but compatible standards that can be used within the same band, which all comply with the spectrum usage rights.

7.5.2 Unlicensed access

The market for infrastructure based communication services can be augmented by a market for devices based on unlicensed access.[261] For example, the technology that is used by (mobile) operators with spectrum usage rights can also be used under a general authorization, although with a more restricted power level. This will lead to another kind of business opportunities. In the case of mobile communications, a market for low power mobile communication devices and applications can be developed, such as a market for in-house communication applications.

However, as already stated in the introduction, the current European legislation on unlicensed access to spectrum is very application specific and based on the separate treatment of various applications. Whereas, unlicensed access is supposed to provide unencumbered access to radio spectrum, it is oriented towards protection of vested interests. A good example can be found in the regulations on the 2400 – 2483.5 MHz band for unlicensed access. In this band there are 4 overlapping radio profiles defined for different kinds of applications. Hence, the European regulations are very application specific, favors one type of applications above the other, resulting in an unnecessary market barrier.

The regulations could be very much simplified by defining a radio profile and associated interference potential in terms of general spectrum utilization criteria, such as occupied geographic location, time and frequency, for a given frequency band – regardless of the technology or application for which the technology is used (Kruys, Anker and Schiphorst, 2016).[262]

More general, i.e. less specific, rules will provide private actors more flexibility to cater for changes in the demand for certain applications and will provide a lower entrance barrier for the introduction of new applications and new business opportunities by avoiding the need to enter into a lengthy process to change the regulations. These general rules based on the behavior of the radio will shift the coordination on the type of usage towards decentralized coordination, e.g. in a standardization arena to implement these rules in technology and to reach economies-of-scale. If actors fail to coordinate due to a large diversity of actors, the government can encourage, facilitate or mandate the development of a standard (see also section 3.3).

[261] Sometimes the terms license-exempt is used in the literature The term unlicensed access is preferred, because the term license-exempt has the connotation that it is an exemption of the (general) rule of an exclusive license.

[262] A simple example of two applications that are at the moment separated in the regulations, but have comparable radio profiles are a wireless doorbell and a (social) alarm.

Although standardization at the international level will typically lead to a time consuming process, it also has advantages. First, more general rules will provide more possibilities for new innovative technologies and applications to enter the market. Secondly, once a standard is set it is easier to adapt the standard to cater for advances in technology then to enter a process to adapt the regulations.

7.5.3 A market for niches

Currently, there are a large number of licenses issued on a "first come first served" basis for all kinds of specific services. Especially, the licenses for private mobile radio[263] and fixed wireless access could be used to broaden the market for communication services. These kind of services have very specific license conditions based on a historic approach in which these specific services were delivered through distinct technologies. However, the technologies for these services are now converging. Both fixed wireless access and private mobile radio can make use of the same type of (LTE) technology as used by mobile operators. LTE and especially 5G technology are assumed to accommodate the diverse connectivity needs of a wide range of business sectors (such as transport, logistics, automotive, health, manufacturing, energy, media, entertainment) and the public sectors (including smart cities, public safety and education).

Making the licenses more general will provide a possibility to broaden the market for wireless communication services with a market for niche players to develop specialized services tailored for specific business users groups by providing licenses with a limited geographical area of operation.

The ability to enter the market, although only on a local level, will make the market also more contestable. Baumol, Panzar and Willig (1982) demonstrated that in industries with no barriers to entry, the threat of entry would restrain incumbents' market power, and enhance competition.[264] Licenses for local usage will constrain the market power of the dominant (national) operators by the competitive fringe, which is important because the market for mobile communications tends towards consolidation. The dominant operators cannot behave as being protected by high entry barriers, but must take the activity of the competitive fringe into consideration. Hence there will be less need for government to regulate the behavior of the dominant operators (Church and Ware, 2000).

At the moment, these licenses for local usage are in most countries non-tradable. The argument is that there is no need for trading because licenses are not scarce and offered on a "first-come-first served" basis. Nonetheless, there are two good reasons to allow trading of those licenses. First, these licenses offer a possibility for niche players to start in a local area and grow towards a regional or even national player. Secondly, making these licenses more generic will make them more attractive. Although, they are not scarce at the moment they may become scarce in the (near) future.

7.5.4 A broad market for wireless communication services

A mixed approach with spectrum usage rights, (local) licensed access and unlicensed access combined with broad allocations and general usage rules will provide possibilities for: (1) gradual innovation from one generation of mobile communications to another by national operators based on exclusive spectrum usage

[263] Private mobile radio means the use of radio communications for business purposes within a company, e.g. a taxi company to have contact between the drivers and the central dispatching unit.

[264] The example of Baumol et al. (1982) of a contestable airline market was soon challenged by others. Although potential competition may not cause prices to descend to the competitive level, it may nonetheless provide some restraint on monopolistic pricing (Audretsch, Baumol and Burke, 2001).

rights, (2) delivery of specialized services targeted at a specific group of business users can be offered by both national operators and niche players based on a tradable (local) license and (3) small scale applications (e.g. in-house communications) and more disruptive innovations in unlicensed radio spectrum.

7.6 Informing the market

An essential element in decentralized coordination and decision making is the availability of information on the use of the resource and its variability over time (McGinnis and Ostrom, 2008). This information can lower the transaction cost (Dietz, Ostrom and Stern, 2003; Stern, 2011). This information on the ownership of spectrum usage rights and the usage of radio spectrum is also needed by government for monitoring and enforcement purposes. This brings government in a perfect position to gather information on the ownership and use of the spectrum not only for its own purpose, but also to provide this ownership and monitoring information to the market to facilitate coordination among private actors. This factual information about actual usage of the radio spectrum can not only facilitate trading but may also provide insights in the possibilities for additional (secondary) usage in bands which are already assigned to a rightful owner of a radio spectrum property right, but actually not used in a specific geographical area or time period. It is recommended that a transfer of a right is to be notified to the government. This information can be complemented by making also the price involved in this trade available to facilitate secondary trading even further.

Furthermore, government can provide additional information to reduce uncertainty for private actors by providing timely information on the availability of future radio spectrum for mobile communications, e.g. as the result of international negotiations at the World Radio Conference, on the timing of future radio spectrum auctions and on societal objectives of the government related to the use of radio spectrum. This can be accomplished through e.g. a spectrum memorandum or a memorandum on mobile communications, which states the government's objectives for mobile communications and provides information on the necessary tools to be applied, actions to be taken to implement those objectives and the timing thereof.[265]

7.7 Facilitating the market

If allocations are made more generic, the radio spectrum is no longer subdivided in a large number of multiple single-use frequency bands. A smaller number of wider frequency bands will be shared among various user groups. This will fundamentally change the characteristic of the coordination problem. In a single-use resource, the users share a common interest in the exploitation of the resource. In a multiple-use resource, the resource is shared among various user groups which may have conflicting interests. This makes coordination a multiple use resource more difficult, and may lead to a situation in which coordination does not take place (McGinnis and Ostrom, 1996; Stern, 2011).

One of the reasons for coordination not taking place is the existence of private information. The users of the resource may not share their knowledge about the exploitation of the resource for competitive reasons. Research has shown that the existence of private information will lead to a situation in which economic (Pareto) efficiency cannot be achieved (Baland and Platteau, 1996). Another important aspect is the existence of conflicting interests among the heterogeneous users of the complex resource with a lack of solidarity and a lack of trust as a result.

[265] See also section 3.4.

The government can as a neutral third party facilitate coordination among user groups with a conflicting interest. One possibility to do so, is to facilitate the development of a platform for resource use negotiation (Steins and Edwards, 1999). Face-to-face communication in a platform can help the group of actors to share information, gain a sense of solidarity and build trust between the members of the group.[266]

An historic example of the creation of a platform can be found in the history of GSM.[267] The European governments and the private actors shared an interest to develop a system for mobile communications that could provide services to a mass market at low cost. This led to the creation of ETSI, the European Telecommunications Standards Institute, in which manufacturers, operators, administrations and user groups cooperate (Lemstra, Anker and Hayes, 2011).

A forward-looking example could be a platform to define the requirements of mobile communications technology (LTE and its development towards 5G) for business critical applications and public safety, i.e. mission critical, applications. Governmental involvement may be needed to assist sectors to formulate their requirements and to bring different sectors with comparable requirements together. A common set of requirements for various sectors may be needed to reach economies-of-scale and will ease standardization.

A government can also facilitate coordination by bringing private actors together to ease the standardization effort itself, or to subsidize research and development of new technology ahead of standardization and to strengthen the relation between research and development and radio spectrum users. Governments already subsidize R&D projects and within the European Union there is already a coordinated approach to research and development related to spectrum use in the EU funded framework programs (FP7, Horizon2020) and COST.[268] However, while the manufactures and operators are involved in those research programs, the linkage between those programs and the spectrum management community is rather weak. Information from the research within those programs could be used to make better informed decisions in the allocation process at the international level and to define spectrum rights and sharing rules.

7.8 Adjusting the market

Until now, it has been assumed that objectives of government related to the public interests are realized by the private actors, as a result of the alignment achieved between the objectives of both parties However, this will not always be the case. Hence, government may impose rules to realize the public interests. The rules to adjust the market will necessarily constrain the behavior of the private actor and the possible business opportunities.

The need for specific regulations to adjust the market is not only of importance when a decision on the allocation or assignment for a specific service is made. It may also be triggered by a change in the public interest itself. A good example is the provisioning of mobile communications. When the market was created, there was only a need for coverage in the cities and the roads in between. Nowadays, with the growing trend towards mobile and wireless communications, they may become an essential facility for the proper functioning of the society at large, with the delivery of services related

[266] See also chapter 6 for reasons why government could establish a platform.

[267] See section 4.1.3.

[268] FP7 is 7th Framework Programme funded European Research and Technological Development from 2007 until 2013. Horizon 2020 is its succesor for the years 2014 – 2020. COST is a European platform for cooperation among researchers, engineers and scholars.

to e-banking, e-learning, and e-health (Osseiran, Boccardi, Braun, Kusume, Marsch, Maternia, Queseth, Schellmann, Schotten and Taoka, 2014). This means that the national availability of the once purely commercial service of public mobile communications will get a societal interests attached to it. This may for instance necessitate regulations to assure coverage by a mobile network in commercially unattractive areas.

Currently, services related to the public interest are in many cases safeguarded by allocating dedicated spectrum to these services. However, the current technology allows to shift this coordination to the assignment and standardization arena to enhance possibilities for the market to deliver those services and to provide more flexibility. A good example can be found in the implementation of a set of PPDR (Public Protection and Disaster Relief) related services in the current and upcoming releases of LTE. This applies more broadly for the development of the next generation of mobile communications (5G). This 5th generation of mobile communications is expected to support not only the increase in mobile data volume but also to broaden the range of application domains that mobile communications can support beyond 2020.[269] This includes the possibility to deliver public and societal services and applications that currently are provided through the use of dedicated spectrum allocations, such as public safety services (Public Protection and Disaster Relief) and services related to transport and traffic management (Intelligent Transport Systems).

Hence, narrowly defined allocations are not always needed to cater for public and societal services.

However, there may be a need for governmental involvement in the standardization to assure that the system will be able to support the requirements associated with the public task or societal service. This is the case if the public objectives are not compatible with the objectives of the private actors. Interconnection and interoperability are examples of public objectives that were in the past a reason for a combined standardization effort which led to the development of GSM. Nowadays, these public objectives align with the private objectives and are reached through standardization because of the need for economies-of-scale.

Other public interests can be realized by putting additional restrictions or obligations on commercial services or applications. A government must be very careful to do so. The effects of governmental intervention will never be neutral. These regulations will impose limitations to the business opportunities. Hence, they will influence the proper functioning of the market.

As a matter of 'last resort', there might be a need for a narrowly defined allocation to protect the use of radio spectrum for a particular service under all circumstances. This 'command-and-control' approach can involve an exclusive license or unlicensed access. This is especially the case for applications that need very specific frequencies, such as radio astronomy or a weather radar or for services that are essential for the functioning of the society, such as air traffic control.

The question is whether business opportunities can materialize if these additional restrictions are imposed? In other words, will the incentives of the private actors to exploit the spectrum align with the public objectives imposed on this exploitation? This is most easily explained with an example. A spectrum usage right for mobile communication services may include a coverage obligation to assure

269 This shift in service offering of a mobile network from a generic mass market service towards more specialized service offerings is already starting in the existing networks based on the 4th generation (LTE). The next generation of mobile networks will have more enhanced capabilities to differentiate the service offering based on the actual requirements of the customer.

nation-wide availability of the service.[270] However, if the coverage obligations is too strict, in terms of geographical area or in the time within which the coverage must be reached, the obligation can become a hurdle for new entrants or even a hurdle preventing the service to be provided.

Another example can be found in the auctioning of the D Block in the 700 MHz auction in the United States in 2008. The (commercial) D-block licensee had the requirement to develop a shared nationwide broadband network for both commercial use and public safety use, whereby public safety users could pre-empt the commercial services during emergencies. The auction of this block failed. There were no sincere biddings for the D-block received during the auction (Bazelon, 2009). The conclusion can be drawn that the rules were too strict and the pre-emption created too much uncertainty for a private actor. This suggests a mis-alignment between the public objectives and the objectives of the private actors.

Successful alignment is only possible if the government is aware of the intended business opportunities and private actors are aware of the public objectives, i.e. the government should be very clear about the public objectives it wishes to realize. Only then private actors will be able to make a fair judgement of the opportunities and the government can impose realistic conditions. In other words, information on the preferences of all participants must be shared and regarded as common knowledge. When this information is not available, coordination will become difficult, even if the participants have a common goal (Ostrom, Gardner and Walker, 1994).

This information may not only be acquired in a community of practice, but also in consultations, or surveys. The involvement of the private actors will help government to make informed decisions that are aligned with the objectives of the private actors. Incorporation relevant views will also build trust and avoid conflicts during the policy formation process. This may prevent delays and even fatal breakdowns further down in the process.

As stated earlier, a government must be very careful in the considerations to put additional restrictions or obligations on commercial services and applications as it will influence the functioning of the market. It will depend on the political system within which government acts to what extend specific public objectives will be formulated by government. Government may act mainly as a so-called “regulatory state” or as a “developmental state”.[271]

Government in a role as a regulatory state will operate at a distance. The emphasis will be put on the correct functioning of the market. The regulatory state supervises the process. The government intervenes based on strict rules of competition. It monitors and in case it discovers inconsistencies it does not intervene, but feeds information back into the system.

Government in a role as a developmental state will be more influential and hence more emphasis will be put on the formulation of public objectives and the realization thereof. Government develops, often in consultation with the private actors, a vision about the desired future. Government defines the objectives and the instruments to be used to realize that vision. Such a government is well informed, is an authority in society, and usually well respected because of its power to guide and direct structural developments (Groenewegen, Spithoven and Berg, 2010; Lemstra and Groenewegen, 2012).

270 Economides (1996) found that “[p]erfect competition will provide a smaller network than is socially optimal”.

271 The term “developmental state” was introduced by Johnson (1982) to characterize the role of the Japanese government in Japan´s unexpected post-war success in economic growth.

No matter whether a government acts more as a regulatory state or as a developmental state, in either case the involvement of the private actors in the policy formation process are essential to provide information to the process to aid the smooth implementation.

7.9 The expanded role of monitoring

In both the regulatory and the developmental perspective, having created the market, a key responsibility for governments is to monitor the proper functioning of the market. Monitoring will become a more central aspect of the work of the government as a facilitator of decentralized coordination. The functionality of monitoring will be broader than the classic role of monitoring for enforcement purposes usually associated with radio communications. Rules require enforcement to be effective (Kiser and Ostrom, 2000). Monitoring of the activities of the private actors in the market for service provisioning and their use of frequencies is thereby needed to judge whether private actors behave as supposed and expected.

Monitoring will be needed also to provide general information on actual usage of the radio spectrum to lower transactions costs. Last but not least, monitoring will be required to validate whether the public objectives are met through the exploitation of the resource by the private actors. This will require another kind of monitoring. It involves general monitoring of the functioning of the market as well as more specific monitoring that is related to the stated public objectives.

Monitoring information may be incorporated in a periodic review and revision process of spectrum policy and captured in a Spectrum Policy Memorandum, which takes into account (1) changes in the public interest; (2) technological advances; (3) changes in market circumstances; and (4) changes in market demand. This memorandum should incorporate a vision of government on the development of the market, including the public objectives to be realized.

7.10 Consequences on the international level

Implementation of this redefined spectrum governance process will have implications for the coordination on all three levels that can be identified in radio spectrum governance being on the worldwide level, the European (regional) level and on a national level.

7.10.1 Coordination on a worldwide level: ITU

The International Telecommunication Union is the worldwide coordination arena for spectrum management. Coordination at the level of the ITU focusses on the allocation of the radio frequency spectrum. Interference is often given as the primary reason for this allocation of spectrum. This is clearly demonstrated by the text of the ITU Convention on the purpose of the Union:

the Union shall in particular:
a) effect allocation of bands of the radio-frequency spectrum, the allotment of radio frequencies and the registration of radiofrequency assignments and, for space services, of any associated orbital position in the geostationary-satellite orbit or of any associated characteristics of satellites in other orbits, in order to avoid harmful interference between radio stations of different countries;

The allocation by the ITU is based on strict separation between over 40 different kind of services. There were already some efforts made in the past to come to a more broadly defined generic allocation. However, these efforts did not lead to any result. Recent technological developments in especially mobile communications create an opportunity to turn the mobile service itself into a broadly defined service which can be used to offer both a generic service to the general public as well as specialized services for specific (business) user groups.

As said, recent developments in mobile communications technology (LTE and its development towards 5G) made it possible to deliver a versatile and flexible mix of communication services. Furthermore, there is broadcasting technology and fixed (point-to-multipoint) technology that use a network architecture that is in its interference potential comparable to that of the mobile service. This will blur the distinction between mobile services, broadcasting services and fixed service (excluding point-to-point links) even further. Most bands allocated to the mobile service already are also allocated to the fixed service. This could be extended with an allocation for the broadcasting service.[272]

It would be logical to integrate Study Group 6 on broadcasting services into Study Group 5 on terrestrial services.[273] The radio determination services (radiolocation and radio navigation) which are under the purview of Study Group 5 are in their interference potential more comparable with some of the science services which are dealt with in Study Group 7. It would be logical to relocate those services to Study Group 7. A more profound restructuring of the ITU-R Study Groups could be made based on the behavior of the radio transmitter and its interference potential (a radio profile). This would enhance possibilities to combine allocations of services with a comparable interference potential. It would mark a shift from a radio services based paradigm to a radio profile based paradigm.

Broadly defined allocations will ease the allocation at the worldwide level. Coordination at the worldwide level is very complicated and time consuming. A World Radio Conference is only held once in 3 to 4 years. Every World Radio Conference sets the agenda for the next one in order to allow for a study period to prepare for each agenda item. This means that the sharing studies will have to be done within this time frame of 3 to 4 years. This also means that changes to the allocation will take at least 3 to 4 years and in some occasions even 6-8 years to allow for coordination in preparation of a proposal for inclusion of an agenda item onto the agenda of the next conference.

Currently the preparation of an agenda item is done by the Study Group with the service under its purview. If broad allocations are made (e.g. broadcasting combined with mobile communications), there might be a need for a restructuring of the ITU which allows for studies done in a combined Study Group of all affected services, as explained above. Studies should then be more oriented towards the sharing rules which may make a combined allocation of those services possible. The most logical place for studies on sharing mechanisms and rules whereby services under the purview of various Study Groups are involved, is Study Group 1 which is tasked to perform studies on general spectrum management principles and techniques.

The administration have the decision power within the ITU. The industry itself has a good representation in the coordination activities associated with the international allocations. However, the research and development sector is not very well represented. There are a number of academic studies done on e.g. new technology to share spectrum and into new technologies which might require spectrum. Information on this research could be used to make better informed allocation decisions which take account of the latest state-of-the-art in technology.

More narrowly defined allocations should only be made if justified by a need to protect a public interest. There are many occasions in which economies-of-scale are used to justify a more specific allocation. However, economies-of-scale can be reached through coordination among private actors within a standardization arena. A good example can be found in the identification of bands

272 This statement refers especially to the mobile downlink part of the allocation. The distinction between a mobile downlink and a broadcasting link is becoming blurred.

273 The working structure of ITU-R is provided in Annex 1.

for the next generation of mobile broadband communications. Most of the targeted bands already have a mobile allocation. The main objective of identification of bands is to reach economies-of-scale. This objective could also be reached by private coordination in a standardization arena (i.c. 3GPP).[274] This should provide possibilities for the WRC to focus its attention to the bands that are not already allocated to mobile communications.

The identification of bands for a new generation of mobile communications may still require sharing studies within the ITU, to enable a clear definition of the usage rights (especially to restrict interference to users in the adjacent bands) and/or to enable possibilities for sharing with other radio services for which the bands are allocated. This task can be performed within the Study Groups in close cooperation with 3GPP, the mobile industry and the stakeholders of the other radio services. This would provide a possibility to decouple the studies from the strict agenda cycle in preparation of the World Radio Conference, and associated time constraints.

This time constraint was an issue in the preparation of WRC 2015. In the preparation of the WRC 2015 agenda item on the identification of bands for the next generation of mobile communications, there were so many studies to be done that it was not possible to finalize all studies in time before the WRC in 2015. Hence, decisions on the identification of bands for the next generation of mobile communications had to be made on sharing studies that were not agreed upon and not finalized.

[274] The 3rd Generation Partnership Project (3GPP) is a collaboration initiative that unites 7 regional telecommunications standard development organizations. Originally, it was set up to define the 3rd generation of mobile communications technology. Nowadays, it is also involved in the definition of the subsequent (4th and 5th) generations.

This argument is even stronger for the World Radio Conference of 2019 where decisions are to be made about the identification of a large number of bands for 5G above 24.25 GHz. Most of these bands already have a mobile allocation, and the frequency bands are relatively high which eases possibilities for sharing.

7.10.2 Regional coordination on the European level

This one-to-one relationship in the allocation between technology and service offering can also be noticed on the European level. There are instances in which the broad ITU allocations are further restricted at the regional level, with a detailed allocation for a specific service or application. As stated earlier, the European radio spectrum regulations is very restrictive and in many instances very specific allocations are made. The European spectrum regulations should be focused on technical harmonization instead of service harmonization, based on broad allocations, and developed in close cooperation between the European regulators and standardization organizations.

One of the examples that is already given is the legislation on short range devices. This regulation could be simplified to lower the barrier for the introduction of new (innovative) applications. Another example can be found in the regulations on the allocation of bands for mobile communications. The regulations specify that the spectrum shall be used for the delivery of electronic communication services. This limits the possibilities and makes the licenses only attractive for the national mobile operators. More neutral regulations based on a purely technological harmonization would still provide economies-of-scale for the industry and users, but would also provide possibilities for niche players to provide specific applications based on the same technology as used by the national operators. An example is provisioning of company specific mobile services by a niche player that provides specific services to a targeted sector (e.g. for the agricultural sector or e-health) and mission-critical

Public Protection and Disaster Relief services to the police force and other emergency services based on mobile (LTE and 5G) technology.

Especially, realization of more generic rules for unlicensed access will not be an easy task, because the current regulations favors vested interests. The best starting place for this change would be by the Radio Spectrum Committee of the European Commission, as the working group of CEPT/ECC dealing with short range devices is heavily populated by industry members and hence will be more oriented towards protection of these vested interests.

More narrowly defined allocations are, as argued, only justified if there is a need to protect a public interest. There are many occasions in which the realization of economies-of-scale are used as an argument to justify a more specific allocation. However, as said coordination to reach economies-of-scale can be performed among private actors themselves within a standardization arena.

The European Commission could play a role to facilitate coordination by bringing private actors together to ease the standardization effort. This is especially the case in instances where specific services are to be offered that used to be based on a more narrowly defined allocation, such as Intelligent Transport System (ITS)[275] and Public Protection and Disaster Relief. European cooperation could help to bring the national user communities together and to define the requirements of those services and assure that the standardized technology has the capabilities that are required by the specific user communities. The need for European cooperation was also noted in chapter 6 in the discussion on new (cognitive radio) technology to share spectrum. Cooperation on the European level is needed to reach the economies-of-scale for the introduction of this kind of new technology.

Within the European Union there is already a coordinated approached to research and development related to spectrum use in the EU funded framework programs and COST. However, as already observed, the linkage between those programs and the coordination on spectrum management is weak.[276] The European Commission could further subsidize research and development of new technology ahead of standardization and strengthen the relationship between research and development and the spectrum management community.

Another point is that at the moment the necessary expertise to cater for the expanded role of monitoring is not available in all countries. Regional cooperation between the responsible national bodies can assist to build up the required expertise and to learn from each other's best practices.

7.11 Experience in the Netherlands

Although, there are changes to be made in the international arenas, there is already some experience with this shifting role of government in the development of spectrum policy at the national level. A first example is already given in the previous chapter on the introduction of cognitive radio. It describes the development of a platform for Cognitive Radio to facilitate coordination between both private actors and government for the introduction of this new technology. This Community of Practice has been established with support of government.

[275] Intelligent Transport Systems (ITS) include telematics and all types of communications in vehicles, between vehicles (e.g. car-to-car), and between vehicles and fixed locations (e.g. car-to-infrastructure). ITS is intended for a range of applications, including vehicle safety purposes, road tolling, information provisioning to the driver and entertainment for passengers.

[276] See also chapter 6 which noted a comparable point in the development of cognitive radio technology.

This section provides two additional examples which contain elements of the governmental role as recommended in the previous sections. The first subsection provides an example of providing information on the objectives for the market for mobile communications. The second example is more far reaching. It describes the process that was taken in the Netherlands to develop a new Radio Spectrum Memorandum to set the national spectrum policy for the next 5-10 years.

7.11.1 Strategic Memorandum on Mobile communications

In the Netherlands, the year 2010 marked a change with respect to the issuing of licenses for nationwide mobile communication services. The government was faced with the task to develop policy to re-assign licenses for mobile communications. The 900 MHz and 1800 MHz GSM licenses were due to expire in February 2013. Until that time all licenses issued since the liberalization were involving additional frequency blocks available for mobile communications. It started with the introduction of competition in the 900 MHz band with the issuing of 2 licenses for GSM. Since then, a new band was opened for mobile communications and licenses were auctioned for each new generation of mobile communication: GSM1800 in the 1800 MHz band, introduction of 3G (UMTS) in the 2 GHz range, followed by the introduction of 4G (LTE) in the 2.6 GHz band. The situation in 2010 was different. For the first time licenses for nationwide mobile communication services were due to expire. Since the spectrum to be (re-)auctioned was already in use by the existing mobile operators, a new policy objective was at stake: continuity of service delivery.

Monitoring and informing the market

The Dutch government decided to publish a policy memorandum on the overall market for mobile communications before any decisions were made about the re-auctioning of licenses for mobile communications. In the memorandum an overall policy objective for the mobile market was formulated.

To support policy making, the Dutch telecommunication regulator OPTA was requested to conduct an analysis of the mobile market in the Netherlands.[277] OPTA concluded that there was effective competition in the market for combined speech and data services. However, there was a risk of tacit collusion of the 3 incumbent operators. Therefore, OPTA recommended taking measures to facilitate potential entry in the market by lowering barriers to entry in the coming spectrum award process.

Based on this information on the behaviour of the incumbent mobile operators and on market consultations, the Dutch ministry of Economic Affairs published a policy memorandum on the market for mobile communications. This policy memorandum provided a vision on the mobile market for the next 5 to 7 years. It provided essential information to existing and potential mobile operators on the overall objectives of the spectrum award processes to be held in that period, as well as on the timing thereof.

The overall policy objective for the mobile market for the years 2011 – 2017 was set to have effective competition in the market for mobile communications, with a need to cater for both innovation and continuity of service offerings. This policy objective was confirmed by stakeholders in the consultation process.[278]

[277] The Dutch telecommunication regulatory authority is nowadays part of a larger regulatory authority, the Netherlands Authority for Consumers and Markets (ACM) which ensures fair competition between businesses, and protects consumer interests.

[278] A review process of this Policy Memorandum has been started in the autumn of 2016 to adjust the policy based on changes in the public interest and to changes in the market structure and conduct. This process started after the public objectives underlying the new Radio Spectrum Policy Memorandum 2016 were set (see section 7.11.2)

Designing the market

The policy objective stated in the Memorandum was further worked out in the auction rules. The auction had the existing 900 MHz and 1800 MHz band on offer as well as new (low) spectrum in the 800 MHz band. It was decided to reserve part of the 800 MHz band for a new entrant.

This reserved spectrum was acquired by Tele2, a company that was until then only active as a mobile virtual network operator on the Dutch market. The remainder of the available radio spectrum was acquired by the 3 existing mobile operators which already had an active mobile network. According to both the government and the four winners of radio spectrum, the auction was a success. The government´s objective of new entrance on the market was fulfilled and the remaining radio spectrum was reasonably evenly obtained by the three incumbents. All four winners said they had been able to obtain the amount of radio spectrum they wanted.[279] This successful outcome was confirmed in an official independent evaluation of the auction. Continuity of service had not been at risk due to the fact that all existing mobile operators had acquired enough spectrum. The transition from the old frequencies to the newly acquired frequencies was made in close cooperation between the mobile operators, the radiocommunication agency and the ministry of Economic Affairs (van Mil, Meuleman, Mulder and Huis in 't Veld, 2014).[280]

The government decided further to make spectrum available for license-exempt mobile communications in the 1800 MHz band, albeit at a low power level. Its intention was to facilitate niche players with innovative products and services. Its intended use is local, mostly indoor, specialised mobile communications applications and services based on small (pico and femto) cells as an wireless extension to the existing fixed telecommunication network at business premises (Anker, 2013). This decision fulfilled its expectations. Several smaller companies entered the market for in-house communications with products and services.

7.11.2 Development of a new Radio Spectrum Policy Memorandum

In the fall of 2015, the ministry of Economic Affairs started a process to develop a new radio spectrum memorandum for the coming 5 – 10 years. The process started with a meeting of the government with the stakeholders in which the results of an (external) evaluation of the current Radio Spectrum Policy Memorandum were presented. At that meeting, also the process to develop a new Radio Spectrum Policy Memorandum was presented and discussed with interested stakeholders, including operators, manufacturers, users (business, private and governmental), academia and others.
This general discussion on the radio spectrum policy was followed by more in-depth discussions over a period of 5 months along 4 different themes:

1. Scarce licenses,
2. Spectrum for market and government,
3. Unlicensed access and vulnerability,
4. Innovations in spectrum (technology) and spectrum management.

The discussions were organized in three rounds of interaction. The first session (diverging) was set up to explore the theme, to collect new ideas and to obtain the view of the various stakeholders. The second session (converging) was aimed to discuss various options and to find common ground in the opinions of the various stakeholders. The third session (concluding) was intended to come to a conclusion on the themes.

279 "Veiling eindigt met vier winnaars, Tele2 nieuwkomer", Telecompaper, 14 december 2012.

280 Legal arrangement were made for the situation that not all existing mobile operators acquired enough spectrum to assure continuity of service. In that case, there was a possibility to extend the duration of the old licenses to make a gradual transfer to the new situation possible.

Participation in the discussions was very good and very diverse, the sessions were populated by a broad representation of private and public stakeholders. There was a high degree of interaction between those stakeholders. The discussions led to various new contacts and follow-on discussions.

There were two remarkable notions put forward during the discussions. First, there was a broad understanding among the stakeholders that the use of radio frequencies has shifted in the last decade from a "nice-to-have" feature to a "need-to-have" integral and critical part of the business process. Nowadays, all kind of business processes are depending on reliable wireless communication services. Examples were given of the wireless communication needs at the airport, in the harbor area, in a (smart) city, in a hospital and for public safety and security by the police force. During the discussions it became apparent that there is a gap between supply and demand for reliable wireless communication services with advanced requirements. The service offering of the mobile operators were focused on mass communications and were not aimed at delivering services targeted to the needs and requirements of specific sectors. On the other hand, the demand from the various sectors are fragmented and the sectors are not capable to clearly articulate their specific requirements. Most of the stakeholders saw a facilitating role for government to bridge this gap between supply and demand.

Secondly, it was noted that the increased use of the radio spectrum leads to more pressure to efficient use of the radio spectrum. It was felt that there is a growing need for shared use of the radio spectrum, not only between private users but also between governmental users (such as the military, police forces and for traffic control) and between private users and governmental users.

The results of these discussions, as well as the overall objectives of the Radio Spectrum Policy were presented at a general meeting with the participants and other interested parties. In this presentation, it was announced that the new radio spectrum policy would mark a shift in the radio spectrum policy. The Radio Spectrum Policy Memorandum of 2005 was focused on the further liberalization of the market. While efficient use of spectrum will remain a key aspect of the spectrum policy, the strong dependence of society on wireless communications will require a shift towards facilitation of these societal developments. The increasing use of radio spectrum thereby creates pressure on the radio spectrum, necessitating more sharing and shared use.

The consequence of this shift in radio spectrum policy was worked out by the government in a new Spectrum Policy Memorandum. This memorandum was put into a consultation before it was adopted. A discussion with stakeholders was organized as part of the consultation. The Memorandum was very well received by the stakeholders. The new Radio Spectrum Policy Memorandum was sent to parliament at the beginning of December 2016. [281]

Additional results of these discussions are various initiatives developed by the participants. Munici-palities are now working on common requirements for smart city projects. The government has been asked to facilitate the start of these discussion. Furthermore, a discussion is started between the government and governmental users to develop a common "governmental broadband service". This service will most probably be partly bought on the market as a service and will be partly make use of "own" infrastructure. The government is facilitating the initial discussions between the governmental users and the mobile operators on this topic. As a second step, it might be broadened with business users for business critical communications.

[281] Nota Frequentiebeleid 2016, ministerie van Economische Zaken. Kamerstuk 24095 nr. 409, vergaderjaar 2016-2017, 8 december 2016.

During the discussions, it also became clear that there is a discrepancy between the wireless services that are offered in the market and the demand for specialized services. The existing CRPlatform.NL is used to discuss this gap between demand and supply. As a start, a discussion was organized to explore the use case of communications in academic hospitals, to obtain a better understanding of the requirements of specialized services and to bridge the gap between the demand and supply in a second step. These discussions also led to an private initiative for the formation of a user association for business critical mobile broadband applications.[282] This initiative is endorsed by the ministry of Economic Affairs.

7.12 Reflection on the redefined process

The redefined spectrum governance process can be regarded as the next and final step in the liberalization of the market for wireless telecommunication services. It is a process whereby the role of government shifts from a controller of the spectrum management process to a facilitator of decentralized coordination in a multi-actor spectrum governance process. The central element of the process is the alignment of the objectives of government with the objectives of the private actors. The focus of government will no longer be on the outcome itself, but on a clear formulation of strategic policy goals and public objectives followed by the facilitation of a process of learning and discovery in order to achieve these goals and objectives.[283]

[282] Kritische Mobiele Breedband Gebruikers (KMBG).

[283] This shift in the role of the government can be observed as being more general than only for radio spectrum governance. It is promoted as a general shift in the role of the government by the secretary-general of the ministry of Economic Affairs in his New Year address of 2016 (Camps, 2016).

This redefined spectrum governance process is made possible by recent advancements in technology, especially mobile communications technology. This technology makes it possible to provide public and societal services over the public mobile network instead of through the use of dedicated technology with their own dedicated radio spectrum allocations. This creates a possibility to broaden the allocations and hence for more flexibility in the use of radio spectrum to adapt to changes in technology and market demand.

The proposed process implements spectrum property rights and unlicensed access (spectrum commons) to optimize the functioning of the market. Government remains as a monitor of the system and can guide and adjust the market, if necessary. This requires an extension of monitoring to verify whether the market is functioning as supposed and to verify whether the governmental objectives related to the public interests are realized in the market.

Depending on the outcome, the market conditions may have to be adjusted. Alternatively, supply may not meet demand and vice versa as a result of high transaction costs. If these are search costs, governments may assist the market by providing information (e.g. by providing price information) or facilitating the interaction between market parties (e.g. by providing a register of radio frequency license-holders). If it concerns a lack of economies of scale, governments may assist through coordination (e.g. by stimulating standardization of products or services).

The proposed shift from spectrum management towards spectrum governance will be a transformation that will require a stepwise approach. The standardization of the next generation mobile communications (5G) offers a good starting point to take the first step.
The evolution of the 1st generation of analogue mobile telephony towards the 4th generation of

mobile broadband communications is different from the transition of the 4^{th} generation towards the 5^{th} generation. Mobile communications is now becoming a commodity and starts to encompass other services that used to have their own dedicated spectrum. This provides a good opportunity for governments to develop a new vision on the public objectives attached to the mobile service.

However, the market cannot instantly deliver all societal services and public tasks that are nowadays relying on their own infrastructure and dedicated allocations. It will require a careful assessment of the requirements of these services. A platform, facilitated by the government, can help to bring all interested parties together and assess the requirements. Only if the requirements of the various business sectors are clear, and technology and standards are capable of providing these requirements, there is a possibility to bridge the gap between supply and demand. To reach economies-of-scale there might be need for such a platform at the European level.

A platform can also help to build trust among various stakeholders to share radio spectrum within more broadly defined allocations. The importance of trust may be a reason to start new radio spectrum sharing arrangements, especially with new (untrusted) technology such as cognitive radio, in a licensed environment and not in an unlicensed domain. It will provide a more controlled environment whereby the device is under control of a licensed operator and the incumbent only has to deal with a limited number of new entrants in “his band”.

The focus of government as a facilitator of this redefined spectrum governance process will no longer be on certain predefined outcomes. The focus will be on a clear formulation of strategic policy goals and public objectives followed by the facilitation of a process of learning and discovery in order to achieve these goals and objectives. Achieving those goals in a complex and uncertain (changing) context requires a process in which different solutions are explored. The learning process is thus as important as achieving the stated goals and objectives.[284]

[284] This statement not only holds for government on the process of spectrum governance, but also holds for the author on the process of performing this PhD project on spectrum governance.

8

Summary and conclusions

This thesis is about the role of government in radio spectrum management. While current literature suggests that avoiding harmful interference and realizing economic efficient use of the radio spectrum are the prime drivers, the study revealed that realizing and safeguarding public interests have played a crucial role, including the realization of specific industrial policy objectives. Based on the insights obtained and building on the institutional analysis and design framework of Ostrom et al., combined with competitive market theory, the study proposes a revision of the radio spectrum governance process. Essentially proposing the next (and likely final) step in the liberalization process. The proposed revision redefines radio spectrum management from a top-down government controlled process to a bottom-up governance process in a multi-actor setting. The role of government shifts from a controller of the process to a role of market design, monitoring and facilitation.

This chapter provides a summary and the conclusions. It starts with a reflection on the approach taken. This is followed by the main findings. In the spirit of Elinor Ostrom, the main findings of this research can be divided into two kinds of lessons.[285] This research does not only provide substantive lessons on radio spectrum governance. It provides also a conceptual lesson: a framework for radio spectrum governance. These (combined) lessons have been used to propose a redefined radio spectrum

[285] Frischmann (2013) framed the large body of research and contribution of Elinor Ostrom in two enduring lessons. See further chapter 5.

"In literature and in life we ultimately pursue, not conclusions, but beginnings."

Sam Tanenhaus
Literature Unbound, 1986

governance process. The chapter concludes with some remarks on the implementation of this process.

8.1 A reflection on the research approach

Radio waves are used to deliver a broad range of services and applications, for instance, mobile telephony, radio and television broadcasting, maritime radio, research into the (birth of) the universe, and heating food in a microwave oven. However, it is not possible to use this resource without limitations. The use of radio waves at a particular frequency by one user will influence the use of the same and nearby frequencies, by other users at the same time. Radio receivers will have difficulty to distinguish the intended signal from all other signals it receives. This phenomenon is called interference. Hence, coordination is needed in the use of radio waves between the various users to manage the problems associated with interference.

Historical developments have led to a situation in which governments have taken the role of 'supreme coordinator' in the use of the radio spectrum. Spectrum management has become based on the avoidance of interference and technically efficient use of the spectrum. Over time the resulting 'command and control' regime led to a number of weaknesses. As recent measurement across many locations have shown, many parts of the radio spectrum are hardly used, when considered in space and time. Moreover, the regime is slow to respond to changes in market needs and to technological developments.

Two competing approaches have been proposed to improve the management of the radio spectrum: (1) an approach based on property rights; and (2) an approach based on a spectrum commons, i.e. unlicensed access with restrictions on the type of use or users. Both approaches are supposed to enhance economic efficient use of the radio spectrum through a shift from centralized coordination by government to decentralized coordination in the market.

Most of the debate seems to focus on the theoretical if not the ideological merits of the two alternative approaches 'property rights' and the 'spectrum commons'. To date empirical evidence does not demonstrate conclusively the superiority of either approach. The empirical evidence does lead to suggestions as to the conditions under which each approach might be deployed successfully. Hence, a new balance is to be sought between the various institutional arrangements, including the role of markets, private coordination initiatives and governmental involvement.

This thesis is intended to facilitate an in-depth debate on the best way forward in managing the use of the radio frequency spectrum. It starts with the premise that spectrum management is essentially an issue of coordination for which different solutions are possible. Historical developments have led governments to assume a dominant role in coordinating the use of radio waves. In relaxing their control over the use of the radio spectrum governments face a dilemma. On the one hand prevailing policy suggests a shift in control to enable efficient use of the radio spectrum, as a shared resource available to the society at large, and on the other hand government is uncertain whether private actors will develop the necessary degree of self-organization required to serve the public interests. This leads to the question how the public interest can be safeguarded if the radio spectrum management regime is shifted towards economic efficient use through decentralized coordination in the market and what the remaining role of government is if this shift in coordination is made.

To answer this question a closer look to the necessary coordination activities is required, and, under which circumstances coordination activities can be performed through market forces and can be left to private initiatives. An analytical framework is used to organize this investigation by specifying the general sets of variables of interest and their relationships. It provides a coherent structure to the inquiry to order material and to reveal patterns (Rapoport, 1985). The framework is based on the "institutional analysis and development framework" (IAD) as developed by E. Ostrom and others. This IAD framework has been developed to enable systematic analysis and design of institutional arrangements' and to compare alternatives (Ostrom, 2007b).

Analysis of historic use cases provide insights in the coordination activities related to radio spectrum management. The findings of the historic cases revealed two kinds of lessons. Firstly, substantive lessons on spectrum governance and secondly, and more importantly, it also revealed a conceptual lesson on the role of government, or more specifically on the connection between governmental actors and private actors.

The conceptual lesson provides an answer to an appeal by Blomquist and deLeon (2011: 5), as they state: "*The connections between governmental and nongovernmental actors themselves are ripe for examination using IAD*." And that is exactly what has been done for the specific common pool resource of the radio frequency spectrum. A new framework is proposed that can be used in the examination of coordination between the government and private actors. This framework which is derived from the substantive lessons on radio spectrum management is used to answer the research question and to propose a redefined spectrum governance process.

8.2 Substantive lessons on radio spectrum management

One of the first lessons that the historic cases revealed is the reason why government has taken the role as prime coordinator in radio spectrum management. This reason is not interference, but to safeguard the public interest. Analysis of historic use cases revealed that the public interest is related to specific interests that are attached to services or applications that use the radio spectrum, such as the use of a radio onboard an aircraft or a ship to safeguard safety-of-life in the air or at sea. Hence, the public interest is not just related to the general interest of economic efficient use of the resource.

Most advancements that have been made in radio spectrum management were triggered by problems with the public interest attached to a specific service in this multiple-use common pool resource. It started with regulations to cope with safety-of-life at sea and interoperability issues in a time that radio was primarily used for maritime wireless telegraphy. The uptake of broadcasting led to "chaos in the ether". A tragedy of the commons occurred which endangered the freedom-to-speech. The introduction of the broadcasting service was not compatible with the existing working routine to share the radio spectrum. All existing services were at that time a form of radio telegraphy service whereby sharing was possible due to the daily working routine of radio telegraphists to listen into a channel before a transmission was made in order to ensure that a channel was free. The characteristics of broadcasting did not align with this (informal) institutional arrangement. As a result, the uptake of broadcasting led to "chaos in the ether". This triggered the creation of the "command and control" regime in 1927. It is a regime in which the multiple-use resource is subdivided into multiple single-use sub-resources for the various radio services. Although the name "command-and-control" suggest otherwise, it is a diversified regime in which government is the prime coordinator, but part of the coordination is left to private actors themselves, outside the scope of government. This private coordination in standardization organizations and user associations is often overlooked in the debate on radio spectrum management.

The introduction of an approach with property rights was triggered by the deregulation and liberalization of sectors thus far characterized by publicly controlled monopolies, including the mobile telecommunications sector. The institutional change, that was already proposed in the late 1950s by Coase (1959), perfectly fitted the new public objectives attached to the liberalization of telecommunication infrastructure and the introduction of competition in the market for mobile telephony. Various countries chose to auction the spectrum rights for the second generation of mobile telephony.

The introduction of a spectrum commons approach also had its roots in deregulation. It was triggered by the decision of the FCC to allow spread spectrum technology for civil communication purposes. This decision enabled shared use of the radio spectrum by a large number of radio devices although over a relatively short range, such as wireless local area networks and wireless telephones. The decision of the FCC led to the (very) successful introduction of Wi-Fi. The coordination activities necessary to develop this wireless local area network technology were only realized after a private actor (NCR) had a private objective that materialized in a compelling business case. This private coordination took place in a standardization arena outside the scope of government. The private objective of NCR that triggered this coordination activity was compatible with the public objectives of the FCC with regard to its spread spectrum decision.

From these observations, the lesson can be drawn that there is not a simple solution to the radio spectrum governance problem and that there is not a single approach that can serve all purposes. The recent debate on private property rights versus a spectrum commons have blurred the road to come to a solution for the spectrum governance problem. It replaced the dichotomy of government regulations versus privatization with a new one of spectrum property rights versus a spectrum commons. The historic use cases show that both alternative approaches have their merits and are relevant next to the existing "command-and-control" regime.

In the property rights approach, radio spectrum is regarded as an input for the delivery of typically commercial services by a limited number of users, such as mobile communications or broadcasting, which require a large upfront investment. The provider of the service is only willing to pay for this investment if it can be sure that there is a proper return on investment. Exclusive usage rights will ensure that the owner can have access to spectrum for a period of time long enough to recoup the investments and make a return on his investments. The exchange of usage rights in a market is only feasible if the transaction costs are low.

The spectrum commons approach is especially useful for device centric applications, where due to the unrestricted amount of potential users the coordination costs can become prohibitive. In this case, a general authorization will provide rules to restrict the behavior of the transmitter to prevent interference. Every manufacturer should be able to put devices on the market as long as the devices adhere to the regulations in the general authorization.

This each alternative approach cannot deal with all aspects of radio spectrum management on its own is clearly demonstrated by the specific case of Guatemala. The radio spectrum management reform in Guatemala was inspired by Coase´s idea with the large scale introduction of property rights. It shows the success of this approach to trigger investments in mobile telecommunications infrastructure. However, the case study also shows some limitations to the private property rights approach. It shows the difficulty of this approach for the use of radio spectrum by short range radio devices such as Wi-Fi. It also shows the difficulty of the Guatemalan government to deal with the public interest, e.g. the public interest of "freedom-of-speech" related to the broadcasting service, especially the use of FM-radio by the various indigenous communities.

Hence, it is not a matter of choosing the best (alternative) approach. An approach combining individual spectrum usage rights, unlicensed access and public regulations will be required. This is comparable to observations from Ostrom and others with regard to the governance of complex common pool resources. Large and complex common pool resources require more formal rules through government involvement involving elements of individual property rights, common property and public regulations (Ostrom, 1990; McGinnis and Ostrom, 1996; Libecap, 2005; Pennington, 2013).

8.3 A conceptual lesson: A framework for radio spectrum governance

The substantive lessons do not provide an answer how to implement such a combined approach. To provide an answer a closer look to the coordination activities is required. This is leading us to the topic of the conceptual lesson (see chapter 5). The coordination activities required in radio spectrum management between actors do not take place in a static environment. If this were the case, the institutional arrangements as set in 1927 would still be sufficient. Coordination is triggered by the need to adjust to changes in one of the external variables. The biggest challenge of radio spectrum management is not in the allocation, the assignment, or in the control of interference as such, but in the need to adjust to change. This change can be of a technical nature, e.g. development of a new technology; or can be of an economic nature, e.g. to adapt to changes in the demand for services; or this can be of a political nature, e.g. a change in the public objectives.

In most literature on radio spectrum management, interference is put at the center of the discussion. However, it is important to realize that the control of interference is not the object of radio spectrum management, but the subject of a coordination activity which is triggered by the need to respond to change. All (public and private) actors involved in this coordination activity will have their own objective to participate.

The IAD framework posits that the behavior of actors in the action arena where coordination takes place is influenced by three sets of external variables: (1) the physical and material conditions, of which the characteristics of the resource, the services that are provided and the technology used to provide these services are important elements; (2) the characteristics of the formal and informal institutions; and (3) the characteristics of the (groups of) actors that are involved. The IAD framework further posits that if a change in the external environment occurs, coordination will take place to adapt to the new situation. Adaptation of the institutional environment to cope with this change, may require a coordination activity at the next higher level, e.g. coordination at the collective choice level may be needed to change the institutional arrangements at the operational level. In the case of radio spectrum governance, a coordination activity may not only lead to changes in the institutional setting (for the lower level), but may also lead to a technological solution, or to a mix of both institutional change and technological change. This role of technology as an outcome of coordination is largely neglected in the current literature on the IAD framework. This alternative of a technological solution instead of a institutional solution for the coordination problem deserves attention.

The exploitation of the radio frequency spectrum for the provisioning of products and services can be regarded as a complex sociotechnical system. These systems involve multiple actors, contain technology subsystems and components central to

its performance and have societal, political and economic relevance and impact. They are dynamic in the sense that they are constantly changing and adapting. Technology and institutions are strongly interwoven in these systems (Hughes, 1987).
The application of new technology may require a need for changes in the institutions. In turn, the institutions that are in place may influence investment decisions that determine the path of future innovation and technology adoption.

In their interaction the actors are guided by the structure, being both institutions and technology. They will try to influence and change the structure if this contributes to the realization of their objectives. In the interaction among actors there is not necessary an overall goal. Each actor has its own reasons to participate and is behaving in order to pursue its own interests, which might be partially conflicting with the interests of other actors (Economides, 1996; Scharpf, 1997). This coordination will be successful if the outcome is mutually beneficial to all actors (Ostrom, 2005b). In other words, if actors participating in this coordination activity can all (more or less) realize their own objectives. This means that there is not only a need to align institutions with technology, but that this alignment can only lead to a successful outcome if there is alignment possible between the objectives of the various participants in this coordination activity.

The interaction between actors to align the technology with the institutional setting and vice versa is shown in Figure 5-2 and repeated here in Figure 8-1.

The actors can be broadly classified in two distinctive groups. First, there are private actors (further denoted by the simplified term firms) that have capabilities to innovate and develop new technologies, new products and new services. By doing so, they force other actors to react. These are private firms such as equipment manufacturers and service providers. On the other hand, there are actors who are capable to shape the institutions under which all actors have to act. These are public actors (further denoted by the simplified term government), including

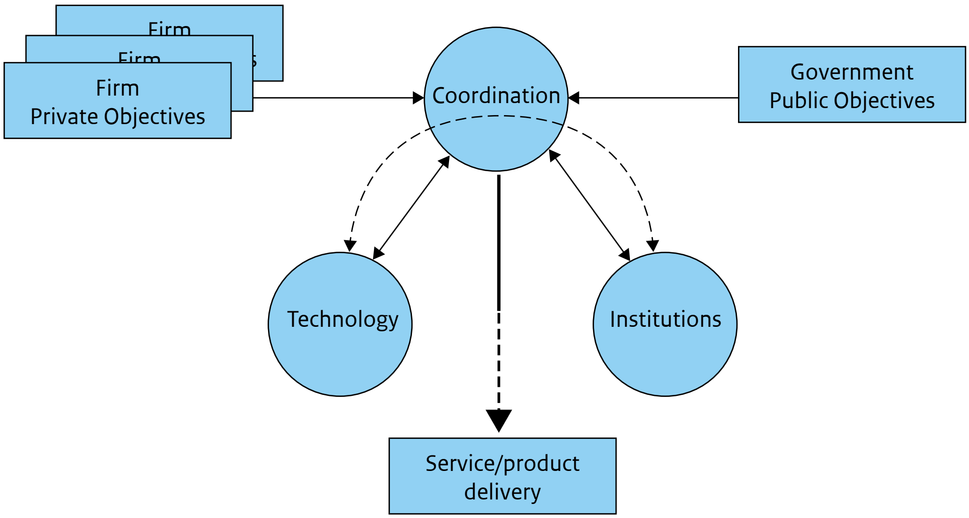

Figure 8-1 Two levels of alignment in the interaction between actors to achieve alignment between institutions and technology.

political authorities, public administrations and regulators (Finger, Crettenand, Laperrouza and Künneke, 2010).

The alignment framework is built around the idea that the exploitation of the radio spectrum resource by private actors does not only serve the private objectives of the firms, but should also serve the public objectives of government. Safeguarding of the public interest is realized through an institutional setting that imposes rules and regulations on the exploitation of the radio spectrum by those private actors. This institutional setting will have to be in alignment with the technology to allow successful exploitation of the resource. Although this alignment between the institutional setting and the technology is necessary, it is not sufficient. There is also a need for alignment between the objectives of government and those of the private actors. This second level of alignment will guarantee that the intended business opportunity that has to serve the public interest is supported by the institutional setting.

The necessity of this second level of alignment, between the objectives of private actors and those of public actors is shown for the introduction of new (cognitive) radio technology in chapter 6. The case study of the introduction of cognitive radio technology in (white spaces of) the television broadcasting band in the United States shows that the FCC took a very careful step by step approach to implement institutional arrangements that are aligned with the current state of technology. However, whether there is alignment between the public objective of the FCC to provide broadband access in rural areas with the objectives of private actors which are supposed to provide this broadband service remains to be seen.

The proposed alignment framework can be regarded as a refinement of the IAD framework for a specific type of common pool resources. It is a framework for coordination with regard to a complex sociotechnical system in which governmental actors and private actors are highly interdependent in the realization of their respective objectives. The institutional arrangements that are set up will have to provide the certainty to entrepreneurial firms to invest in new technology and the exploitation thereof. If as a result of considerations of profitability firms decide not to exploit the system as intended, the government fails in realizing its governance objectives.

The proposed framework combines insights in the governance of complex common pool resources with insights on the alignment between institutions and technology. Although it is a framework that is derived from observations in the coordination activities related to a particular complex socio-technical system, i.c. the exploitation of the radio frequency spectrum, it´s applicability is probably wider. It is the believe of the author that the framework can be used in the assessment of complex sociotechnical systems in general whereby there is a need for coordination between governmental actors and private actors to govern the system. These systems include energy, communication, transport and postal services. These systems can be regarded as common pool resources providing essential services to society (Künneke and Finger, 2009). Further investigations of other complex sociotechnical systems will have to be performed to confirm the applicability of the framework.

The alignment framework was built on case studies of the development of successful technology. There are also a number of technologies that did not come into practice.[286] Analysis of the failure of these technologies is recommended to test the robustness of the framework and its underlying hypothesis on the two levels of alignment.

[286] The examples of ERMES, HIPERLAN and TFTS are mentioned in chapter 5.

8.4 A redefined radio spectrum governance process

The alignment framework is used to propose a redefined spectrum governance process in chapter 7. As said, radio spectrum management is a process of coordination to adapt to changes in market demand, technological progress and changes in the public interest. The proposed framework suggests that coordination activities required to adapt to change is only successful if the outcome aligns with the objectives of the various participants in this coordination activity. Hence, the starting point for a redefinition of the process are the objectives of the actors involved in the coordination activities with regard to spectrum governance.

It is not a coincidence that the debate on both alternative approaches for spectrum governance only got traction after the liberalization of the telecom sector in the 1990s. Liberalization added the objective of economic efficient use to the set of objectives pursued by government. It started a process in which free competition was preferred to a centralized organization of markets. Competition is thereby seen as an instrument to reach this added objective by encouraging industrial efficiency, an optimal allocation of resources, technical progress and the flexibility to adjust to a changing environment (Motta, 2004).

Since then, proper functioning of the market became part of the public interests to be safeguarded. Governments rely on a market design and associated regulations to serve a mixture of economic and societal objectives. The societal objectives are to be realized by private actors. In the case of mobile communications, radio spectrum policy is used to create a market for mobile telephony and mobile internet access. Specific obligations may be attached to the licenses to serve societal objectives, e.g. a coverage obligation.

The market is supposed to provide a solution to the two weaknesses of the current command-and-control regime. Decentralized coordination in the market is supposed to lead to more efficient use of the resource and the market is regarded as being more adaptive to change. This ties in with the literature on the governance of common-pool resources. This literature came with evidence that a governance approach in which government is in "command-and-control" is not the most effective approach and may lead to economically inefficient exploitation of the resource. The main reason being that government lacks knowledge of the exploitation of the resource to be successful as the central coordinator in the governance of the resource (Ostrom, 1990; Baland and Platteau, 1996; Dietz, Ostrom and Stern, 2003).

This market design requires a shift in the role of government. The government's role shifts from a government in control of a centrally managed spectrum management process to a facilitator of decentralized coordination in the market using a (multi-actor) spectrum governance process. This shift can be regarded as a next (and possibly final) step in the liberalization process which has not been recognized yet.

The government's role in this coordination effort is to design a market in which decentralized coordination can take place. Government can improve the functioning of the market by providing specialized information or as a second step by facilitating the market. Government may need to adjust the market, with specific regulations, to realize governmental objectives if they are not realized as an outcome of the decentralized market process.

The market design proposed is based on a mixed regime of spectrum usage rights, licenses and unlicensed access. This design will provide possibilities for infrastructure based service provisioning (e.g. mobile communications) by national operators based on exclusive spectrum usage rights. More specialized services targeted at a specific group of business users can be offered by both national operators and niche players based on tradable (local) licenses. The ability to enter the market on a local level will make the market more contestable. Hence, there will be less need for government to regulate the behavior of the dominant operators (Church and Ware, 2000). This market is augmented by a market for devices based on unlicensed access. This will provide private actors flexibility to cater for changes in the demand for certain applications and will lower the entrance barrier for the introduction of new applications and business opportunities without the need to enter into a lengthy process to change the regulations.

An essential element in decentralized coordination and decision making is the availability of information on the use of the resource and its variability over time (McGinnis and Ostrom, 2008). Availability of this information in the market can lower the transaction cost (Dietz, Ostrom et al., 2003; Stern, 2011). The government can provide this information on the actual use of the resource. Governments can also provide additional information to reduce uncertainty for private actors by providing information on e.g. the availability of future spectrum for mobile communications as the result of international negotiations at the World Radio Conference, on the timing of future spectrum auctions and on societal objectives of the government related to the use of radio spectrum.

A functional market which allows for decentralized decision making will require more broadly defined allocations and clearly defined property rights. In the past, very specific allocations were made for the various radio services. This strict separation of the various radio services is not only undesirable, it is also no longer necessary. Nowadays, there is technology available that can be used to offer various services. A good example is the convergence of mobile communications and broadcasting. Hence, this one-to-one relationship between service offering and technology is no longer valid. Nonetheless, the control of interference by the grouping of comparable technology in the frequency domain is still valid. Hence, the allocation could be broadened, based on the behavior of the technology in the frequency domain.

The same kind of reasoning applies to the legislation of unlicensed access. The European legislation of unlicensed access is still very specific and based on the separate treatment of various applications. The regulations could be very much simplified by defining a radio profile and associated interference potential in terms of general spectrum utilization criteria, such as occupied geographic location, time and frequency, for a given frequency band – regardless of the technology or application for which the technology is used (Kruys, Anker et al., 2016).

As allocations are made more generic, the radio spectrum is no longer subdivided in multiple single-use frequency bands. Instead, the frequency bands will be shared among various user groups. This will fundamentally change the characteristic of the coordination problem. In a single-use resource, the users share a common interest in the exploitation of the resource. In a multiple-use resource, the resource is shared among various user groups which may have conflicting interests. This makes coordination of a multiple use resource more difficult, and may lead to a situation in which coordination does not take place. Government can as a neutral third party facilitate coordination among different user groups and within user groups with a conflicting interest. One possibility to do so, is to facilitate the development of a platform for resource use negotiation (Steins and Edwards, 1999). Face-to-face communication in a Community of Practice can help the group of actors to share information, gain a sense of solidarity and build trust between the members of the group.

Until now, it has been assumed that the objectives of a government related to the public interest are realized by the private actors. However, this will not always be the case. Hence, a government may have to impose rules to realize the public interest. Government must be very clear and transparent in their public objectives in order for the market to make a proper response. The rules to adjust the market will necessarily constrain the behavior of the private actor and the possible business opportunities. Currently, services related to the public interest are in many cases safeguarded by allocating dedicated spectrum to these services. However, the current technology allows to shift this coordination to the assignment and standardization arena to enhance possibilities for the market to deliver those services and to provide more flexibility. Especially recent developments in mobile communications technology (LTE and its development towards 5G) made it possible to deliver a versatile and flexible mix of communication services, including specialized services that until now have their own dedicated allocation. However, this may require participation of government in the standardization of mobile technology in order to ensure that the technology is able to deliver the intended service, in support of the public interests, such as Public Protection and Disaster Relief and Intelligent Transportation Systems (ITS). There may also be a need for governments to facilitate cooperation between the users of that service and the providers of the services. Both the standardization and market facilitation may need to take place at a European level to reach the necessary economies-of-scale.

Having created the market, a key responsibility for governments is to monitor the proper functioning of the market. Monitoring will become a more central aspect of the work of government as a facilitator of decentralized coordination. The scope of monitoring will be broader than the monitoring task usually associated with radio communications. Monitoring will not only be needed in its classic role of providing information on activities in the radio spectrum for enforcement purposes. Monitoring will also be needed to provide general information on actual usage of the spectrum to lower the transactions costs. Last but not least, monitoring will be required to see whether the public objectives are met through the exploitation of the resource by the private actors. This will require general monitoring of the functioning of the market as well as more specific monitoring related to the stated public objectives. To be followed by market adjustments as and when required.

The focus of government as a facilitator of this redefined spectrum governance process will no longer be on certain predefined outcomes. The focus will be on a clear formulation of strategic policy goals and public objectives followed by the facilitation of a process of learning and discovery in order to achieve these goals and objectives. Achieving those goals in a complex and uncertain (changing) context requires a process in which different solutions are explored. The learning process is thus as important as achieving the stated goals and objectives.[287]

[287] This statement not only holds for government on the process of spectrum governance, but also holds for the author on the process of performing this PhD project on spectrum governance.

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"Read, read, read. Read everything -- trash, classics, good and bad, and see how they do it. Just like a carpenter who works as an apprentice and studies the master. Read! You'll absorb it. Then write. If it's good, you'll find out. If it's not, throw it out of the window."

William Faulkner, American author, 1897 - 1962

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I

What is radio spectrum and how is it governed?

This annex provides information on what radio spectrum is, it explains the phenomenon of interference and it provides information on the international regulatory framework for radio spectrum management.[288]

[288] This Annex is based on a book chapter: Anker (2015), "International regulatory framework for spectrum and spectrum sharing", In O. Holland, H. Bogucka and A. Medeisis (eds), *Opportunistic Spectrum Sharing and White Space Access: The Practical Reality*. New York: Wiley and a Working paper: Anker (2010), "What are radio waves and how can this resource best be managed? Towards a framework for further analysis". This working paper was provided for a workshop "Radio spectrum governance: the need for coordination" during the 13th International Annual Conference on the Economics of Infrastructures, Delft, May 2010.

I.1 What is the radio spectrum?

Radio waves are technically speaking a subset of electromagnetic waves within a specific frequency range. The International Telecommunication Union defines radio waves or Hertzian waves as: *"electromagnetic waves of frequencies arbitrarily lower than 3,000 GHz, propagated in space without artificial guide."*[289] The complete range of radio waves up to 3,000 GHz is called the radio frequency spectrum or radio spectrum.

Although radio waves have been around as a natural phenomenon, their artificial use started with the

[289] ITU Radio Regulations, Volume 1, article 1.5, edition of 2008.

"Lists of facts don't comprise knowledge. Analyzing, hypothesizing, concluding from data, sharing insights, those comprise knowledge. You can't google for knowledge."

Elaine Ostrach Chaika
American author

postulation of the existence of electromagnetic waves by Maxwell and the first demonstrations by Heinrich Hertz. The radio spectrum, as a resource held in common, remained unused and unclaimed until the end of the 19th century. At that time the technology was being developed to turn the electro-magnetic waves into a valuable resource. The filing of a patent for a wireless telegraph system by Marconi in 1896 is generally regarded as the birth of (commercial) radio and thereby the use of the radio frequency spectrum. In these early days, the only way to transmit information was through switching the radio transmitter on and off. Information was transferred using Morse code with shorter and longer periods of radio transmission. It was primarily seen as a means to provide wireless telegraphy in places where the normal (wired) telegraphy could not be used, especially in ship-to-shore and ship-to-ship communications. Radiotelegraphy was used to enhance maritime safety, for naval operations and to provide ship-to-shore public correspondence. The most active company in these early days was the Marconi Wireless Telegraph Company Ltd.[290]

Advancements in technology made it possible to transmit voice, leading to the introduction of other services. At first radiotelephony, and as technology of the radio transmitter and receiver where further advanced, the use of radio broadcasting. Today, the radio spectrum is used to deliver a broad range of services and applications, such as terrestrial broadcasting, mobile telephony, radio navigation and RF-Identification (RF-ID).

Radio waves have particular characteristics which have to be taken into account in the governance of the radio spectrum. It is in one sense a very peculiar natural resource. It is **non depletable.** As soon as one user stops using the resource it is immediately available for another user.

The problem associated with the use of radio waves is that the use of a particular frequency by one user will influence the use of radio waves by other users who want to use the same frequency at the same time. This phenomenon is called interference. Interference occurs when two (or more) signals with the same (or nearly the same) frequency and with sufficient power arrive at a receiver simultaneously.[291] In that case, the receiver will not be able to distinguish between the intended signal and the interfering signal(s). In other words, the use of the spectrum is **rivalrous**; it is not possible for users to use this resource simultaneously without limitations. But, different from most natural commons it is not a matter of depletion, it is a matter of congestion at that moment in time in that geographical area.

Another important aspect of spectrum is that it is **non-homogeneous**. The propagation characteristics of a radio wave depends on the actual frequency. Generally speaking radio waves at lower frequencies travel larger distances and are able to penetrate through dense material such as buildings. Radio waves at higher frequencies are subject to higher attenuation and travel over shorter distances. This does not automatically make higher frequencies less attractive. Firstly, it also means that interference is a more local problem, and hence higher frequencies can be reused over a shorter distance.[292]

Secondly, at lower frequencies there is less bandwidth capacity available than at higher frequencies. It means that a trade-off will have to be made. Maritime radio is better off at lower frequencies, since low frequencies travel over longer distances while services

[290] See chapter 3 for more details on the early days of radio.

[291] Interference may not only occur if two transmitter use the same frequency, but also if transmitters use adjacent channels, albeit to a lesser degree.

[292] The propagation conditions can even vary for a particular frequency. A simple example of this is AM radio. During the day AM radio signals propagate only over relatively short distances. However, at night, AM signals can be reflected by the ionosphere, which makes it possible to receive distant radio stations.

Frequency Band	Frequency range	Propagation characteristics	Applications
ELF (Extremely Low Frequency)	Less than 3 kHz	Worldwide communications along the surface of the earth	Worldwide military communications
VLF (Very Low Frequency)	3 – 30 kHz	Worldwide guided transmission	Navigation and military communications
LF (Low Frequency)	30 – 300 kHz	Stable signal, long distance (1500 km)	Navigation, radio broadcasting (AM)
MF (Medium Frequency)	0,3 – 3 MHz	Medium distance along the surface; long distance through reflections by the ionosphere (esp. at night)	Radio broadcasting (AM), maritime communications
HF (High Frequency)	3 – 30 MHz	Short distance along the surface; long distance through reflections by the ionosphere.	Radio broadcasting, amateurs, maritime and aeronautical communications.
VHF (Very High Frequency)	30 – 300 MHz	Direct (straightforward) propagation	Television broadcasting, FM broadcasting, mobile communications
UHF (Ultra High Frequency)	0,3 – 3 GHz	Clear path point-to-point communications	Television broadcasting, mobile communications, radar systems
SHF (Super High Frequency	3 – 30 GHz	Clear path point-to-point communications; small objects (rain) becomes an obstacle.	Fixed links, satellite communications, radar systems
EHF (Extremely High Frequency)	30 – 300 GHz	Clear path point-to-point communications; large attenuation due to atmospheric gasses.	Fixed links, military use. Hardly any use above 60 GHz.

Table I-1 Characteristics and typical usage of the various frequency ranges (adapted from Minoli, 2003).

that carry a lot of information (such as television broadcasting or mobile telephony) are better placed in the higher frequency bands. However there is an optimum if the frequency becomes too high the number of base stations needed to build a network will rise too much because of the shorter distances the radio waves can travel.

Table I-1 provides an overview of the various frequency bands, their propagation characteristics and some typical usage.

From the table it can be concluded that due to the varying propagation characteristics not all frequencies are suited for all types of services. Each frequency range is optimal suited for some particular kind of services.[293] The most attractive and most used part of the radio spectrum is the frequency range between roughly 100 MHz and 3 GHz.

I.2 What is interference?

Interference is a phenomenon that is inextricably linked to radio communications. Interference is defined in the Radio Regulations of the ITU as *(ITU, 2012, Article 1.166)*:

[293] There are also applications that have to make use of a specific frequency, e.g. radio astronomy observes astronomical objects and phenomena by observation and analysis of radiated radio signals from these objects.

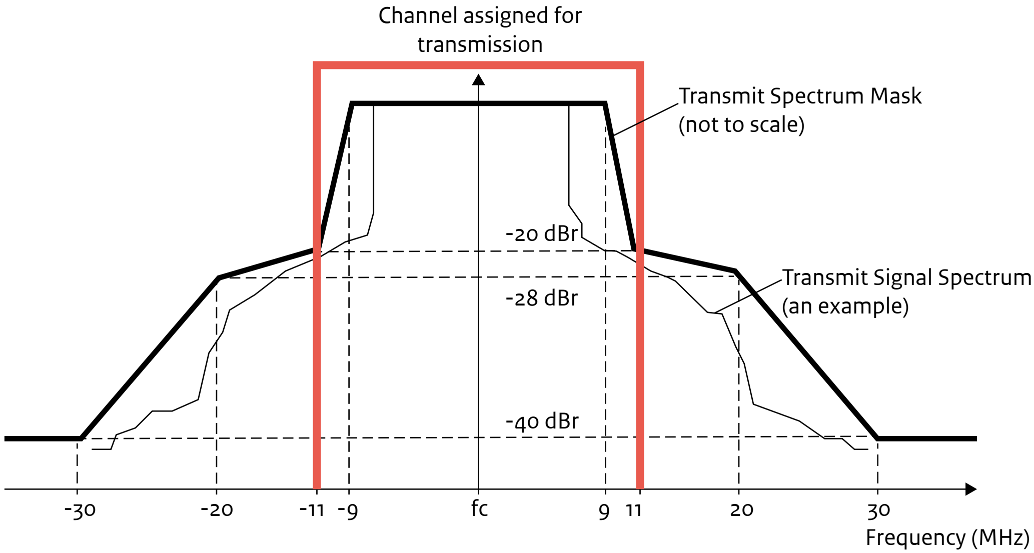

Figure I-1 In-band and adjacent channel transmission of a typical signal (adapted from IEEE Standard 802.11-2007).[294]

interference: The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy.

Interference manifests itself as a degradation of the performance of a receiver. It is caused by a number of different mechanisms. An important source of interference is the interference caused by other transmitters that are working on the same or adjacent frequency in the same geographical area.[295]

Co-channel interference can occur when there are two or more transmitters that are transmitting on the *same* frequency (channel).[296] This type of interference can be avoided by using a large enough separation distance between transmitters that use the same frequency simultaneously.[297]

In a perfect world, this co-channel interference would be the only source of interference. However, in reality both transmitters and receivers are not perfect. This will lead to interference in the adjacent channel. Figure I-1 shows the typical radiation of a radio transmitter with respect to the assigned channel.

[294] The figure is made by the author, based on the OFDM spectral mask used for 802.11a/g/n/ac in a standard 20 MHz channel, as can be found in the IEEE Standard 802.11-2007.

[295] In reality there are also other sources of interference, such as unwanted emissions from a radio transmitter or radio frequency transmissions from other electronic equipment (not being radio transmitters). The latter type of interference is usually denoted by the term electro-magnetic interference.

[296] There is a possibility to have a limited number of transmitters using the same frequency channel if the transmitters all use their own unique coding scheme. However, in that case the information is spread over a wider bandwidth then necessary for the transfer of information.

[297] Another possibility would be to separate the transmission in time.

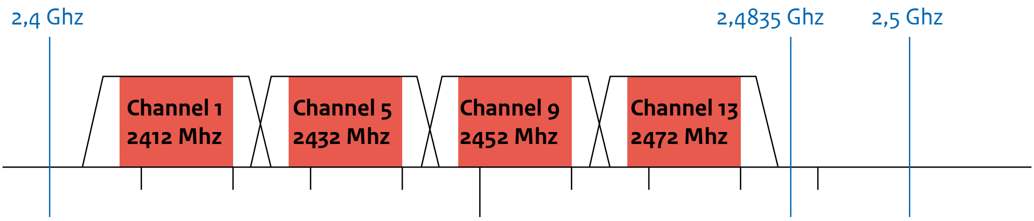

Figure I-2 Non-overlapping channels in the 2.4 GHz band for IEEE 802.11g/n (OFDM).[298]

The figure clearly shows that some of the energy will be transmitted outside the assigned frequency channel. The amount of interference that a user is allowed to emit in the neighboring bands is called the adjacent channel interference limit.[299]
The transmit spectrum mask is an example of the allowed transmission as defined in a spectrum usage right. The amount of adjacent channel interference can be reduced by a filter. However, this filter will never be perfect, if the filter is too tight, to limit the transmission within the assigned channel, it will also affect and distort the intended signal.

A second reason for adjacent channel interference is that the filter in the receiver will also not be perfect. A radio receiver tuned at a particular channel will also receive some energy from the adjacent channels. The signal in the adjacent channel will be suppressed but will not be totally removed. This is depicted in the following figure. Figure I-2 shows the non-overlapping channels in the 2.4 GHz band for a common Wi-Fi signal.[300] Ideally, all transmitters and receivers will only transmit in the assigned channel. However some of the energy will be emitted in the adjacent channels and the receivers will receive some of the signal in the adjacent channel.

To avoid interference there is a need to separate the signals of various users in frequency, in geographical space or in time.[301] Hence, To manage interference, there is a need for coordination between the users of the radio frequency spectrum.

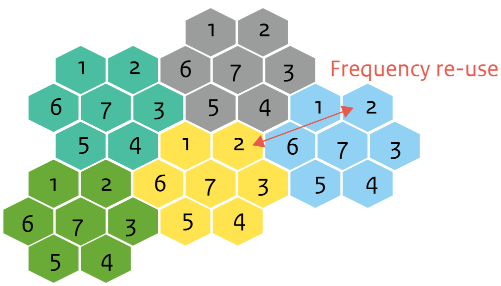

Figure I-3 Cellular structure.

A common practice is the use of a so-called cellular structure, in which a frequency is used in an area, called a cell, which is surrounded by other cells which use another frequency. The same frequency is used again over a distance that is large enough to avoid co-channel interference. This is depicted in Figure I-3.

298 This figure was created by Liebeskind under a Creative Commons license (http://creativecommons.org/licenses/by/3.0) and published via Wikimedia Commons.

299 Some of the interference may even be emitted in the next channel (adjacent to the adjacent channel). The total emission outside the assigned channel is called the out-of-band emission.

300 To be precise a standard IEEE 802.11g/n OFDM signal.

301 One could argue that a fourth dimension is relevant: the information dimension that is exploited by coding. However, the use of coding affects the other three parameters and therefore it cannot be considered independently.

A cellular structure can be used to provide a service over a large geographical area with a limited set of frequencies. This kind of structure is used in mobile telephony. The same type of frequency re-use is also common practice by national radiocommunications agencies in the planning of licenses with a limited geographical area and it is used internationally, e.g. in the planning of broadcasting frequencies to be used in Europe.

I.3 How is the radio spectrum governed?

Coordination is needed to manage the problems (such as interference) associated with the use of this resource. The term spectrum management then refers to coordination activities that have to take place in order to facilitate the use of this resource by a large and diverse number of users.

Particularly for users, it is also often important that services and the related equipment are standardized, i.e. these services can operate with similar equipment in various countries in the same frequency band. As a result of this harmonization, the spectrum can be used more efficiently and the equipment can be used over much wider geographical areas, increasing the size of the market for such equipment and reducing production costs. In the case of a number of applications, international harmonization is even necessary owing to the nature of the application.

Historical developments have led to a situation in which governments have taken the role of 'supreme coordinator' in the use of the radio spectrum. Spectrum management has become based on the avoidance of interference and the technically efficient use of the radio spectrum. This section gives an overview of the international regulatory framework for spectrum regulations (Anker, 2010b; Nekovee and Anker, 2012).

I.3.1 International Telecommunications Union

The International Telecommunications Union (ITU) is the global governing body for spectrum. The ITU is a specialized agency of the United Nations. The Radiocommunication Sector of the ITU (ITU-R) develops and adopts the Radio Regulations, a binding international treaty, with a voluminous set of rules, recommendations and procedures for the regulation of radiocommunications. One of the prime objectives of the Radio Regulations is avoidance of interference through the division of spectrum in bands which are allocated to one or more services out of some 40 different radio services. These radio services include services such as fixed, mobile, satellite, amateur, radio navigation and radio astronomy. Figure I-4 gives a stylized overview of the services.

In the ITU Radio Regulations, the world is divided in three regions for the international allocation of frequencies. Region 1 comprises of Europe including the Russian Federation, Africa and the Middle-East. Region 2 is comprised of North and South America and Region 3 comprises South-East Asia and Oceania.

Because there are many more requests for an allocation of frequencies than there are frequencies available, many bands are allocated to more than one service. Before such allocations are made, the possibilities for (cross-border) sharing and the conditions for sharing are extensively studied and documented. Countries then can choose the allocation that best meets the national requirements.

In a sharing arrangement, there may be a priority for one allocation above another. The main service becomes the primary service and the other service(s) receive a secondary status. The primary service is protected from interference from the other services in the band; the rules state: '*Secondary services shall not cause harmful interference to stations of primary services … [and] cannot claim protection from harmful interference from stations of a primary service*' (ITU, 2012a: Nos. 5.28 to 5.30).

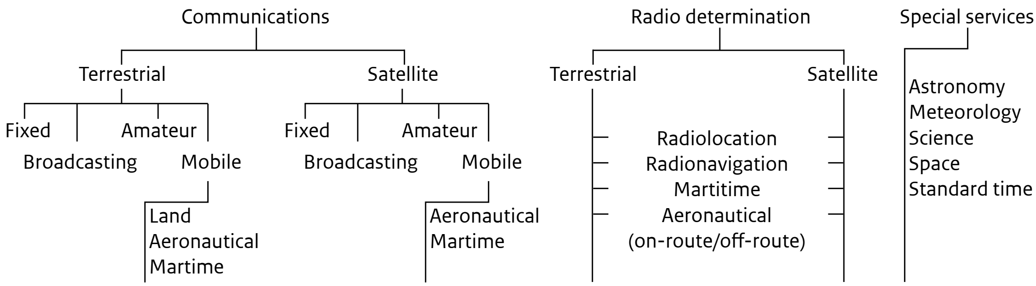

Figure I-4 Stylized overview of ITU radio services.

Harmful interference is defined as *interference* which endangers the functioning of a *radionavigation service* or of other *safety services* or seriously degrades, obstructs, or repeatedly interrupts a *radiocommunication service* operating in accordance with Radio Regulations (ITU, 2012: article 1.169). A wide range of regulatory, operational, and technical provisions ensure that radio services are compatible with one another and harmful interference among services of different countries is avoided. The Radio Regulations provides the rules for the international coordination between countries for the agreed services.

The Radio Regulations are an international treaty between countries. This means that it only concerns the relations between countries. Individual countries can adopt some or all of the allocated services of each band and they are allowed to deviate from the Radio Regulations as long as no harmful interference is caused to the recognized services in other countries.

The Radio Regulations are regularly updated in response to changes in needs and to new demands at World Radiocommunication Conferences (WRC), which are held every three to four years (ITU, 2004).

Study Group	Scope
Study Group 1 Spectrum management	Spectrum management principles and techniques, general principles of sharing, spectrum monitoring, long-term strategies for spectrum utilization, economic approaches to national spectrum management, automated techniques and assistance to developing countries in cooperation with the Telecommunication Development Sector.
Study Group 3 Propagation of radio waves	Propagation of radio waves and the characteristics of radio noise, for the purpose of improving radiocommunication systems.
Study Group 4 Satellite services	Fixed-satellite service, mobile-satellite service, broadcasting-satellite service and radiodetermination-satellite service.
Study Group 5 Terrestrial services	Fixed, mobile, radiodetermination, amateur and amateur-satellite services.
Study Group 6 Broadcasting service	Radiocommunication broadcasting, including vision, sound, multimedia and data services principally intended for delivery to the general public.
Study Group 7 Scientific services	Space operation, space research, Earth exploration, meteorology, radio astronomy and radar astronomy, remote sensing and standard-frequency and time-signal services.

Table I-2 ITU-R Study Groups (ITU-R, 2015).

The ITU-R has several Study Groups to prepare the technical basis for World Radiocommunication Conferences and to cooperate in radiocommunication matters. In these Study Groups, administrations, the telecommunications industry and academic organizations participate on topics such as efficient management and use of the radio spectrum, radio systems characteristics and performance, spectrum monitoring and the development of standards for radiocommunication systems. The work of the Study Groups is published in ITU-R Recommendations, Reports and Handbooks.

Table I-2 provides a list of the Study Groups and the work that is assigned to each Study Group.

I.3.2 Regional cooperation in Europe

The various regions work together in their preparation on the harmonization of the use of spectrum and the coordination of positions for WRCs. The following regional groups are recognized within the ITU:

- APT: Asian-Pacific Telecommunity,
- Arab Group,
- ATU: African Telecommunications Union,
- CEPT: European Conference of Postal and Telecommunications Administrations,
- CITEL: Inter-American Telecommunication Commission,
- RCC: Regional Commonwealth in the Field of Communications.[302]

Cooperation on the field of spectrum harmonization and utilization is probably most intense in Europe. The following subsection gives an overview of this cooperation in Europe.

CEPT/ECC

The Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT) brings together 48 countries to develop common policies and regulations in electronic communications and related applications for Europe. Its primary objective is to harmonize within Europe the efficient use of the radio spectrum, satellite orbits and numbering resources so as to satisfy the requirements of users and industry.

It takes an active role at the international level. European common positions and proposals are prepared to represent European interests in the ITU and other international and regional bodies.
The ECC work is carried out in partnership with all stakeholders including the private sector, the European Commission and The European Telecommunications Standards Institute (ETSI).

From a regulatory perspective there are mainly four different deliveries that are developed by ECC:

- *ECC Decisions* are regulatory texts providing measures on significant harmonization matters, which CEPT member administrations are strongly urged to follow. ECC Decisions are not obligatory legislative documents, as any other CEPT deliverable; however, they are normally implemented by many CEPT administrations.
- *ECC Recommendations* are measures which national administrations are encouraged to apply. They are principally intended as harmonization measures for those matters where ECC Decisions are not yet relevant, or as guidance to CEPT member administrations.
- *ECC Reports* are the result of studies by the ECC normally in support of a harmonization measure of the ECC.
- *CEPT Reports* are the final results of studies developed in order to support responses to EU mandates. In many cases the results in the report form the basis for future EC Decisions on harmonized technical conditions of use.

[302] Russian Federation and 11 countries of the former U.S.S.R.

CEPT deliverables are non-binding, as noted above, and this gives the national administrators a large level of flexibility when it comes to adopting these to country specific conditions/legacy usages (Nekovee and Anker, 2012).

In order to achieve its objectives, CEPT endorsed in 2002 the principle of adopting a harmonized European Table of Frequency Allocations and Applications. This European common Allocation table (ECA-table) establishes a strategic framework for the utilization of the radio spectrum in Europe. The Table should be used as a source document by CEPT member countries for the development of Decisions, Recommendations, and European Common Proposals (ECPs) for future Radio-communication Conferences of the ITU and as a reference document when developing national frequency allocation tables and national frequency usage plans. The ECA-table is further detailing the ITU Radio Regulations (ECC, 2013).

European Union

Throughout the 1990s the European Commission gradually increased its involvement in spectrum issues, as the RF spectrum use started to affect the 'internal market'. The first interventions were related to the creation of harmonized spectrum for pan European radio services, notably GSM, ERMES and DECT. This was later followed by the creation of a single European (internal) market for radio equipment and telecommunications terminal equipment. On the 9th of March 1999 the European Commission published the R&TTE Directive 1999/5/EC (EC, 1999). This Directive covers most products which use the radio frequency spectrum, including unlicensed devices. All equipment that is placed on the market must comply with a set of essential requirements, covering the protection of health and safety, electromagnetic emission and immunity of the equipment and effective use of the radio spectrum so as to avoid harmful interference.

Equipment manufactured in accordance with a "Harmonized Standard" may be placed on the market within the whole European Union (see also the following subsection on ETSI). However, certain restrictions may apply to the use of radio equipment if the frequencies are not harmonized in the European Union. If a Harmonized Standard is used, the manufacturer has to perform some specific radio tests and can make its own declaration of conformity (self-declaration) which states that the product satisfies the essential requirements. There is no need for an external body to perform the testing. When a Harmonized Standard is not available or not appropriate, a manufacturer needs to demonstrate more extensively how the requirements of the Directive are being met through testing, to be documented in a 'technical construction file'. This file has to be reviewed and approved by a notified body.

The European Commission published in 2014 a new Radio Equipment Directive (RED) that will replace the R&TTE Directive.[303] The directive is still based on the self-declaration of conformity to the essential requirements. One of the main differences is that Software Defined Radio is explicitly brought under the scope of the directive. In the new Directive explicit reference is made to radio equipment based on both hardware and software. Compliance to the essential requirements has to be demonstrated for the combination of the radio equipment and its software.

Involvement of the European Union with radio spectrum management in general was strengthened in 2002 with the introduction of the new regulatory framework. This framework was aimed at further

[303] DIRECTIVE 2014/53/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC (see: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:JOL_2014_153_R_0002)

liberalization, harmonization and simplification of the regulations in the telecommunications sector. The Framework Directive (2002/21/EC), *on a common regulatory framework for electronic communications networks and services*, states that the allocation and assignment of radio frequencies by national regulatory authorities are to be based on objective, transparent, non-discriminatory and proportionate criteria (EC, 2002c). The related Authorization Directive (2002/20/EC) specifies the circumstances under which the granting of an individual license is being allowed (EC, 2002b). The Directive states that granting of an individual license is only allowed to ensure efficient use of radio frequencies. The Directive also limits the conditions that may be attached to the rights of use for radio frequencies. The licensing and the formulation of the conditions under which the radio frequencies may be used are left to the Member States.

Under this new regime harmonization of spectrum is still left to CEPT. However, the associated Radio Spectrum Decision by the European Commission (2002/676/EC) created the possibility to impose technical harmonization measures upon the Member States (EC, 2002a). This Decision created a legal framework for 'the harmonized availability and efficient use of radio spectrum in the European Union for the establishment and functioning of the internal market in Community policy areas, such as electronic communications, broadcasting and transport'. In the implementation of the Decision the European Commission is assisted by the newly formed Radio Spectrum Committee (RSC). The RSC is composed of experts from the Member States.

The European Commission can issue mandates to CEPT to advice on technical harmonization measures. The CEPT Report can be used by the European Commission to develop a Commission Decision with technical implementing measures that can ensure harmonized conditions for the availability and efficient use of radio spectrum. The implementation of these measures is mandatory for the EU Member States.

Next to the RSC, the Radio Spectrum Policy Group (RSPG) was set up to facilitate consultation and to develop and support radio spectrum policy. The Radio Spectrum Policy Group (RSPG) is a group of high-level representatives of the Member States which advises the European Commission on radio spectrum policy at a strategic level.

The revision of the regulatory framework in 2009 introduced two governing principles for spectrum regulation. Firstly, general authorization should be the general rule when authorizing access to spectrum. Individual licensing can still be used but such deviations from the general principle must be justified. Secondly, the principles of technology and service neutrality should be the general rule for both general and individual authorization of access to spectrum. Deviations from this principle will still be allowed but must be justified. As the allocation of spectrum to specific technologies or services is an exception to the principles of technology and service neutrality and reduces the freedom to choose the service provided or technology used, any proposal for such allocation should be transparent and subject to public consultation (EC, 2009; Nekovee and Anker, 2012).

The European Parliament and Council adopted on 14 March 2012 the first Radio Spectrum Policy Programme (RSPP). The RSPP outlined at a strategic level how the use of spectrum can contribute to the most important political objectives of the European Union from 2011 to 2015. The programme sets general regulatory principles and policy objectives to be applied for spectrum in all sectors of the internal market, defines actions and common principles to enhance efficiency and flexibility, preserve and promote competition, support wireless broadband communications as well as other EU policies. The guiding principles as defined in the RSPP for spectrum management are spectrum efficiency and flexibility, technology and service neutrality and competition.

One of the primary goals of the RSPP was the identification of at least 1200 MHz of spectrum suitable for wireless data traffic (including frequencies already in use) by 2015, by means of, among others, new ways of sharing spectrum resources. In article 4, which deals with sharing, is an explicit reference made to cognitive radio (EU, 2012):
Member States, in cooperation with the Commission, shall, where appropriate, foster the collective use of spectrum as well as shared use of spectrum.
Member States shall also foster the development of current and new technologies, for example, in cognitive radio, including those using "white spaces".

The European Commission started an initiative to promote shared use of spectrum resources with the commissioning of a study "Perspectives on the value of shared spectrum access" (Forge, Horvitz et al., 2012). The aim of the study was to contribute to a better understanding of the socio-economic value of shared spectrum access, including its impact on competition, innovation and investment. In its recommendations it sees cognitive technology as a way forward to increase the possibilities for sharing. It promotes Authorized Shared Access (ASA) and Licensed Shared Access (LSA) as steps on the way to more shared spectrum (Forge, Horvitz et al., 2012). ASA and LSA are comparable concepts to share spectrum between incumbents and (licensed) LSA-users. Providing spectrum for mobile broadband is seen as the first application of LSA.

ETSI

The European Telecommunications Standards Institute (ETSI) is an independent, non-profit organization, whose mission is to produce globally applicable standards for Information & Communications Technologies including fixed, mobile, radio, broadcast, internet and several other areas. ETSI plays a major role in developing a wide range of standards and other technical documentation as Europe's contribution to world-wide ICT standardization. This activity is supplemented by other activities such as interoperability testing services. ETSI's prime objective is to support global harmonization by providing a forum in which all key players can contribute actively.

ETSI is recognized as an official European standards organization by the European Commission and works under mandates from the Commission to prepare Harmonized Standards under the provisions of the R&TTE Directive. Membership is open to all interested parties. Harmonized Standards are standards adopted by European Standards Organizations, prepared in accordance with the General Guidelines agreed between the Commission and the European standards organizations (ETSI, CEN and CENELEC), and in response to a mandate issued by the Commission after consultation with the Member States. The reference of a Harmonized Standard must be published in the Official Journal (OJEU) in order to give a presumption of conformity to the essential requirements of the R&TTE Directive.

ETSI is an officially recognized partner of the ECC, which is reflected in a Memorandum of Understanding (MoU). The cooperation between ETSI and the ECC plays an important role to ensure the objective of harmonized and efficient use of the radio spectrum across Europe (Nekovee and Anker, 2012).

I.4 National Spectrum Management Authority

Based on the international allocations and regulatory provisions the national spectrum management authority allocates frequency bands for certain purposes in a national frequency allocation table. Specific frequencies are then assigned to specific users or applications.

Usually a license gives an exclusive right to operate in a specific frequency range, in a specific location or geographic area and under specific technical conditions (e.g., power level, antenna height, antenna location etc.) and other conditions such as service obligations and (network) build-out requirements. Some bands may be used for (mainly) short range applications under a general authorization without the need for an individual license. Although this general authorization is often referred to as " license-exempt" there are strict (general) regulations attached to these authorizations to avoid interference. The compliance of spectrum users with the general or individual authorization is monitored and enforced.

If the demand for spectrum within a particular band is considered to be significantly less than the supply licenses are usually granted on a first come first served basis. When spectrum demand exceeds the supply, the spectrum regulator has to use another mechanism to award the licenses. Increasingly, regulators have turned to comparative hearings or "beauty contests" and more recently to spectrum auctions (Anker, 2010b; Nekovee and Anker, 2012).

A EU Member State has the right to set conditions on the use of spectrum under the Framework Directive. These conditions can include appropriate limits that aim to avoid harmful interference to other radio services. These conditions can be harmonized on a European wide basis either through a European Commission Spectrum Decision (which is mandatory for EU Member States) or by an ECC Decision or Recommendation. Alternatively, if no mandatory or voluntary harmonized guidance is available a regulatory measure can be developed on a national basis.

This annex provides a list of publications of the author and presentations of the author at conferences and workshops.

II

List of publications and presentations

II.1 List of publications

Anker, P. (2008) “Does Cognitive Radio needs Policy Innovation?”, CRNI First Annual Conference. Brussels.

Anker, P. (2010a) “Cognitive Radio, the Market and the Regulator”, New Frontiers in Dynamic Spectrum Access Networks, 2010 IEEE Symposium on.

Anker, P. (2010b) “Does Cognitive Radio need Policy Innovation?”, *Competition and Regulation in Network Industries*, 11 (1): 2-26.

Anker, P. (2013) *Governance of the radio spectrum. An actor–centric framework for analysis*. 1st International Conference on Public Policy. Grenoble.

Anker, P. (2014) “International Regulations and DSA”, *Cognitive Radio Policy And Regulation*. Springer. pp. 2-14.

Anker, P. (2014) “Finding a Sweet Spot for CR”, *Cognitive Radio Policy And Regulation*. Springer. pp. 367-372.

Anker, P. (2015) “12. International regulatory framework for spectrum and spectrum sharing”, In O. Holland, H. Bogucka and A. Medeisis (eds), *Opportunistic Spectrum Sharing and White Space Access: The Practical Reality*. New York: Wiley. pp. 259 - 276.

Anker, P. (2017) “From spectrum management to spectrum governance”, *Telecommunications Policy*.

Anker, P. (2017) “Cognitive Radio:The Need to Align Regulations with Technology”, In W. Zhang (ed) *Handbook of Cognitive Radio. Springer.*

Anker, P. and Lemstra, W. (2011) “The governance of radio spectrum: licence-exempt devices”, In W. Lemstra, V. Hayes and J. Groenewegen (eds), *The Innovation Journey of Wi-Fi: The Road to Global Success*. Cambridge: Cambridge University Press. pp. 288-330.

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I learned most from writing the articles that did not make it to this list.

Peter Anker, 2016

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Ende, B., Brouwer, F., et al. (2010) "Radio voor OOV - Op weg naar de intelligente kameleon", *Verbinding* (Juni 2010): 12-17.

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Kruys, J., Anker, P., et al. (2014) "Spectrum Sharing Metrics", *Info*, 16 (5): 19-31.

Kruys, J., Anker, P., et al. (2016) "Sharing License-Exempt Spectrum based on Multi-dimensional Metrics", *info*, 18 (2): 38-52.

Lemstra, W., Anker, P., et al. (2011) "Cognitive Radio: Enabling technology in need of coordination", *Competition and Regulation in Network Industries*, 12 (3): 210-235.

Minervini, L.F. and Anker, P. (2014) "Impact Assessment of CR Policy and Regulation", *Cognitive Radio Policy And Regulation*. Springer. pp. 251-307.

Nekovee, M. and Anker, P. (2012) "Regulatory Policy and Economics of Cognitive Radio for Secondary Spectrum Access", *Cognitive Communications*. John Wiley & Sons, Ltd. pp. 283-317.

II.2 List of presentations

"Does Cognitive Radio needs Policy Innovation?", CRNI First Annual Conference, Brussels, 2008.

"Towards a EU Policy for Cognitive Radio?", Cognitive Radio – Technology and Regulation Workshop, Brussels, 28 January 2010.

"Cognitive Radio, the Market and the Regulator", IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks, Singapore, April 2010.

"What are radio waves and how can this resource best be managed? Towards a framework for further analysis". Workshop "Radio spectrum governance: the need for coordination", 13th International Annual Conference on the Economics of Infrastructures, Delft, May 2010.

"Cognitive Radio: Enabling Technology in Need of Coordination", 3rd Annual CRNI Conference, Brussels, 19 November 2010.

"Cognitive Radio – The Need for Coordination", 2nd meeting of COST Action IC0905 TERRA, Lisbon, 19-21 January 2011 (2nd Best Presentation Award).

"CR: the need for coordination – Lessons from the past", 3rd meeting of COST Action IC0905 TERRA, Brussels, June 2011 (2nd Best Presentation Award).

"CR: the need for coordination – Lessons from the past", Wireless Innovation Forum European Conference, Brussels, 22 – 24 June 2011.

"Cognitive Radio - Aligning the Regulatory Environment with the Technology, a Business Case Perspective", 5th annual CRNI Conference, Brussels, 30 November 2012.

"Cognitive Radio: aligning the regulatory environment with the technology, an actor-centric approach", 7nd meeting of COST Action IC0905 TERRA, Thessaloniki, April 2013 (1st Best Presentation Award).

"Mobile Communications in the Netherlands - Lessons learned", The Canadian Spectrum Summit, Toronto, May 2013.

"Governance of the radio spectrum. An actor–centric framework for analysis", 1st International Conference on Public Policy, Grenoble, June 2013.

"Spectrum Regulations and their Impact on Cognitive Radio", Summer School 2013 on Cognitive Wireless Communications, King's College London, UK, 8-12 July 2013.

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"Sharing license-exempt spectrum based on multi-dimensional metrics", International Spectrum Workshop of Silicon Flatirons Center University of Colorado Law School, Université Paris-Dauphine, Paris, June 2017.

III

List of abbreviations

1G	1st Generation of mobile communications
2G	2nd Generation of mobile communications
3G	3rd Generation of mobile communications
3GPP	3rd Generation Partnership Project
4G	4th Generation of mobile communications
5G	5th Generation of mobile communications
AMPS	Advanced Mobile Phone System
ANSI	American National Standards Institute
BTA	Basic Trading Area
CDG	CDMA Development Group
CDMA	Code Division Multiple Access
CEPT	Conférence Européenne des administrations des Postes et Télécommunications
CR	Cognitive Radio
CTIA	Cellular Telecommunications Industry Association
DCS	Digital Cellular Communications
DECT	Digital Enhanced Cordless Telecommunications
DS	Direct Sequence
DTI	Department of Trade and Industry
ECC	European Communications Committee
ECO	European Communications Office
EIA	Electronics Industry Association
ERC	European Radiocommunications Committee
ERO	European Radiocommunications Office
ERMES	Enhanced Radio Messaging System
ETNO	European Telecommunications Network Operators
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access

FH	Frequency Hopping
FM	Frequency Modulation
FOMA	Freedom of Mobile Multimedia Access
FPLMTS	Future Public Land Mobile Telecommunications System
GHz	GigaHertz
GSM	Global System for Mobile Communications, originally Groupe Spécial Mobile
HIPERLAN	High Performance Local Area Network
Hz	Hertz
IAD	Institutional Analysis and Development framework
IEEE	Institute of Electrical and Electronics Engineers
IMT-2000	International Mobile Telecommunications for the year 2000
IMTS	Improved Mobile Telephone System
IP	Intellectual Property
ISM	Industrial, Scientific and Medical
ITU	International Telecommunication Union
kHz	kiloHertz
LTE	Long Term Evolution
MTA	Major Trading Area
MTS	Mobile Telephone Service
MHz	MegaHertz
NCE	NeoClassical Economics
NIE	New Institutional Economics
NMT	Nordic Mobile Telephone
NOI	Notice of Inquiry
NPRM	Notice of Proposed Rulemaking
OIE	Original Institutional Economics
OLN	Openbaar Landelijk Net
PCN	Personal Communications Network
PCS	Personal Communications Service
PTT	Postal Telegraph and Telephone service
RACE	Research and development in Advanced Communications technologies in Europe
RBOC	Regional Bell Operating Company
RCC	Radio Common Carrier
RHC	Regional Holding Company
RLAN	Radio Local Area Network
RSPP	Radio Spectrum Policy Programme
SCP	Structure-Conduct-Performance
SMA	Spectrum Management Authority
SOLAS	Safety of Life at Sea
TACS	Total Access Communication System
TCE	Transaction Cost Economics
TDMA	Time Division Multiple Access
TFTS	Terrestrial Flight Telecommunications System
TIA	Telecommunication Industry Association

TUF	Título de Usufructo de Frecuencia
UMTS	Universal Mobile Telecommunications System
UTRA	Universal Terrestrial Radio Interface
WARC	World Administrative Radio Conference
WECA	Wireless Ethernet Compatibility Alliance
WIDL	Wireless Industrial Data Link
WLAN	Wireless Local Area Network
WRAN	Wireless Regional Area Network
WRC	World Radiocommunication Conference

Samenvatting in het Nederlands

Het radio frequentiespectrum is een hulpbron die gebruikt wordt voor een veelheid aan diensten en toepassingen. Het is echter niet mogelijk om deze hulpbron zonder beperkingen te gebruiken. Het gebruik van een frequentie door een gebruiker beïnvloedt op dat moment het gebruik van (bijna) dezelfde frequentie door andere gebruikers in de directe omgeving. Dit wordt veroorzaakt door een fenomeen dat interferentie wordt genoemd. Radio-ontvangers hebben moeite om het gewenste signaal te onderscheiden van andere signalen met (bijna) dezelfde frequentie als de ontvangst-frequentie. Er is coördinatie nodig tussen de gebruikers om problemen met interferentie te voorkomen.

Het gebruik van het frequentiespectrum is van oudsher sterk gereguleerd door de overheid. Het beheer van het radio frequentiespectrum is daarbij gebaseerd op het opdelen van het frequentiespectrum in frequentiebanden die zijn bestemd voor een bepaalde dienst of toepassing. Deze wijze van opdelen van het frequentiespectrum legt de nadruk op het voorkomen van interferentie en technisch efficiënt gebruik van het frequentiespectrum door een strikte scheiding tussen de verschillende toepassingen aan te brengen. Het voorkomen van interferentie wordt in de literatuur altijd aangehaald als de belangrijkste reden voor de overheid om de rol van centrale coördinator op zich te nemen. In dit proefschrift wordt er vanuit gegaan dat de overheid nog een tweede, zelfs belangrijkere, reden had en dat is de bescherming van het publieke belang. Dit is een aspect dat in de literatuur niet of nauwelijks wordt geadresseerd.

Dit traditionele spectrummanagement regime heeft zijn beperkingen. De twee belangrijkste beperkingen zijn ten eerste dat delen van het frequentiespectrum nauwelijks worden gebruikt, alhoewel het in zijn geheel is toebedeeld aan specifieke diensten en toepassingen, en ten tweede is dit regime (te) traag om het gebruik van frequenties aan te passen aan veranderende marktomstandigheden en veranderingen in technologie.

Om tegemoet te komen aan deze bezwaren zijn twee alternatieve benaderingen voorgesteld om het frequentiegebruik te managen. Eén voorstel is gebaseerd op eigendomsrechten en het andere voorstel is gebaseerd op het creëren van een spectrum commons, waarbij eenieder vergunning-vrij van het frequentiespectrum gebruik kan maken onder strikte voorwaarden ten aanzien van dat gebruik.

De discussie rond frequentiemanagement heeft zich de afgelopen jaren vooral gericht op de theoretische voor- en nadelen van het ene voorstel ten opzichte van het andere. Het is daarmee vooral een ideologische discussie over de (veronderstelde) superioriteit van de ene oplossing ten opzichte van de andere. Het empirisch bewijs is mager en vooral anekdotisch van aard. De laatste tijd wordt steeds meer aandacht gevraagd voor een samenstel waarbij beide voorstellen worden gebruikt voor het beheer van het frequentiespectrum. Daarbij is echter niet of nauwelijks aandacht voor hoe een dergelijk samengesteld regime eruit zou moeten zien en wat de rol is die dan voor de overheid is weggelegd.

In beide voorstellen wordt de coördinatie meer aan de markt of andere private initiatieven overgelaten en is de rol van de overheid in de coördinatie verkleind. De focus ligt daarbij op economisch efficiënt gebruik van het frequentiespectrum. De rol van de overheid ten aanzien van het beschermen van het publieke belang wordt hierbij zoals gezegd niet geadresseerd.

Dit proefschrift beoogt een bijdrage aan de discussie te leveren door aandacht te vragen voor de rol van de overheid en de bescherming van het publieke belang in een regime dat is gericht op economisch efficiënt gebruik. Centraal hierin staat de verschuivende rol van de overheid als de coördinatie meer bij private actoren wordt belegd. Dit brengt ons tot de volgende onderzoeksvraag:
Hoe kan economisch efficiënt spectrum gebruik worden bereikt, onder borging van het publieke belang?

Bij de beantwoording van deze vraag, wordt er allereerst vanuit gegaan dat spectrummanagement in essentie een coördinatieprobleem is waarvoor meerdere oplossingen mogelijk zijn. Om deze centrale vraag te beantwoorden wordt een analyse gemaakt van de coördinatie-activiteiten die nodig zijn in spectrummanagement. Het proefschrift bestaat dan ook uit twee delen. In het eerste deel wordt een analyse gemaakt van het coördinatie-activiteiten die plaats vinden rond het gebruik van frequenties en onder welke omstandigheden deze coördinatie in de markt of anderszins aan private actoren kan worden overgelaten. Deze analyse wordt gemaakt aan de hand van een aantal historische casussen.

Een raamwerk wordt gebruikt om deze analyse te structureren. Een raamwerk specificeert de algemene set aan variabelen en hun onderlinge relatie. Het voorziet in een coherente structuur om het materiaal te ordenen en om patronen te ontwaren (Rapoport, 1985). Het gekozen analytische raamwerk is gebaseerd op het "institutionele analyse en ontwikkeling raamwerk" (IAD) zoals ontwikkeld door E. Ostrom en anderen. Dit IAD raamwerk is ontwikkeld om een systematische analyse en het ontwerp van de benodigde instituties mogelijk te maken en om alternatieven te vergelijken (Ostrom, 2007b).

De analyse van de historische casussen wordt afgesloten met een concluderend hoofdstuk dat inzicht geeft in de coördinatie-activiteiten met betrekking tot spectrummanagement. De bevindingen van de historische casussen bestaan uit twee soorten lessen. Ten eerste, inhoudelijke lessen over spectrum management zelf, en in de tweede plaats, en belangrijker, een conceptuele les over de rol van de overheid, of meer specifiek over de relatie tussen overheidsactoren en private actoren. De conceptuele les geeft een antwoord op een oproep van Blomquist en DeLeon (2011): "De relatie tussen overheids- en niet-overheids actoren zelf is rijp voor onderzoek met behulp van IAD." En dat is precies wat er is gedaan, hoewel slechts voor de specifieke gemeenschappelijke hulpbron van het radiofrequente spectrum.

Op basis van deze inzichten wordt een verfijning van het raamwerk voorgesteld dat in spectrummanagement gebruikt kan worden bij de analyse van de coördinatie tussen de overheid en private actoren. Dit conceptuele raamwerk dat is afgeleid van de inhoudelijke lessen over spectrummanagement wordt in het tweede deel allereerst gebruikt om een analyse te maken van een recente casus over de rol van de overheid bij de introductie van een nieuwe innovatie technologie voor het gebruik van frequentieruimte. Vervolgens wordt het raamwerk gebruikt om de onderzoeksvraag te beantwoorden en een geherdefinieerd spectrummanagement proces voor te stellen. Spectrummanagement wordt hierbij geherdefinieerd van een centraal (door de overheid) aangestuurd proces tot een decentraal proces waarin coördinatie tussen actoren plaatsvindt. De rol van de overheid verschuift hierbij van een centrale aanstuurder van een proces naar een facilitator en monitor van dit proces.

Inhoudelijke lessen over het beheer van het frequentiespectrum

Eén van de eerste lessen die de historische casussen hebben onthuld, is bevestiging van de reden waarom de overheid de rol van centrale coördinator in spectrummanagement op zich heeft genomen. Deze reden is niet het voorkomen van interferentie maar bescherming van het publieke belang. Uit analyse van de historische casussen blijkt dat het publieke belang verband houdt met specifieke belangen die verbonden zijn aan diensten of toepassingen die het radiospectrum gebruiken, zoals het gebruik van een radio aan boord van een vliegtuig of een schip om de veiligheid van passagiers te waarborgen in de lucht of op zee. Het publieke belang is dan ook meer omvattend dan enkel het algemene belang van economisch efficiënt gebruik van het frequentiespectrum.

De meeste veranderingen in het beheer van het frequentiespectrum werden veroorzaakt door problemen met het publieke belang dat aan een specifieke dienst is gekoppeld. Het begon met regelgeving omtrent de veiligheid van personen op zee en interoperabiliteit in een tijd dat de radio voornamelijk werd gebruikt voor maritieme draadloze telegrafie. De opkomst van met name de radio-omroep heeft geleid tot "chaos in de ether". Door deze "tragedy of the commons" werd de vrijheid van meningsuiting bedreigd. Deze "chaos in de ether" kon ontstaan doordat het gebruik van de ether door de radio-omroep, waarbij continu een kanaal bezet wordt gehouden, niet verenigbaar was met de bestaande routine van radiotelegrafisten om het frequentiespectrum te delen. Alle tot dan toe bestaande diensten waren destijds een vorm van radiotelegrafie waarbij het mogelijk was om het frequentiespectrum gezamenlijk te gebruiken door de dagelijkse werkroutine van radiotelegrafen om naar een kanaal te luisteren, zodat duidelijk was dat een kanaal vrij was, voordat het in gebruik werd genomen. De kenmerken van de radio-omroep waren niet verenigbaar met deze (informele) institutionele regeling met een "chaos in de ether" tot gevolg. De opkomst van de radio-omroep heeft in 1927 geleid tot het "command and control" regime. Het is een regime waarbij de voor meerdere soorten gebruik geschikte hulpbron werd onderverdeeld in meerdere delen voor de verschillende radiodiensten. Hoewel de naam "command-and-control" anders suggereert, is het een gediversifieerd regime waarin de overheid de primaire coördinator is, maar een deel van de coördinatie wordt overgelaten aan de private actoren zelf, buiten de overheid om. Deze private coördinatie in standaardisatieorganisaties en gebruikersverenigingen wordt vaak over het hoofd gezien in het debat over het beheer van het frequentiespectrum.

De invoering van een aanpak met eigendomsrechten werd getriggerd door de deregulering en liberalisering van sectoren die tot nu toe gekenmerkt werden door publiek beheerde monopolies, waaronder de mobiele telecommunicatiesector. De institutionele verandering, die al in de late jaren 1950 door Coase (1959) werd voorgesteld, paste perfect bij de nieuwe publieke doelstellingen die zijn verbonden aan de liberalisering van telecommunicatie-infrastructuur en de invoering van concurrentie op de markt voor mobiele telefonie. Diverse landen kozen ervoor om vergunningen voor de tweede generatie mobiele telefonie te veilen.

De invoering van een spectrum commons benadering had ook zijn oorsprong in deregulering. Het werd getriggerd door de beslissing van de FCC om spread spectrum technologie toe te staan voor civiele communicatiedoeleinden. Met deze technologie werd gedeeld gebruik van het frequentiespectrum door een groot aantal radioapparaten mogelijk, zei het over een relatief korte afstand, zoals draadloze lokale netwerken en draadloze telefoons. De beslissing van de FCC heeft geleid tot de (zeer) succesvolle introductie van Wi-Fi. De coördinatie-activiteiten die nodig waren om deze draadloze lokale netwerktechnologie te ontwikkelen, werden pas gerealiseerd nadat een private actor (NCR) een eigen belang had in de vorm van een prangende business case. Deze private coördinatie vond plaats in een standaardisatie-arena buiten de overheid om. Het private belang van NCR om deze technologie te standaardiseren, was verenigbaar met het publieke belang van het FCC met betrekking tot zijn spread spectrum besluit.

Uit deze observaties kan de les worden getrokken dat er geen eenvoudige oplossing is voor het beheer van het frequentiespectrum en dat er geen enkelvoudige aanpak mogelijk is die altijd bruikbaar is. Het recente debat over eigendomsrechten versus een spectrum commons heeft de discussie om tot een oplossing te komen voor het beheer van het frequentiespectrum vertroebeld. Deze discussie verving de dichotomie van nationalisering versus privatisering met een nieuwe van eigendomsrechten versus een spectrum commons. De historische casussen laten zien dat beide alternatieve benaderingen bruikbaar en relevant zijn naast het bestaande command-and-control-regime.

In de benadering met eigendomsrechten wordt spectrum beschouwd als een input voor de levering van commerciële diensten door een beperkt aantal gebruikers, zoals mobiele communicatie of omroep, die vooraf een grote investering vereisen. De dienstverlener is alleen bereid om deze investering te doen als deze zeker kan zijn dat er een goed rendement op de investering mogelijk is. Exclusieve gebruiksrechten zorgen ervoor dat de eigenaar voor een lange tijd zekerheid heeft over toegang tot spectrum om de investeringen terug te verdienen en een zekere winst te maken.
De verhandelbaarheid van gebruiksrechten in een markt is alleen haalbaar als de transactiekosten voldoende laag zijn.

De spectrum commons-aanpak is vooral handig voor apparatuur, waarbij door de onbeperkte hoeveelheid potentiële gebruikers de coördinatiekosten te hoog kunnen worden. In dit geval worden algemene regels omtrent het gedrag van de zender gebruikt om interferentie tussen de apparaten te voorkomen. Elke fabrikant mag apparaten op de markt brengen zolang deze zich houden aan de algemeen gestelde voorschriften.

Dat geen van beide alternatieve benaderingen algemeen kan worden gebruikt blijkt ook duidelijk uit de specifieke casus van Guatemala. De hervorming van het frequentiespectrumbeheer in Guatemala werd geïnspireerd door Coase's idee met de grootschalige introductie van eigendomsrechten. Het aanpak was zeer succesvol om investeringen in mobiele telecommunicatie-infrastructuur te stimuleren. De casus toont echter ook enkele beperkingen aan van deze benadering. Het laat de problemen zien van deze aanpak voor het gebruik van het frequentiespectrum door korte afstandsradioapparaten, zoals Wi-Fi. Het toont ook aan dat de overheid in deze benadering problemen heeft met het borgen van het publieke belang dat aan sommige soorten van gebruik is gekoppeld, b.v. het publieke belang van de "vrijheid van meningsuiting" bij de omroep, met name het gebruik van FM-radio door de verschillende inheemse gemeenschappen.

Vandaar dat het niet een kwestie is van het kiezen van de meest geschikte (alternatieve) aanpak. Een gemengde benadering is nodig, met individuele eigendomsrechten voor spectrumgebruik en vergunningvrij gebruik naast het bestaande overheidsbeheer. Dit is vergelijkbaar met waarnemingen van Ostrom en anderen met betrekking tot het beheer van complexe 'common pool resources'. Grote en complexe 'common pool reosurces' vereisen meer formele regels door overheidsbetrokkenheid, waarbij gebruik wordt gemaakt van een mix van individuele eigendomsrechten, gemeenschappelijk eigendom en regelgeving (Ostrom, 1990; McGinnis en Ostrom, 1996; Libecap, 2005; Pennington, 2013).

Een conceptuele les: Een raamwerk voor het beheer van het frequentiespectrum

De inhoudelijke lessen geven geen antwoord op hoe zo'n gemengde aanpak kan worden geïmplementeerd. Om hier een antwoord voor te formuleren, is het noodzakelijk om de coördinatie-activiteiten nader te bekijken. Dit heeft geleid tot een conceptuele les (zie hoofdstuk 5). De coördinatie-activiteiten die nodig zijn tussen actoren vinden niet plaats in een statische omgeving. Als dit het geval was, zouden de institutionele afspraken zoals vastgesteld in 1927 nog volstaan. Coördinatie wordt veroorzaakt door de noodzaak om in te spelen op veranderde omstandigheden. De grootste uitdaging van het frequentiespectrumbeheer ligt niet in de allocatie, de toewijzing van vergunningen, of in de aanpak van interferentie als zodanig, maar in de noodzaak om aanpassingen te maken als de omstandigheden veranderen. Deze verandering kan van technische aard zijn, b.v. ontwikkeling van een nieuwe technologie; of kan van economische aard zijn, b.v. een veranderende vraag naar diensten; of dit kan politiek zijn, b.v. een verandering in het publieke belang.

In de meeste literatuur over het frequentiespectrumbeheer wordt interferentie gezien als de centrale reden voor dit beheer. Het is echter belangrijk om te beseffen dat de controle van interferentie niet het doel van het frequentiespectrumbeheer is, maar het onderwerp is van een coördinatieactiviteit die wordt veroorzaakt door de noodzaak om te reageren op veranderingen. Alle (publieke en private) actoren die betrokken zijn bij deze coördinatie-activiteit zullen hun eigen belang hebben om aan deze activiteit deel te nemen.

Het IAD-kader stelt dat het gedrag van actoren in de arena waar coördinatie plaatsvindt beïnvloed wordt door drie sets van externe variabelen: (1) de fysieke en materiële condities, waarvan de kenmerken van de hulpbron, de aangeboden diensten en de technologie die gebruikt wordt om deze diensten te leveren belangrijke elementen zijn; (2) de kenmerken van de formele en informele regelgeving; en (3) de kenmerken van de (groepen van) actoren die betrokken zijn. Het IAD-kader stelt verder dat als er een externe verandering plaatsvindt, coördinatie nodig is om zich aan te passen aan de nieuwe situatie. Aanpassing van de regelgeving om deze verandering aan te pakken, kan een coördinatie-activiteit op het volgende hoger niveau vereisen. Coördinatie op het collectieve niveau is nodig om de regels op operationeel niveau te wijzigen. In het geval van het beheer van het frequentiespectrum kan een coördinatie-activiteit niet alleen leiden tot veranderingen in de institutionele omgeving (voor het lagere niveau), maar kan dit ook leiden tot een technologische oplossing of een mix van zowel institutionele veranderingen als technologische veranderingen. Deze rol van technologie als resultaat van coördinatie krijgt nauwelijks aandacht in de huidige literatuur over het IAD-kader. Dit alternatief voor een technologische oplossing in plaats van een institutionele oplossing voor het coördinatieprobleem verdient deze aandacht echter wel.

De exploitatie van het radiofrequentiespectrum voor het leveren van producten en diensten kan worden beschouwd als een complex socio-technisch systeem. Deze systemen betreffen meerdere actoren, bevatten technologische subsystemen en componenten die van invloed zijn op de prestatie van het systeem en hebben maatschappelijke, politieke en economische relevantie en impact. Ze zijn dynamisch in de zin dat ze voortdurend veranderen en aanpassen. Technologie en regelgeving zijn sterk verweven in deze systemen (Hughes, 1987). De toepassing van nieuwe technologie kan veranderingen in het regelgevend kader nodig maken. Op zijn beurt kan de bestaande regelgeving van invloed zijn op investeringsbeslissingen ten aanzien van innovatie en gebruik van technologie.

In hun interactie worden de actoren geleid door de structuur, die wordt bepaald door het regelgevend kader en de technologie. Zij zullen proberen de structuur te beïnvloeden en te veranderen als dit bijdraagt aan de realisatie van hun doel. In de interactie tussen actoren is er niet altijd een gemeenschappelijk doel. Elke actor heeft zijn eigen redenen om deel te nemen en streeft zijn eigen belang na, waarbij de belangen van verschillende actoren tegenstrijdig kunnen zijn (Economides, 1996; Scharpf, 1997). Coördinatie zal alleen succesvol als het resultaat wederzijds voordeel oplevert voor alle actoren (Ostrom, 2005b). Met andere woorden, als de actoren die aan deze coördinatie-activiteit deelnemen, allemaal (in voldoende mate) hun eigen doel kunnen bereiken. Dit houdt in dat er niet alleen behoefte bestaat aan afstemming (alignment) tussen het regelgevend kader en technologie, maar dat deze afstemming alleen kan leiden tot een succesvol resultaat als ook afstemming mogelijk is tussen de belangen van de verschillende deelnemers in deze coördinatieactiviteit.

De interactie waarbij de actoren proberen de technologie af te stemmen op het regelgevend kader en omgekeerd, wordt getoond in onderstaande figuur S-1.

De actoren kunnen grofweg worden ingedeeld in twee zich onderscheidende groepen. Ten eerste zijn er private actoren (aangeduid met de versimpelde term bedrijven) die mogelijkheden hebben om innovatieve technologieën, nieuwe producten en nieuwe diensten te ontwikkelen. Daardoor kunnen zij andere actoren dwingen om te reageren. Dit zijn bedrijven zoals fabrikanten van apparatuur en dienstaanbieders. Anderzijds zijn er actoren die in staat zijn het regelgevend kader te bepalen waarbinnen alle actoren moeten optreden. Dit zijn publieke actoren (aangeduid met de versimpelde term overheid), waaronder de politiek, overheidsdiensten en toezichthouders (Finger, Crettenand, Lapernrouza en Künneke, 2010).

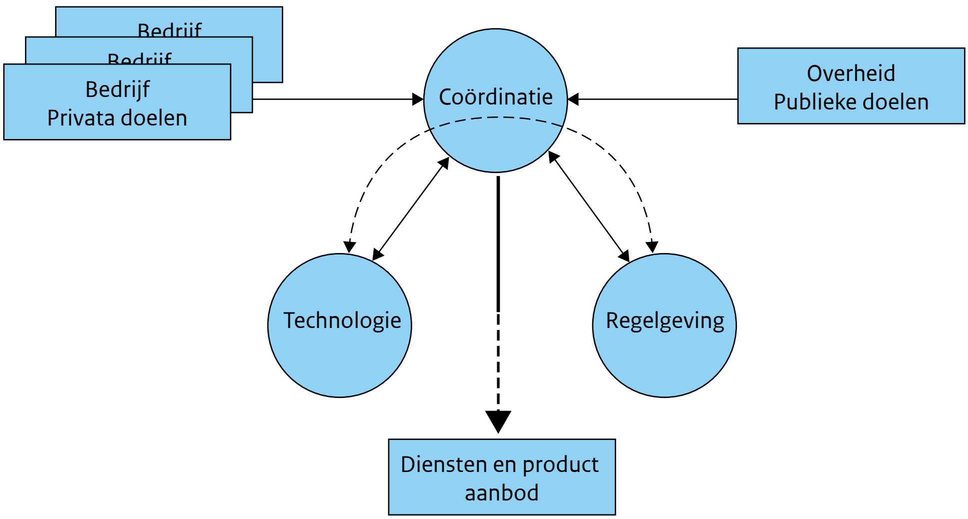
Dit 'alignment'-raamwerk is gebouwd rond het idee dat de exploitatie van het frequentiespectrum door private actoren niet alleen de private belangen van bedrijven dient, maar ook de publieke belangen van de overheid dient. Het publieke belang wordt gerealiseerd door middel van een regelgevend kader die regels en voorschriften oplegt voor de exploitatie van het frequentiespectrum door deze private actoren. Dit regelgevende kader moet zowel afgestemd zijn op de technologie als ook een succesvolle exploitatie mogelijk maken. Hoewel afstemming tussen het regelgevend kader en de technologie nodig is, is het dus niet voldoende. Het is ook nodig dat de belangen van de overheid en die van de private actoren op elkaar aansluiten. Dit tweede niveau van afstemming garandeert dat de beoogde commerciële exploitatie die het publieke belang dient, wordt ondersteund door het regelgevend kader.

De noodzaak van dit tweede niveau van afstemming tussen de belangen van de private actoren en die van de publieke actoren wordt expliciet gemaakt in hoofdstuk 6. Uit de casus van de introductie van cognitieve radiotechnologie in (witte vlekken in) frequentiespectrum van de televisieomroep in de Verenigde Staten blijkt dat de FCC een zeer voorzichtige stap voor stap benadering heeft gevolgd om het regelgevend kader zo goed mogelijk af te stemmen op de huidige stand van technologie. Echter, of er afstemming is tussen het door de FCC geformuleerde publieke belang van het mogelijk maken van breedband toegang in plattelandsgebieden met het private belang van bedrijven die deze breedbanddienst zouden moeten leveren, blijft nog te bezien.

Het voorgestelde afstemmingsraamwerk kan worden beschouwd als een verfijning van het IAD-kader voor een specifiek type 'common pool resource'. Het is een raamwerk voor coördinatie met betrekking tot een complex socio-technisch systeem waarin overheidsactoren en private actoren van elkaar afhankelijk zijn bij het realiseren van hun respectieve doelen. Het regelgevend kader moet zekerheid bieden aan private actoren om te investeren in nieuwe technologie en de exploitatie ervan. Als uit winstoogmerk wordt besloten om het systeem niet te gebruiken zoals bedoeld, zal de overheid zijn doel ook niet kunnen realiseren.

Het voorgestelde raamwerk combineert inzichten in het beheer van complexe 'common pool resources' met inzichten in de afstemming tussen het regelgevend kader en technologie. Hoewel het een raamwerk is dat ontwikkeld is op basis van waarnemingen in de coördinatieactiviteiten die verband houden met een bepaald complex socio-technisch systeem, i.c. de exploitatie van het radiofrequentiespectrum, is de mogelijke toepassing hiervan breder. De auteur is van mening dat het raamwerk kan worden gebruikt in de analyse van complexe socio-technische systemen in het algemeen, waarbij er behoefte bestaat aan coördinatie tussen overheidsactoren en private actoren om het systeem te beheren, zoals bijvoorbeeld energie-, communicatie-, transport- en postdiensten. Deze systemen kunnen worden beschouwd als 'common pool resources' die essentiële diensten leveren aan de samenleving (Künneke en Finger, 2009). Verder onderzoek is nodig om te kunnen bevestigen of dit raamwerk inderdaad geschikt is voor analyse van het gezamenlijke beheer bij andere complexe socio-technische systemen.

Het afstemmingsraamwerk werd ontwikkeld op basis van case studies met betrekking tot de ontwikkeling van succesvolle technologie. Er zijn ook een aantal technologieën die niet succesvol zijn



Figuur S-1 Een dynamisch model voor de interactie tussen actoren om afstemming tussen technologie en regelgeving te bereiken.

gebleken.[304] Analyse van het falen van deze technologieën wordt aanbevolen om de robuustheid van het raamwerk en de onderliggende hypothese ervan op de twee niveaus van afstemming te testen.

Een geherdefinieerd spectrummanagement proces

Het afstemmingsraamwerk wordt gebruikt om een hernieuwd spectrummanagement proces in hoofdstuk 7 voor te stellen. Zoals gezegd is het beheer van het frequentiespectrum een coördinatieproces om aan te passen aan veranderingen in marktvraag, technologische vooruitgang en veranderingen in het publiek belang. Het voorgestelde raamwerk suggereert dat coördinatieactiviteiten die nodig zijn om zich aan te passen aan veranderende omstandigheden alleen succesvol zijn als de uitkomst zodanig is dat de doelstellingen van de verschillende deelnemers aan deze coördinatieactiviteit verenigbaar zijn. Vandaar dat het uitgangspunt voor een herdefiniëring van het proces de doelstellingen zijn van de actoren die betrokken zijn bij de coördinatie-activiteiten met betrekking tot spectrumbeheer.

Het is niet toevallig dat de discussie over beide alternatieve benaderingen voor spectrumbeheer pas in de jaren negentig tractie kreeg na de liberalisering van de telecomsector. Liberalisering heeft het doel van economisch efficiënt gebruik toegevoegd aan de door de overheid nagestreefde doelstellingen. Een proces werd opgestart waarbij aan marktwerking en concurrentie de voorkeur werd gegeven boven een gecentraliseerde marktordening door de overheid. Concurrentie wordt daarbij gezien als een instrument om dit toegevoegde doel van economisch efficiënt gebruik te bereiken door het stimuleren van industriële efficiëntie, een optimale allocatie van middelen, technische vooruitgang en de flexibiliteit om zich aan te passen aan een veranderende omgeving (Motta, 2004).

Sindsdien werd een goed functionerende markt één van de publieke belangen die moeten worden geborgd. De overheid vertrouwt op marktwerking aangevuld met regulering om een mix van economische en maatschappelijke doelen te dienen. De maatschappelijke doelen worden gerealiseerd door private actoren. In het geval van mobiele communicatie wordt het frequentiespectrumbeleid gebruikt om een markt voor mobiele telefonie en mobiel internet te creëren. Specifieke verplichtingen kunnen aan de vergunningen worden gekoppeld om maatschappelijke doelen te dienen, bijv. een dekkingsverplichting.

Marktwerking beoogt een oplossing te bieden voor beide zwakke punten van het huidige ‘command-and-control’ regime. Gedecentraliseerde coördinatie in de markt zou moeten leiden tot een efficiënter gebruik van het frequentiespectrum en de markt zou beter in staat moeten zijn om in te spelen op veranderende omstandigheden. Dit komt goed overeen met de literatuur over het beheer van ‘common pool resources’. In deze literatuur wordt bewijs geleverd dat beheer met een overheid in ‘command-and-control’, niet de meest effectieve aanpak is en kan leiden tot een economisch inefficiënte exploitatie van de hulpbron. De belangrijkste reden is dat de overheid kennis ontbreekt over de exploitatie van de hulpbron om succesvol te zijn als de centrale coördinator in het beheer van de bron (Ostrom, 1990; Baland en Platteau, 1996; Dietz, Ostrom en Stern, 2003).

‘Market design’ vereist een verschuiving in de rol van de overheid. De rol van de overheid verschuift van een overheid in controle van een centraal aangestuurd proces van spectrumbeheer naar een facilitator van gedecentraliseerde coördinatie in de markt met behulp van een (multi-actor) spectrum governance proces. Deze verschuiving kan worden

[304] Daarbij kan gedacht worden aan bijvoorbeeld het Europese paging systeem ERMES, het Terrestrial Flight Telephone System en de Europese standaard voor draadloze netwerken HiperLAN.

beschouwd als een volgende (en eventueel laatste) stap in het liberaliseringsproces dat nog niet is erkend.

De rol van de overheid in deze coördinatie-activiteit is het ontwerpen van een markt waarin gedecentraliseerde coördinatie kan plaatsvinden. De overheid kan het functioneren van de markt verbeteren door de markt te faciliteren, bijvoorbeeld door deze van gespecialiseerde informatie over het gebruik van spectrum te voorzien. De overheid moet de markt, met specifieke regelgeving, corrigeren om de publieke belangen te borgen als deze niet gerealiseerd worden als resultaat van het gedecentraliseerde marktproces zelf.

Het voorgestelde 'markt design' is gebaseerd op een gemengd regime van exclusieve gebruiksrechten, vergunningen en vergunningvrije toegang. Dit ontwerp biedt mogelijkheden voor infrastructuur gebaseerde dienstverlening (bijvoorbeeld mobiele communicatie) door nationale aanbieders op basis van exclusieve spectrumgebruiksrechten. Meer gespecialiseerde diensten gericht op een specifieke groep zakelijke gebruikers kunnen worden aangeboden door zowel nationale aanbieders als niche spelers op basis van verhandelbare (lokale) vergunningen. De mogelijkheid om de markt op lokaal niveau te betreden, maakt de markt 'contestable', wat de noodzaak om het gedrag van dominante nationale aanbieders te reguleren vermindert (Church and Ware, 2000). Marktwerking wordt verder versterkt door een markt voor apparaten gebaseerd op vergunningvrije toegang. Dit biedt bedrijven eenvoudig toegang tot spectrum om nieuwe applicaties en diensten aan te bieden en biedt flexibiliteit om tegemoet te komen aan veranderingen in de vraag naar bepaalde applicaties en diensten zonder de noodzaak om eerst een langdurig proces in te gaan om de regelgeving te wijzigen.

Een essentieel onderdeel van gedecentraliseerde coördinatie en besluitvorming is de beschikbaarheid van informatie over het gebruik van de hulpbron en de variabiliteit ervan over de tijd (McGinnis en Ostrom, 2008). De beschikbaarheid van deze informatie in de markt kan de transactiekosten verlagen (Dietz, Ostrom et al., 2003; Stern, 2011). De overheid kan deze informatie verstrekken over het daadwerkelijk gebruik van de hulpbron, omdat het deze informatie zelf ook al nodig heeft om effectief toezicht te kunnen houden. De overheid kan ook aanvullende informatie verstrekken om onzekerheid voor private actoren verder te verminderen door informatie te verstrekken over b.v. de beschikbaarheid van toekomstig spectrum voor mobiele communicatie als gevolg van internationale onderhandelingen op de World Radio Conference, over de timing van toekomstige frequentieveilingen en over maatschappelijke doelstellingen van de overheid in verband met het gebruik van het frequentiespectrum.

Een functionele markt die decentrale besluitvorming mogelijk maakt, vereist ruimer gedefinieerde toewijzingen en duidelijk gedefinieerde gebruiksrechten. In het verleden werden zeer specifieke toewijzingen gemaakt voor de verschillende radiodiensten. Deze strikte scheiding van de verschillende radiodiensten is niet alleen ongewenst, het is ook niet meer nodig. Tegenwoordig is er technologie beschikbaar die kan worden gebruikt om verschillende diensten aan te bieden. Een goed voorbeeld is de convergentie van mobiele communicatie en omroep. De strikte relatie tussen dienstverlening en technologie is dan ook niet meer geldig. Desalniettemin is de achterliggende gedacht om interferentie beheersbaar te houden door vergelijkbare technologie in het frequentiedomein te groeperen nog steeds geldig. Dit betekent dat de toewijzing van frequentiespectrum kan worden verbreed, gebaseerd op het gedrag van de technologie in het frequentiedomein.

Dezelfde soort redenering is van toepassing op de regelgeving voor vergunningvrij gebruik van het frequentiespectrum. De Europese regelgeving van vergunningvrij gebruik is nog steeds zeer specifiek en gebaseerd op de afzonderlijke behandeling van diverse toepassingen. De regels kunnen vereenvoudigd worden door een radioprofiel en bijbehorend interferentiepotentieel te definiëren in termen van algemene spectrumbenuttingscriteria, gebaseerd op het frequentiebeslag in termen van geografische locatie, tijd en bandbreedte, voor een bepaalde frequentieband - ongeacht de technologie of toepassing waarvoor de technologie wordt gebruikt (Kruys, Anker et al., 2016).

Als de toewijzingen meer generiek worden gemaakt, wordt het spectrum niet langer onderverdeeld in aparte frequentiebanden per gebruikersgroep. In plaats daarvan worden de frequentiebanden gedeeld tussen verschillende gebruikersgroepen. Dit zal de karakteristiek van het coördinatieprobleem fundamenteel veranderen. Als een hulpbron slechts door een enkele gebruikersgroep wordt gebruikt, hebben de gebruikers een gemeenschappelijk belang in de exploitatie van de hulpbron. Als een hulpbron wordt gedeeld tussen verschillende gebruikersgroepen kunnen die tegenstrijdige belangen hebben. Dit maakt het coördineren van een door meerdere type gebruikers gedeelde hulpbron moeilijker en kan leiden tot een situatie waarin coördinatie niet plaatsvindt. De overheid kan als een neutrale derde partij coördinatie tussen verschillende gebruikersgroepen met een tegenstrijdig belang faciliteren. Een mogelijkheid om dit te doen is het faciliteren van een overlegplatform voor onderhandelingen over het gebruik van de hulpbron (Steins and Edwards, 1999). 'Face-to-face' communicatie in een 'community of practice' kan de groep actoren helpen om informatie te delen, begrip te verkrijgen en vertrouwen te creëren tussen de leden van de groep.

Tot nu toe is aangenomen dat de overheidsdoelstellingen met betrekking tot het publiek belang door de private actoren worden gerealiseerd. Dit is echter niet altijd het geval. Daarom kan het nodig zijn dat de overheid regels oplegt om het publieke belang te realiseren. De overheid moet heel duidelijk en transparant zijn in zijn publieke doelstellingen, zodat de markt hierop in kan spelen. De regels om het publieke belang te borgen, zullen noodzakelijkerwijs het gedrag van de private actoren beïnvloeden en kunnen beperkingen opleggen aan de commerciële mogelijkheden. Momenteel worden diensten die een publieke belang dienen beschermd door exclusief spectrum aan deze diensten toe te wijzen. De huidige technologie maakt het echter mogelijk om deze coördinatie te verleggen naar de vergunningverlening en de standaardisatie-arena. Dit vergroot de mogelijkheden voor de markt om deze diensten te leveren en om meer flexibiliteit te bieden. Vooral de recente ontwikkelingen in de mobiele communicatietechnologie (LTE en de doorontwikkeling naar 5G) hebben het mogelijk gemaakt om een veelzijdige en flexibele mix van communicatiediensten te leveren, waaronder gespecialiseerde diensten die tot nu toe hun eigen exclusieve toewijzing hebben, zoals de hulp- en veiligheidsdiensten en intelligente transport systemen (ITS). Dit kan er echter toe leiden dat dat de overheid zal moeten deelnemen aan de standaardisering van mobiele technologie om ervoor te zorgen dat de technologie de beoogde dienst daadwerkelijk kan leveren. Ook kan de overheid faciliteren om de samenwerking tussen de gebruikers van die dienst en de beoogde dienstverleners te vergemakkelijken. Zowel de standaardisatie als het faciliteren van de markt kunnen op Europees niveau nodig zijn om de benodigde 'economies-of-scale' te kunnen bereiken.

Nadat de overheid de markt heeft gecreëerd, is een belangrijke verantwoordelijkheid voor de overheid om de goede werking van de markt te controleren. Monitoring wordt een meer centraal aspect van het werk van de overheid als facilitator van gedecentraliseerde coördinatie. De benodigde monitoring zal breder zijn dan de klassieke monitoringtaak met betrekking tot radio-communicatie. Monitoring is niet alleen nodig in zijn klassieke rol om informatie te verkrijgen over activiteiten in het frequentiespectrum voor toezichts- en handhavingsdoeleinden. Dergelijke algemene informatie over het gebruik van het spectrum kan ook aan de markt worden verstrekt om de transactiekosten te verlagen. Last but not least is het nodig om te controleren of de publieke belang ook daadwerkelijk wordt gerealiseerd door de private actoren. Dit vereist algemene monitoring van het functioneren van de markt en meer specifieke monitoring in verband met de genoemde publieke doelen. Indien nodig kan de markt op basis van deze informatie worden bijgestuurd.

De focus van de overheid als facilitator van dit hernieuwde spectrum governance proces zal niet gericht zijn op bepaalde voorgedefinieerde resultaten. De focus ligt op een duidelijke formulering van strategische beleidsdoelstellingen en publieke doelstellingen, gevolgd door het faciliteren van een proces van leren en ontdekken om deze doelstellingen te bereiken. Het bereiken van deze doelen in een complexe en onzekere (veranderende) context vereist een proces waarin verschillende oplossingen worden onderzocht. Het leerproces is dus even belangrijk als het bereiken van de gestelde doelen.[305]

305 Deze constatering is ook van toepassing op het proces dat door de auteur is gevolgd om tot dit proefschrift te komen.

Curriculum Vitae

Peter Anker was born in Haarlem, the Netherlands on the 13th August 1965. He studied Electrical Engineering at the Delft University of Technology. He graduated in the field of Avionics in 1988. He started his professional career at the Neher Laboratories of KPN Research in Leidschendam. He has been working in the field of telecommunications ever since, with the main focus on radio communications.

At the moment he is working as an expert on (inter) national radio spectrum management, spectrum policy and related telecommunication policies at the ministry of Economic Affairs. Peter performed his PhD at the section Economics of Infrastructure of faculty Technology, Policy and Management of the Delft University of Technology next to his daily job at the ministry.

Peter is at the ministry actively involved in policy to further liberalize spectrum usage. He regularly participates in the RSPG Working Groups (e.g. on "Public Use of Spectrum", "Cognitive Technologies", "Review of Spectrum Use" and "Spectrum related aspects for next-generation wireless systems (5G)") and is also participating in the ITU World Radio Conferences since 2000. In the WRC-2012, he was especially involved in the agenda item dealing with liberalization and the agenda item on software defined radio and cognitive radio systems and the preparation thereof in ITU Study Group 1. As such he chaired the group that was responsible for the CPM text on Agenda Item 1.19 "Software Defined Radio and Cognitive Radio Systems".

On the national level he was one of the main authors of the "Radio Spectrum Policy Memorandum 2005" and the main author of its successor "Radio Spectrum Policy Memorandum 2016" in which the principles, choices and intentions for the current radio spectrum policy are defined. He was also the main author of the Strategic Plan on mobile communications which defines the policy behind licensing of mobile communications for the period of 2012 – 2017.

In 2010, he was co-founder of the Dutch Community of Practice on Cognitive Radio (CRPlatform.NL). Recently, he was involved in the formation of a national user association on business critical mobile broadband communications (de BTG expertgroep Kritische Mobiele Breedband Gebruikers).

Currently, he leads the program that started with the development of a new radio spectrum memorandum, followed by the development of a new Memorandum on Mobile Communications and will end with the (re)auctioning of radio spectrum for mobile communications in 2019. Moreover he is involved in the development of a strategic memorandum on (digital) connectivity. He will be the head of delegation for the Dutch administration at the World Radio Conference in 2019.

This book deals with the role of government in radio spectrum management. While current literature suggests that avoiding harmful interference and realizing economic efficient use of the radio spectrum are the prime drivers, the study revealed that realizing and safeguarding public interests have played a crucial role, including the realization of specific industrial policy objectives. A revision of the radio spectrum governance process is proposed, based on the insights obtained and building on the institutional analysis and design framework of Ostrom et al., combined with competitive market theory. Essentially proposing the next (and likely final) step in the liberalization process. The proposed revision redefines radio spectrum management from a top-down government controlled process to a bottom-up governance process in a multi-actor setting. The role of government shifts from a controller of the process to a role of market design, monitoring and facilitation.