

EFFECT OF THE OPTIMISATION TIME INTERVAL ON THE PERFORMANCE OF MOBILE NETWORKS

MASTER OF SCIENCE THESIS



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PREFACE

This Graduation Project has been undertaken as a part of the Master's in Electrical Engineering-Telecommunications program at TU Delft and has been done in cooperation with KPN. The project is supervised by Dr. Remco Litjens MSc (TU Delft) and Drs. Mathhijis Klepper (KPN). The project involves the self-optimisation of mobile networks and has been carried out using real data from KPN's network which helps to simulate a realistic cellular network. The project is designed as a simulation study with realistic network input in terms of the network layout, propagation characteristics in traffic aspects, and the implementation has been done in MATLAB. This project has been built on the base of another thesis project carried out by a colleague, Ignas Stankus, at KPN [1]. The areas used for this project are Friesland - a province in the north-east of the Netherlands, and Purmerend - a city in the north-west of the Netherlands, also a part of the Randstad. Friesland is typically considered a rural area, while Purmerend is sub-urban. The data obtained from the KPN network for Friesland and Purmerend contains a 24 hour log of the data traffic in all the 33 and 24 selected cells in the areas, respectively. This information has been processed to ascertain inter-arrival times between sessions and the sizes of the data sessions. All these parameters are crucial to this thesis study as they help in recreating a realistic network with data sessions coming in, selection of a cell, experienced SINR and throughput, and eventual departure of the session from the cell. Further, a realistic mobile network consists of several cells and each user experiences two types of signals- the signal that serves it, and the signal that interferes with the serving signal. This aspect of the network too has been realistically modelled using data from KPN. The scope of this thesis is limited to LTE in the 800 MHz band in the downlink and has been modelled for data traffic. The bandwidth for this study is 10 MHz.

The main study comprises of self-optimising the network based on three optimisation parameters – antenna tilt, RS power, and cell individual offsets. An algorithm has been designed for the optimisations in such a way that it suits the data we have available from KPN. Furthermore, the study is temporal, and thus, the optimisations are carried out at different timescales in an effort to ascertain the timescale most suitable for the self-optimisation of a network. The use of two different areas in the study also helps to compare the performance of the self-optimisation algorithm in different types of areas. The performance of the network is constantly monitored, and key performance indicators such as call drop rate, 10th percentile throughput and coverage failure probability are assessed in relation to the loads experienced by the cell in order judge performance.

In the end, recommendations have been made to KPN after thoroughly studying the results of the simulation study. These recommendations help KPN to choose an optimal time interval to carry out self-optimisations in their network.

ABSTRACT

This thesis project researches the effect of the optimisation time interval on the performance of a self-optimised mobile network. The goal of the thesis is to ascertain if there exists an optimal time interval for the self-optimisation of the KPN network, and what that interval is. In order to research this question, the project uses data from the KPN network as input, and sets up a simulation study in MATLAB. Two areas in the Netherlands are considered in this study – Friesland and Purmerend. The self-optimisation of the network is carried out through the modification of three optimisation parameters – antenna tilt, RS power, and Cell Individual Offset. The scope of the study is limited to LTE in the downlink, for the 800 MHz band. The bandwidth used in this study is 10 MHz. The performance of the mobile network has been studied using KPIs such as 10th throughput percentile, coverage failure rate, call drop rate, and load. In the end, the study analyses the results for each area, for the self-optimisation carried out by modifying the three parameters over several different optimisation time intervals, and discusses their impact on the performance of the network. A comparison has also been drawn between the performance of a self-optimised network and an un-optimised network, to highlight the gains achieved with SON. Finally, recommendations are made regarding a suitable time interval, and a relative comparison between suitability of the three optimisation parameters has been drawn.

The study finds that a suitable time interval for optimisation does exist, and is 240 minutes, for both the simulation areas. The study finds RS power to be the most suitable parameter for self-optimisation, in both the areas. However, the research runs into some unexpected results with respect to the optimisations using tilt angle, and has been discussed in detail in the report. Significant gains are observed with SON, as compared to the case of 'No SON' or an un-optimised network.

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LIST OF ABBREVIATIONS

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
ANR	Automatic Neighbour Relation
BLAST	Bell Laboratories Layered Space-Time
BPL	Building Penetration Loss
BSA	Best Server Area
CCO	Coverage and Capacity Optimisation
CDF	Cumulative Distribution Function
CIO	Cell Individual Offset
COC	Cell Outage Compensation
CPICH	Common Pilot Channel
E-UTRA	Evolved Universal Terrestrial Radio Access
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
eNB/eNodeB	Evolved Node B
EPC	Evolved Packet Core
FDD	Frequency Division Duplex
FDPS	Frequency Domain Packet Scheduling
GoS	Grade of Service
GPEH	General Performance Event Handling
GSM	Global System for Mobile Communications
HO	Handover
HSDPA	High Speed Downlink Packet Access
HSS	Home Subscriber Server
ICIC	Inter-Cell Interference Coordination
IMS	IP Multimedia Subsystem

KPI	Key Performance Indicator
LTE	Long Term Evolution
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output
MLB	Mobility Load Balancing
MME	Mobility Management Entity
MRO	Mobility Robustness Optimisation
NADC	NetAct Advanced Configurator
NGMN	Next Generation Mobile Networks
OAM	Operations, Administration and Maintenance
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OSS	Operations Support System
OVSF	Orthogonal Variable Spreading Factor
P-GW	Packet Gateway
PDN	Packet Data Network
PDSCH	Physical Downlink Shared Channel
PRB	Physical Resource Block
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RE	Resource Element
RRC	Radio Resource Control
RS	Reference Signal
RSRP	Reference Signal Received Power
S-GW	Serving Gateway
SEMAFOUR	Self-Management for Unified Heterogeneous Radio Access Networks
SFPM	SON Function Parameter Model
SINR	Signal to Interference and Noise Ratio

SON	Self-Optimising Networks/ Self-Organising Networks
SRB	Scheduling Resource Bock
TBS	Transport Block Size
TDD	Time Division Duplex
TTT	Time to Trigger
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
WCDMA	Wideband Code Division Multiple Access
XML	Extensible Markup Language

Chapter I INTRODUCTION

As mobile phones become an indispensable part of our lives, the number of mobile subscribers continues to increase across the world. The increasing number of subscribers is seen as an opportunity, and so many services are now accessible through our phones. The last decade has seen an increase in the demand for entertainment, banking, education, chat applications, etc. to be accessible on our mobile phones. This has led to an increase in the data consumption and a demand for better and faster services. Mobile network operators will face several challenges in the coming years, as the network traffic will increase manifold, and the demands placed on the network in terms on quality will increase too.

Mobile network operators aim to minimize both operational effort and cost, while also providing enhanced quality of service. They generally aim to offer a targeted quality of service level, at minimal costs. The concept of Self-Optimising Networks (SON) introduced by the Next Generation Mobile Networks (NGMN) alliance in 2008 helps to simplify the operation and maintenance of next generation mobile networks. SON aims at [2]

- Reducing operating cost, by reducing the degree of human involvement in network design, build and operate phases.
- Reducing capital expenditure by optimising the usage of available resources.
- Protecting revenue by reducing the amount of errors introduced by humans.
- Providing enhanced QoS, and improving both user experience and network performance.

The above goals can be accomplished by automating the tasks within a network, in order to facilitate self-configuration, self-optimisation, and self-healing. SON can be seen as an approach in which many functions, which were earlier done manually as a part of network planning and optimisation tool chain, have now been moved to automatic execution in the network elements and their OAM (Operations, Administration, and Maintenance) system. SON functionality is mostly vendor specific, and network operators usually engage a vendor that is able to satisfy the demands of the network and its needed functionality.

While SON concepts are very appealing to network operators, they need to be carefully integrated into the existing tool chains realizing OAM processes. Moreover, SON needs to be carefully tested before being rolled out into the live network, to make sure it does not disrupt the current operation and/or worsen it.

RESEARCH MOTIVATION

KPN started trials on the self-optimisation of its network in 2008 in Hilversum using pilot power in UMTS. Today, it has SON rolled out for the whole country and the network self-optimizes for pilot power, antenna tilt and neighbour list. This is done with the help of a tool called Mentor which has been created by Teoco [3]. However, Mentor has some limitations - it collects data from the network for a minimum of eight hours, and only then can it start optimising. At any given point of introducing an optimisation change, it needs data of a minimum of the last eight hours from the network. This is a serious limitation, because it means that we do not know whether the

network performs better when optimised for a shorter time interval, and which interval is better suited for the self-optimisation. In addition, a large self-optimisation interval, such as eight hours or one day, means the network will not be able to respond to node failures promptly, and will have reduced or no self-healing capabilities. As a part of my thesis I investigated why Mentor has this limitation, by reading some documentation on the same [4] [5] and speaking to employees within KPN [6] [7] [8] [9], and it was discovered that the software needs to process a minimum amount of input data in order to start its optimisations. This data input is collected from the network in the form of counters, general performance event handling (GPEH) traces, topology etc. The optimisations within KPN were done at a sliding window of three days for pilot power and neighbour list, and one week for antenna tilt.

The above limitation led KPN to question whether optimising the network more frequently would be good for the performance of the network. This forms the basis of my research. In this project I research smaller time intervals for optimisation, and explore whether the network performs better if the optimisation was done at a smaller time scale, for example, a few hours or minutes. It was decided to construct a simulation study around the same, in order to investigate the effect of the optimisation time window on the performance of the network. The simulation study would observe a network over a small time scale, say 15 minutes and then recommend a change in the network to ameliorate the KPIs. While in a real network, changes take time to come into effect in the network, a simulation study assumes that the network implements those changes almost instantaneously and the time to implement the changes is not factored in. The network performance is then monitored with these changes over our chosen time interval before recommending a new change.

The self-optimisation of a network is done by changing or optimising certain parameters. It was researched (Chapter 5) and ascertained that pilot power and antenna tilt are the two most widely used parameters for self-optimisations, and are also used by KPN. In addition, Cell Individual Offset (CIO) is a parameter that can be modified to impact cell selection by the UE. These three serve as the parameters of our optimisation for this thesis study, and have been discussed in detail Chapter 4.

RESEARCH QUESTION

The research question can be condensed into the following

What is the effect of different self-optimisation time intervals on the performance of a mobile network, through the modification of the optimisation parameters, namely, antenna tilt, RS power and cell individual offset?

The primary goal of the thesis is to observe and analyze whether optimizing a network at different time intervals yields different results, and if yes, which is the most suitable optimisation time interval for optimisation. The selection of the most suitable interval will be done on the basis of the KPIs. In order to realise this, the following steps are followed.

- Qualitative analysis of the three different parameters for self-optimisation.
- Creation of a realistic mobile network in simulation.

- Selection of a self-optimisation algorithm suitable for all parameters.
- Optimisation of the network using the algorithm over several different time intervals. This is done for both the selected areas and by using all three parameters.
- Analysis of the performance of the network through KPIs for these different self-optimisation intervals.

Ultimately, the project should be able to make recommendations to KPN for a suitable time interval for self-optimisation of their network. In addition, comments will be made on the effectiveness of the three methods, for each of the two areas.

STRUCTURE OF THE REPORT

The report spans across nine chapters. Chapter 2 introduces and discusses the cellular concepts relevant to this thesis project. Chapter 3 gives an introduction to self-optimising networks and discusses a few relevant use cases for SON. Chapter 4 offers a qualitative analysis of the three different parameters used for optimisation in the thesis. Chapter 5 is a review of the literature studied in preparation for this thesis, and discusses literature on all three methods of optimisation. Chapter 6 discusses modelling, which includes details such as the network layout and simulation methodology. Chapter 7 discusses the optimisation parameters, the key performance indicators, and the optimisation algorithm itself. The results are presented and discussed in Chapter 8, and conclusions and recommendations for future work are presented in Chapter 9.

Chapter II RELEVANT CELLULAR CONCEPTS

In this section we introduce and discuss cellular concepts relevant to this thesis study, so as to make the reader familiar with the terminology and concepts used in the further chapters. Since the radio access technology used for this study is Long Term Evolution (LTE), we start with the basics of LTE and its associated terminology. The chapter further explains a physical resource block in LTE, and also how a user equipment selects a serving cell.

LTE

LTE, or Long Term Evolution, can be considered as the most recent generation of cellular communications systems. LTE is a Radio Access Technology (RAT) and has higher spectral efficiency and performance than previous generations of cellular technologies, and is packet-switched only. The LTE air interface can employ either Frequency Division Duplex (FDD) or Time Division Duplex (TDD) duplexing schemes. In Europe, LTE-FDD has been deployed as LTE1800 with 1710-1785 MHz for uplink and 1805-1880 MHz for downlink, LTE800 deployed with 832-862 MHz for uplink and 791-821MHz for downlink, LTE2100 deployed with 1920-1980 MHz for uplink and 2110-2170 MHz for downlink, LTE900 deployed as 880-915 MHz for uplink and 925-960 MHz for downlink, and LTE-TDD deployed as LTE2600 within the range of 2570-2620 MHz. LTE has rather flexible channel bandwidths: 1.4, 3, 5, 10, 15 and 20 MHz, that are convenient for spectrum reallocation purposes. In this study we work with LTE in the 800 MHz band and for 10 MHz bandwidth [10].

In the downlink, LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) multiplexing which allocates resources to users in time and frequency domains, and employs narrow subcarriers instead of using a single wide band. Subcarriers are spaced every 15 kHz and 12 subcarriers make up a Physical Resource Block (PRB) (180 kHz), multiples of which are assigned to users. In the time domain carriers are divided by 10 ms long frames which are divided into 10 subframes. Each subframe is further subdivided into two slots, 0.5 ms duration each, and each slot into 7 symbols. A physical resource block in LTE is of single slot length. The LTE scheduler works on subframe basis and assigns users resources that are 180 kHz wide and 1 ms long, known as a Scheduling Resource Block (SRB). A bandwidth of 10 MHz contains 50 PRBs.

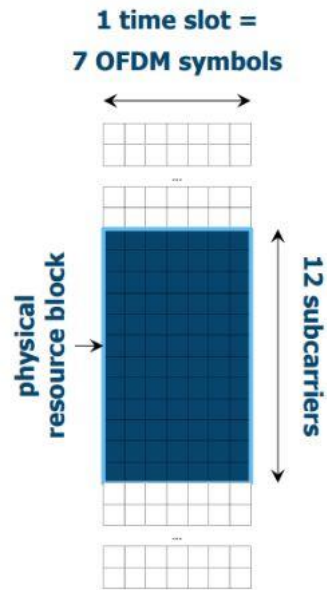


Figure 1: Physical Resource Block (PRB) [11]

Each PRB is made up of 12 subcarriers across 7 symbols, which results in 84 resource elements (RE). The figure above shows a PRB and each small square box represents one RE. 2 of the 7 symbols in each PRB are used to transmit either the Reference Signal (RS) or Physical Downlink Shared Channel (PDSCH). The PDSCH is the physical channel that carries user data. Assuming a typical deployment with two transmit antennas per cell, while one antenna port is transmitting the RS, the second antenna port transmits neither RS nor PDSCH, and is thus, silenced. The silence in that resource element is in order to avoid interference on the RS originating from the same cell. The other five symbols carry only the PDSCH. This has been illustrated in the figure below.

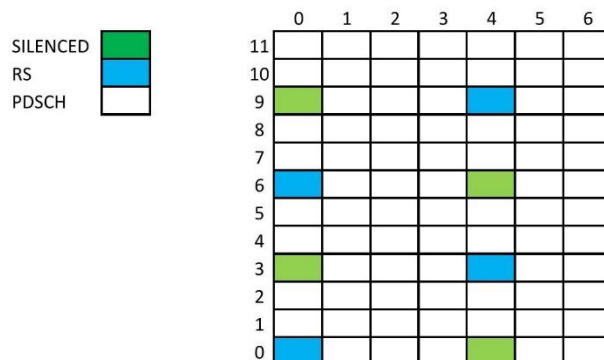


Figure 2: Resource element allocation [12]

The antennas in KPN's LTE network typically use 20 W per antenna port. This means that 40 W of power is available in each symbol of the PRB for all 50 PRBs combined, if we take both antenna ports into account. In the five symbols that only carry the PDSCH, it means that this power is dedicated entirely to transmitting the user data. For the two remaining symbols, the power has to be distributed between the PDSCH and the RS. Given a uniform energy distribution over the REs, the energy not used by the silenced REs can be used to boost either the RS or the PDSCH REs in the same symbol. For the scope of this thesis, we assume it is used to boost the PDSCH REs. The distribution of power between the RS and the PDSCH is of vital importance and is used in the self-optimisations based on the modification of the RS power.

When we increase the power in the RS, the power available in the PDSCH reduces. This is because total power in the antenna port stays constant. Since the increase in RS power leads to a decrease in the power available for the PDSCH, there is a reduction in the experienced SINR. A decrease in SINR translates directly into a decrease in user experienced bit rates and throughput. Thus, in essence, power distribution between the RS and PDSCH presents itself as a trade-off between good coverage and a good user throughput.

LTE ARCHITECTURE

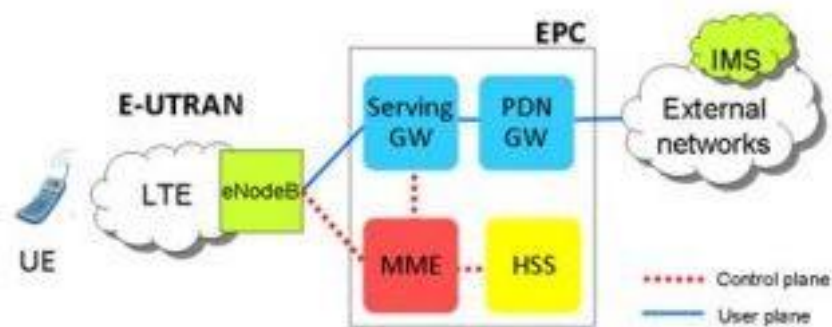


Figure 3: LTE architecture [13]

LTE is said to have a 'flat architecture'. The idea is to handle the payload (the data traffic) efficiently from a performance and costs perspective. Few network nodes are involved in the handling of the traffic, such as the eNodeB and the Packet Gateway (P-GW), which are used to tunnel IP packets between the UE and the Evolved Packet Core (EPC). It was also decided to separate the user data (also known as the user plane) and the signalling (also known as the control plane). Figure 3 shows the LTE architecture. The E-UTRAN or the Evolved Universal Terrestrial Radio Access Network is the radio access network for LTE and comprises of only one element, i.e., the eNodeB. The user equipment is connected to the E-UTRAN through its connection with the

eNodeB. The E-UTRAN is connected to EPC, the Evolved Packet Core. The EPC forms the core network for LTE and is completely packet-switched. The EPC is composed of four network elements: the Serving Gateway (S-GW), the PDN Gateway (PDN-GW), the Mobility Management Entity (MME) and the Home Subscriber Server (HSS). The EPC is connected to the external networks, which can include the IP Multimedia Core Network Subsystem (IMS).

We now briefly discuss the elements of the LTE architecture.

- User equipment (UE): UE is any device used directly by an end-user to communicate.
- Evolved NodeB: An eNodeB communicates with the UEs as well as the Evolved Packet Core (EPC), and is a part of the E-UTRAN. The eNodeB is responsible for all radio related functions, which include radio resource management, header compression, security (encryption), and connectivity to the EPC. Radio resource management includes functions such as radio admission control, scheduling, dynamic allocation of resources to UEs, etc., while header compression is basically compressing the IP packet headers to reduce the overhead and allow efficient use of the radio interface [14].
- Serving Gateway (S-GW) and Packet Data Network Gateway (PDN-GW): The gateways (Serving GW and PDN GW) deal with the user plane. They transport the IP data traffic between the User Equipment (UE) and the external networks. The Serving GW is the point of interconnect between the E-UTRAN and the EPC. The PDN-GW is the point of interconnect between the EPC and the external IP networks.
- Mobility Management Entity (MME): The MME deals with the control plane. It handles the signalling related to mobility and security for E-UTRAN access.
- Home Subscriber Server: The HSS is a database that contains user-related and subscriber-related information. It also provides support functions in mobility management, call and session setup, user authentication and access authorization.

CELL SELECTION

The pilot power received by the user equipment for an LTE network is known as the Reference Signal Received Power (RSRP). The RSRP is the basis of cell selection by the UE. The value of the RSRP is directly affected by the power allocated to the reference signal in the PRBs (discussed above). If more power is allocated to the reference signal in the PRB, the RSRP will be higher (stronger). This also means that increasing the power in reference signal increases the coverage of the cell, at the expense of the SINR.

At any given point of time, a UE receives RSRP from several different cells. When the UE wants to make a call or start a session, it looks for a serving cell. In order to select a serving cell, the UE compares all the RSRP values it is receiving, and picks the strongest signal. This cell is now the serving cell for the current call or session. It is important to note here that the value of the strongest RSRP should be greater than a minimum coverage threshold, in our case that is -124 dBm. A value lower than that will result in a coverage failure, and the session cannot be established.

Changing the RS transmit power, leads to a change in the value of the RSRP experienced by the UE. However, there is another way to impact cell selection which does not include changing the RS, but adding an offset to the existing RSRP value, in order to make the RSRP *seem* stronger (or weaker), and thus force to UE to select a different serving cell. This offset is known as Cell Individual Offset (CIO), and can have either a negative or a positive value. The purpose of the CIO is to make a cell seem less or more desirable, by modifying the RSRP through the addition of the offset. This is possible strategy to shift loads between cells, and can be used to improve the performance of a cell. CIO will be discussed in more detail in Chapter 4.

At this point, I would also like to make a distinction between coverage and Best Server Area (BSA), for the understanding of the reader. As explained above, each UE receives RSRPs from several different cells simultaneously. Coverage of a cell is that physical area where the RSRP experienced by the UE for that particular cell is above the coverage threshold, such that the area is said to be 'covered' by the cell. However, the Best Server Area is that physical area where the particular cell is the 'best server', in other words, the RSRP experienced by the UE for that particular cell is the strongest, and thus selects that cell as its serving cell. This is visualized in Figure below. A change in the RS power directly affects the BSA. An increased RS will result in a greater RSRP at the UE, and thus the area for which the cell is the best server will also increase.

Figure 4 visualises the difference between BSA and coverage area. The dotted lines represent the coverage area of the cell, and extend well into the BSA of other cells. This helps to highlight the concept that while a cell may be covering a certain area, it may not necessarily be the best server in that area.

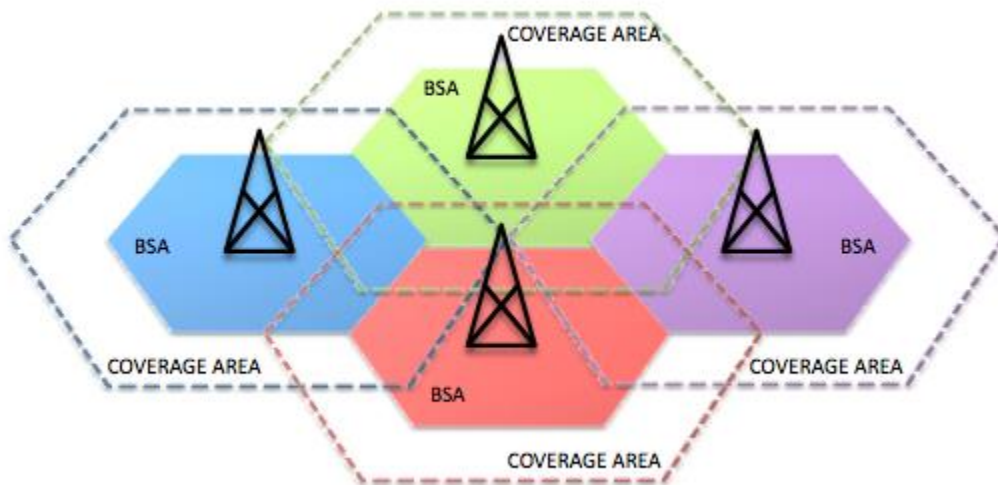


Figure 4: Difference between BSA and coverage area

AN INTRODUCTION TO SON

In recent years, the amount of wireless data consumed by users, as well as the associated growth rate has increased dramatically with significant implications for mobile operators. Modern networks are expected to cope with this demand and deliver high data rates with high Quality of Service (QoS) for a variety of applications without the need for extensive operational effort. The scale and complexity of modern mobile communication systems are strong reasons to develop self-optimising/self-organising networks.

The need for Self-Organisation in mobile networks was identified based on the day-to-day operational experience of mobile operators. The requirement was first formulated in 2008 by the Next Generation Mobile Network alliance (NGMN) [15]. Later, the Self Organising Networks (SON) concept was introduced together with the Long Term Evolution standard starting from 3GPP Release 8 as a new approach to mobile network configuration, maintenance and operation, aimed at reducing operational expenditures and improving the users' Quality of Service (QoS). The main drivers are the increasing complexity, heterogeneity and management effort [16].

At a high-level, the introduction of SON should allow for new base stations to be added in a plug-and-play manner, while existing base stations should be able to automatically adapt to network conditions and change their operational parameters. From a functional point of view, SON can be split into self-configuration, self-optimisation and self-healing [17].

Self-Configuration is a function that should be performed in the pre-operational stage, which is the deployment stage, when the radio interface is not active. This allows newly deployed eNodeBs to automatically configure their operational parameters and download required software, once they have established a connection to the core network. The configuration can include radio parameters (operating frequency, transmit power), neighbour relations and cell identification. Automatic Neighbouring Relation planning (ANR) is one of the use cases that falls under self-configuration.

Self-optimisation is performed in the operational stage, where measurements from the user equipment and eNodeB are used to assess the network performance and automatically tune operational parameters in order to optimize performance. This is done through Key Performance Indicators or KPIs and can be prioritized in the SON tool used by the operator. The KPIs may vary from operator to operator, and can also be assigned a level of priority, for e.g., an operator may set targets in the following way - the cell load in an urban location during peak hours should be minimized with a very high priority, and with high priority the dropped call rate in an urban location should be minimized [18]. Some examples where self-optimisation can be applied are Coverage and Capacity Optimisation (CCO), Mobility Robustness Optimisation (MRO), interference reduction, Mobility Load Balancing (MLB) or energy savings.

Self-healing will allow for automatic failure detection and response. There can be situations when the failure of an eNodeB can be detected by the surrounding eNodeBs or the UEs. This can be

fixed by a single eNodeB or the process may involve several eNodeBs. An example of the first case can be detecting a software failure and falling back to a previous one, while the more complex second case can be a complete failure of the eNodeB which will create a coverage hole or cause a loss in the performance or capacity. In this situation, neighbouring cells might adjust their radio parameters (antenna tilt, transmit power) to reduce the size of the coverage hole and improve the performance or capacity. Cell Outage Compensation (COC) is a self-healing function.

The figure below visualizes the three SON functions and their stage of implementation. As discussed above, self-configuration is carried out in the deployment stage of the network, while self-optimisation and self-healing are functions implemented in the operational stage of the network.

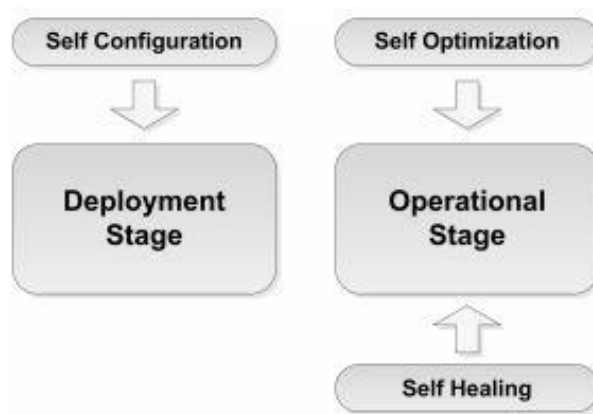


Figure 5: SON Concept [17]

ARCHITECTURE FOR SON

There are different architectures in which a SON solution can be deployed, depending on the network element where the SON process resides. They can either be centralized, distributed or hybrid. The choice of a particular architecture will depend on the implementation and the functionalities that need to be achieved.

In a centralized architecture, the SON process will run on a central server. The inputs will be gathered from the radio access network in form of KPIs and measurements such as GPEH traces, and then analysed. Changes to output parameters can be forwarded back to the RAN at regular intervals or based on triggers. A centralized architecture will be able to maintain global knowledge of the network status. Also, it will be able to estimate the impact of parameter changes over multiple cells. However, latency will be introduced by forwarding data to and from a central location and in the time interval between receiving, analysing and forwarding changes, the networks status might change again. This makes the centralized approach suitable for use cases that are not delay sensitive.

The distributed architecture will have a SON process running in each network element, e.g. eNodeB. This approach reduces the response times to within seconds or milliseconds, since the data gathering and analysis will be made at the base station. Also it doesn't present a single point of failure, such as the centralized architecture. The distributed architecture will lose the ability to estimate the overall status of the network since the information is limited to the KPIs recorded at a single network element.

The third type, hybrid architecture is a combination of the previous two. In a hybrid architecture, the SON process can be run individually for different use cases, either centralized or distributed, depending on the requirements. For example a time-sensitive or repetitive use case can be run in a distributed manner while one which impacts a larger area of the network or requires a picture of the overall network status might be run centralized.

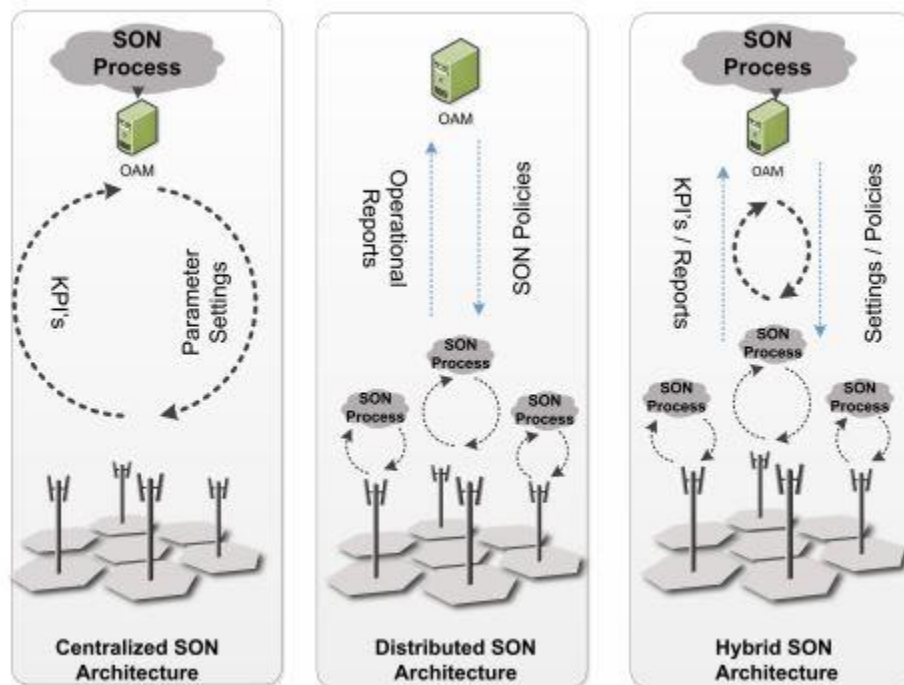


Figure 6: Architecture for Self-Organising Networks [17]

USE CASES FOR SON

Self-optimisation functions are aimed at maintaining network quality and performance with a minimal manual involvement from the operator. They monitor and analyze performance data and automatically trigger optimisation action on affected network element(s) when necessary. This significantly reduces manual involvements and replaces them with automatic adjustments, keeping the network optimized at all times. Self-optimisation, when compared to manual optimisation, can be done with finer temporal and spatial granularity, i.e. optimisations in the

network can be done more often, and also differently per cell. Several processes that were too complex to be executed manually or needed to be executed too fast such that manual execution would delay it, can now be automated using SON functions. These processes have a certain goal in mind, and optimize the network in a way that the goal can be reached. This will improve the network performance by making the network more dynamic and adaptable to varying traffic conditions and improve the user experience. A SON function that has a specific goal and optimises the network according to that goal, is called a SON use case. A SON use case changes the network in a certain way that leads it closer to its goal, for example, mobility load balancing (MLB) aims to balance the loads across the cells, while Inter-Cell Interference Coordination (ICIC) coordinates transmissions between different cells in such a way that inter-cell interference is reduced and primarily cell edge performance is enhanced. We now discuss a few use cases that are relevant to the focus of this thesis.

MOBILITY ROBUSTNESS OPTIMISATION

MRO is one of the use cases of SON. The MRO functionality is included within the self-optimizing network routines to enable seamless mobility and smooth handovers within the mobile network. Hysteresis and Time to Trigger (TTT) are two parameters crucial to a handover [19]. When the difference between the RSRP of two cells (the target cell and the serving cell) becomes equal to the value of hysteresis, a timer is started which is known as the Time to Trigger (TTT). Once this timer expires, and the RSRP of the target cell is continuously and still no worse than that of the serving cell plus the hysteresis value, then a handover decision is issued, and shortly after there is a Handover (HO) command.

There are a number of aims for the mobility robustness optimisation, including:

- *Minimise unnecessary handovers:* Unnecessary handovers lead to inefficient use of network resource. Often many unnecessary handovers take place as a "ping-pong" between two cells as the signal level especially at the cell border varies between the two cells where small changes in position can lead to multiple handovers between the same two cells.
- *Minimise radio link failures and call dropping:* Radio link failures occur at many times. In case of a radio link failure, the UE has to release the dedicated data and signaling resources which leads to discontinuation of the application [20]. This leads to a dropped call. Obviously the first step is to ensure good coverage so that the failures do not occur, but also if they do occur, to have in place a capability to quickly re-establish the connection. To improve the perceived quality of the network, reducing the fraction of dropped calls is essential.

MOBILITY LOAD BALANCING

MLB is part of the self-organizing network concept, which was introduced in LTE in Release 9. MLB attempts to improve the performance of the network by reducing the loads of highly loaded cells in the network. Usually, the MLB monitors the cell load values and tries to distribute the traffic of highly loaded cells among less loaded neighbouring cells in the network. This can be done by adjusting the cell borders, e.g. adding a Cell Individual Offset (CIO) which will be taken into

consideration for handover decisions and cell selection, or changing the RS power of the cell. The change in the RS power leads to a change in the RSRP, which in turn changes the coverage area and BSA of the cell. On the other hand, addition of a cell individual offset changes the RSRP perceived by the user, thus, makes a certain cell seem more (or less) desirable to the UE, and consequently affects cell (re)selection/handover decisions. Using these methods the service area of highly loaded cells can be made smaller, where on the other hand the service area of less loaded cells will be enlarged. Figure 8 illustrates this concept. In Figure 7, on the left we see three cells, one of which is heavily loaded, one is lightly loaded and one has a medium load. The goal is to enhance the performance in each of the cells by redistributing the loads between the three cells. On the right, we can see that being done. The dotted lines indicate the modified cell borders of the cells, by the addition of CIO, which leads to the loads getting redistributed.

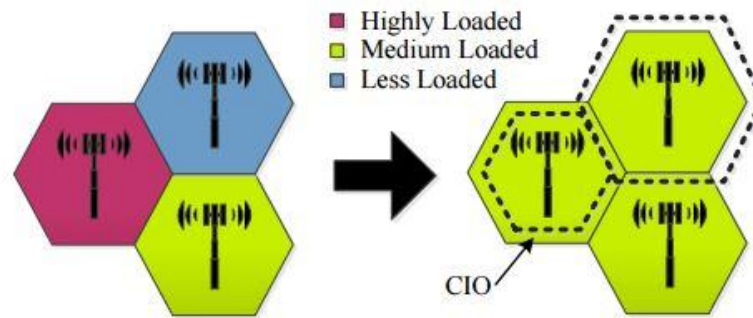


Figure 7: Adjusting Cell Individual Offsets to facilitate load balancing [21]

COVERAGE AND CAPACITY OPTIMISATION (CCO)

The objective of Coverage and Capacity Optimisation is to optimise the balance between coverage and capacity for the radio network, by considering a trade-off between capacity and coverage. The parameters used to carry out CCO are downlink transmit power and antenna tilt. A capacity and coverage optimisation is needed in case problems in the network arise, such as coverage holes, pilot pollution, weak coverage, or overshoot coverage. Pilot pollution occurs when there are too many strong cells in a particular area. Technically speaking, if there are too many cells with their RSRPs within 4 dB of the RSRP of the serving cell, they are said to be strong cells, and can lead to pilot pollution. These problems can be identified through monitoring inputs such as alarms, UE measurements and performance measurements. Once these problems have been identified, a CCO algorithm is used for optimisation to ensure good coverage and good capacity [22].

SON TOOL – MENTOR

KPN optimizes its mobile network with the help of a self-optimizing tool called Mentor, by Teeco. Mentor is a RAN optimisation and analytics software tool that delivers radio access resource optimisation and troubleshooting, while addressing the challenges imposed by LTE and complex environments, the needs of engineers and the priorities of business units [3]. Mentor supports LTE, UMTS and GSM networks and included several use cases such as mobility load balancing, radio parameter optimisation (cell neighbour list, power, antenna tilt), frequency planning, and automatic cell planning [23].

At KPN, Mentor collects data from the network, which includes General Performance Event Handling (GPEH) traces and network topology information. GPEH traces are initiated or automatically ordered by the Operations Support System (OSS), and are used to log and store events in the network [24]. This data is collected for a minimum of eight hours, which is then processed by Mentor, which recommends certain changes in the network, such as a different antenna tilt setting, different RS power value, etc. These values are then pushed to other elements within the KPN network, such as Asset, Prime and the NetAct Advanced Configurator (NADC). Asset is a radio planning tool, also by Teeco, which generates maps for radio planning and coverage management [25]. Prime is a configuration database which stores several details about the network such as the coordinates of a call, etc. The NADC is used to configure the radio and core network, and integrates well with the other elements in the network such as Asset or Prime. It collects command files and data, and distributes it to the other systems [26]. Ericsson's Operations Support System (OSS) is a domain manager for the network infrastructure. It integrates and manages a wide range of network components covering the radio access network, circuit and packet core and IMS [27]. The following figure illustrates the flow of data in the network.

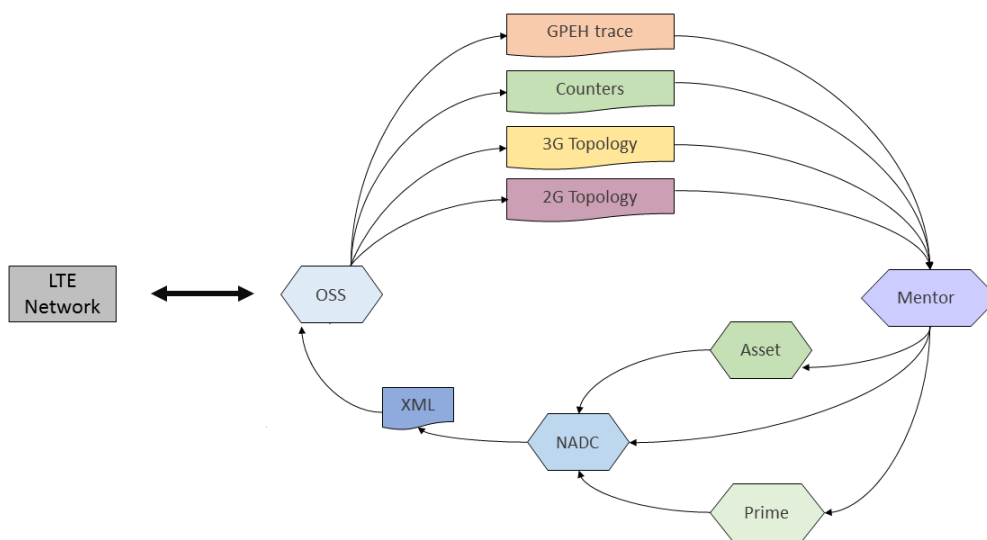


Figure 8: Flow of data in the KPN network [4]

Chapter IV QUALITATIVE ANALYSIS

In this section, we look at the three optimisation parameters used in this thesis and discuss their role in facilitating self-optimisation within a network.

RS POWER OPTIMISATION

Reference signals are used by user equipment for channel quality estimation, cell selection, and handover. The strength of the reference signal determines the best server area and the coverage area of the cell, impacts the network capacity, and thereby the quality of service, and is therefore a crucial parameter in network planning and optimisation.

Tuning the RS power affects the network in the following ways:

- RS power will affect the cell size. Reducing the RS power will reduce the BSA of the cell.
- RS power also affects the inter-cell interference. Strong RS power could lead to pilot pollution in neighbouring cells and must be tuned to avoid such a situation. As discussed earlier (Chapter 3), pilot pollution occurs when too many strong pilots are present in an area. If the RSRP for several cells is within 4 dB of the serving cell's RSRP, there is said to be pilot pollution.
- The increase in RS power, leads to a decrease in the power available in the PDSCH. This leads to lower experienced SINR, and thus a lower user throughput.

In this project, self-optimisation is done by modifying the power in the reference signal. As explained earlier in Chapter 2, an increase in the power of the reference signal leads to a decrease in the value of the PDSCH power, which leads to decrease in the SINR. In addition, an increased RS power in one cell also slightly increases the interference in co-channel cells, thus affecting the SINR of the users of those cells as well. Each time the RS power is changed for a cell, the RSRP values are changed, and thus, the BSA of the cell changes. This causes a change in the load of the cell. The load of the cell along with the SINR affect the user experienced throughput, i.e., a higher SINR leads to a higher throughput, however, a higher load leads to a lower throughput. This trade-off is important to understand while doing self-optimisations via RS power modification. For a lightly loaded cell experiencing a good throughput, the RS power can be increased to increase the BSA.

The correlation between SINR and throughput can be further explained using the Shannon-Hartley theorem, where C represents the channel capacity in bits/sec, which is the bit rate or the throughput, and B is the bandwidth of the channel in Hertz. S represents the received PDSCH signal power in Watt, while N is the average noise power and interference in the channel in Watt, and together they make up the SINR (Signal to Interference and Noise Ratio).

$$C = B \log_2 \left(1 + \frac{S}{N} \right)$$

SINR and channel capacity are directly proportional in this equation, which means an increase in the SINR leads to an increase in the throughput.

ANTENNA TILT OPTIMISATION

Antenna tilt is defined as the angle between the main beam of the antenna and the horizontal plane and is measured in degrees. This value is known as the antenna downtilt. A tilt value of zero degrees shows that the direction of the main beam is parallel to the ground and points towards the horizon.

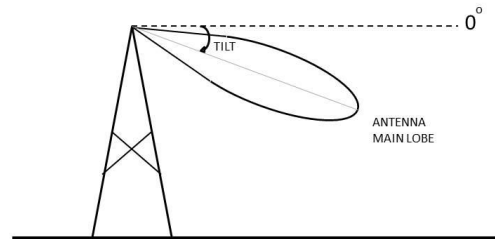


Figure 9: Antenna tilt

There are two methods by which tilt can be adjusted, either mechanical or electrical. Mechanical tilt implies adjusting the mounting brackets of the antenna in such a way that the whole antenna will be tilted in the desired direction, leaving the radiation pattern unchanged. Electrical tilt is achieved with a phase shifter in the feed network of the individual antenna's elements, which will allow for a uniform modification of the radiation pattern.

Antenna tilt modification is one of the methods of Coverage and Capacity Optimisation. Change in the antenna tilt affects the network in the following ways

- Antenna tuning affects the cell size and the coverage area of the cell. The cell size can be increased by a low tilt value, thus more users will be served by this cell. This can be done to relieve an overloaded neighbor. Alternatively, cell size can be decreased by increasing the tilt value. However, a large downtilt value may lead to coverage gaps.
- A low downtilt value can lead to pilot pollution, i.e. too many strong pilots present in a certain area. This could cause the UE to go into a state of ping pong handovers. A higher tilt value can reduce the influence of polluting sectors and prevent overshoot coverage. An optimal tilt value will keep handovers and interference to a minimum.
- A low downtilt value will also increase the inter-cell interference and decrease the SINR experienced by the user from its serving cell.
- It also affects the trade-off between the cell edge and cell average performance. As discussed, the antenna tilt will affect the cell size and for a larger cell the performance at the cell edge will be weaker than for a relatively smaller cell, which will also lead to a weaker cell-average performance.

- Changes in antenna tilt will also lead to changes in the gain values experienced at different locations throughout the cell. A change in the antenna gain effects a change in the SINR.

In this project, the tilt of an antenna is modified to self-optimize the network. When a cell throughput is good, we decrease the tilt of the antenna. A decrease in the tilt leads to a greater BSA, which leads to an increase in the load of the cell. Since the cell load has increased, the throughput is consequently expected to decrease. Similarly, for a highly loaded cell experiencing low throughput, the value of the antenna tilt may be increased, such that the BSA decreases and users could be served better, while avoiding the risk that too high tilts may lead to coverage gaps.

CELL INDIVIDUAL OFFSET OPTIMISATION

Cell Individual Offset is another parameter which can be varied to control the loads in the network. The load of an overloaded cell can be shifted to neighbouring cells by making the UE select a less suitable cell by adding a Cell Individual Offset value to its RSRP. Thus, the effective signal received by the UE is now

$$RSRP_{modified} = RSRP_{actual} + CIO$$



Figure 10: Modified cell size after the addition of a CIO

Thus, while the real RSRP value does not change, the RSRP *perceived* by the UE changes. Since the basis of cell selection is picking the strongest signal (explained in Chapter 2), the CIO addition tricks the UE into picking a different serving cell. This is explained better by the example below.

Let's say that a UE *x* is receiving an RSRP of -80 dBm from cell A and -78 dBm from cell B. The UE will select cell B as the serving cell since the stronger signal is coming from there. Let's say that the network at this moment is such that cell B is overloaded and needs to shift some users to neighbouring cells in order to offload. Cell B then informs UEs to add a CIO of 5 dB to the neighbor cell A. Cell A now has a perceived RSRP of -75 dBm, while the RSRP of cell B is still at -78 dBm. The UE will now select cell A as its serving cell. Note here that the signal from cell A hasn't gotten stronger, but has been made to seem stronger for the purpose of influencing the cell selection by the UE. This is a strategy to balance loads in the network and CIO can be used to make the UE

select a new serving cell. Usually, the customers that are at the cell boundary tend to get shifted to neighbouring cells [28].

It is important to note here that since the RSRP has not increased in reality, the probability of coverage failure does not decrease. Coverage failure is still measured with respect to the *actual* RSRP value.

CIO values can be both positive and negative [29] [30]. In this thesis project, CIO has been used to make the RS signal seem stronger or weaker and to increase or decrease the perceived RSRP at the UE, such that the cell selection gets impacted. However, since the real transmit power of the RS is not changed, the power available to the PDSCH in the PRBs does not change either, differently from the case of RS power optimisations. Thus, the addition of a CIO does effectuate a change in the loads of the cell, as the cell size is changed. If the cell size is increased, the average SINR experienced in the cell goes down, as UEs at a greater distance are served. In an unfavourable case, this could also lead to a UE selecting a cell with very low SINR, and consequently a low user throughput, which could lead to the call getting dropped. In addition, due to an increase in the load of the cell, the channel sharing increases, and the user experienced throughput decrease further.

INTRODUCTION

It is widely believed that the consequences of the wireless data growth rate will change the paradigm of network management. Future networks have to organize and optimize their parameters by themselves and have to reduce the human interaction to a minimum. However, it will take some time until this level of self-organization is achieved because the SON algorithms have to prove their performance and stability in an environment where any failure has a huge commercial impact. Extensive field verification and step by step introduction of SON features is required to develop the confidence of the mobile operators in the SON algorithms.

Conventional management of mobile access networks divides into three phases, namely network planning, deployment of network nodes (base stations) including installation and configuration of operating and radio parameters, and finally network optimisation during operation with maintenance and fault management. The configuration and optimisation of operating and radio parameter settings nowadays requires a high effort of experienced specialists, even if operational procedures are highly tool supported. So, these two phases reveal the highest potential for automation and self-organization, which finally turned out to be a must for introduction of new, more powerful radio technologies. Here we are facing the paradigm change mentioned above. Network configuration and optimisation will be more and more a task for intelligent self-organization and self-management functionality put down into the network. This will finally drastically increase the level of network automation up to widely autonomous operation. [31]

With the introduction of the new radio standard LTE (Long Term Evolution), the 3rd Generation Partnership Project 3GPP had started standardization of the first self-configuration and self-optimisation features already in the first release of LTE standards. These features focus first on self-configuration of neighborhood relations and on self-optimisation of handover performance. It has to be noticed that 3GPP restricts to the definition of procedures especially regarding measurements and signaling that are required to enable self-organization and to guarantee interoperability between user equipment, network infrastructure nodes and network management. Algorithms and procedures for optimisation remain under responsibility and competition of vendors, noting that multi-vendor interoperability is essential and needs be ensured by standardizing e.g. interfaces and measurements [31].

The European Union's Research and Innovation funding programme for 2014 – 2020, called the Horizon 2020 supports and funds several research projects for SON such as Selfnet and CogNet. Selfnet is a framework for self-organized network management in virtualized and software defined networks [32], while CogNet will develop solutions to provide a highly automated and more intelligent level of network monitoring and management, improve operational and energy efficiencies, quality of experience for the end user and facilitate the requirements of 5G [33]. SEMAFOUR (Self-Management for Unified Heterogeneous Radio Access Networks) is another project that developed SON solutions, funded within the EU FP7 funding programme. The SEMAFOUR project designed a unified self-management system, enabling the network operators to holistically manage and operate their complex heterogeneous mobile networks [34].

Research is also being done in the field of SON configuration parameters since the SON functions change based on the input from the network and the SON configuration parameters. [35] proposes the SON Function Parameter Model (SFPM) to understand the impact of these configuration parameters on the KPIs. [18] presents an approach that overcomes the manual gap between technical objectives and SON functions by choosing the best values for the SON functions configurations' manually. [36] discusses the objective of the SON Objective Manager (SOM) and presents an extended and enhanced run-time SOM with more expressive input models, namely, context-dependent, weighted operator objectives allowing a better trade-off and SON Function models defining the possible values of KPIs for some configuration.

The scope of this thesis includes a study of the optimisation time intervals used for self-optimisation of a mobile network. However, no literature could be found addressing a similar problem. Moreover, the scope of this study includes self-optimising on three parameters, namely, antenna tilt, RS power and CIO. However, no literature could be found which used all three methods, and drew a comparison between the methods. The sections that follow discuss the literature studied for each of the three methods, and briefly discuss each relevant publication. At the end of each session, a discussion has been presented which discusses the knowledge gained from the existing literature, and the gap in the knowledge.

SELF-OPTIMISATION OF RS POWER

Pilot power is a widely self-optimised parameter in mobile networks, and is often optimized in conjunction with the antenna tilt. Several papers explore the concept of pilot power optimisations, and relevant literature for the same has been discussed below.

In [37], a hybrid two-layer optimisation framework is proposed to enhance the network capacity and coverage, wherein the so called 'eCoordinator' adjusts the antenna tilt of each cell at large time granularity, and each individual eNB performs its pilot power tuning locally at small time granularity. The paper considers several KPIs essential to network capacity and coverage, such as, coverage holes, coverage overlaps, capacity of the network, etc. These KPIs are combined into a weighted optimisation function. Essentially the system consists of three modules, namely, the network performance measurement and evaluation module, the pilot power tuning module at each eNB, and the tilt and weight adjustment module at the eCoordinator, respectively. The simulation results in the paper demonstrate that the proposed scheme can enhance overall system capacity and coverage performance, as well as adapting to dynamic network requirements.

[38] proposes a method for centralized self-optimisation of pilot powers to perform load balancing between base stations. The proposed method uses a stochastic function to model the functional relationships between KPIs and network parameters, and subsequently performs optimisation using a pattern search algorithm in a recursive manner.

[39] examines the problem of setting the pilot power levels with the objective of load balancing in WCDMA networks, for the cities of Berlin and Lisbon. This objective is modelled using a capacity ratio, which relates the transmission power of the cell to the traffic intensity of its service area. The paper characterizes the optimal pilot power setting for maximizing the capacity ratio over the

cells, and an iterative algorithm that not only finds the maximum overall capacity ratio, but also attempts to minimize the total pilot power. Since the capacity ratio is essentially a ratio of the total transmission power available in the cell to the amount of power needed to serve the users in the service area, maximising the ratio ensures better service for all users.

An algorithm for optimisation of Pilot power in femtocells has been proposed in [40] using genetic algorithm as a basis for the optimisations.

[41] proposes an optimisation algorithm for maximum HSDPA throughput in a moving hotspot scenario. Both antenna tilt and pilot power are tuned in the algorithm which uses a round robin and maximum channel-to-interference ratio scheduler, and simulated annealing to carry out the optimisations.

[42] presents a simple approach to pilot power optimisations in 3G networks. The algorithm uses Grade of Service (GoS) as the deciding factor in the loop. The paper defines GoS as the ratio of the number of served users to the total number of users in the simulation area. As soon the GoS increases above 97%, new users are introduced into the system till GoS falls down to 95% again. This is possible since a simulated network is used. Next, a so-called quality factor is created to determine whether the network is heavily loaded or not, and includes a measure of the uplink cell load, a measure of base station transmit power utilization, and a measure of the Orthogonal Variable Spreading Factor (OVSF) code tree utilization. If the value of this quality factor falls below 0.5, the antenna power and tilts are tuned down, and for a value above 0.7, they are tuned up. No changes are made if the value is found to be between 0.5 and 0.7. The paper presents an algorithm for the same.

DISCUSSION

The section above discusses and summarizes a relevant fraction of the papers read for this project. In addition, several KPN internal reports were also read. No literature could be found that carried out the optimisations as a temporal study, and explored the effects of the optimisation time interval on the KPIs. A trend that can be noticed from the literature review is that most research has been done with a simulated network, and several papers tend to optimise antenna tilt and pilot/RS power together. Contrastingly, several different approaches to optimisation have been used over the bulk of the literature. Successful optimisation results have been achieved with all these different approaches, and the end objective has largely been the amelioration of the network i.e. either capacity gain, or coverage improvement or an improvement in the quality experienced by the user equipment.

This presents us with an opportunity for research i.e. studying the influence of the self-optimisation interval on the optimisation results.

SELF-OPTIMISATION OF ANTENNA TILT

The most impactful parameter for the self-optimisation of a mobile network is the antenna tilt. Antenna tilt needs to be set such that the traffic within the 'own' cell is served with maximum link gain but at the same time the interference in neighbouring cells needs to be minimized, keeping in mind that the notion of 'own' cell is also affected by the tilt of the antenna. Especially in case

of collocated sites with multi-band antennas, there might be strong restrictions on the possible tilts to be taken into account during optimisation. Antenna tilt is a configuration parameter conventionally associated with a high optimisation effort and strongly impacts cell coverage as well as capacity. At the cell border, the cell coverage becomes a critical parameter because SINR may drop down to levels below 0 dB as a result of neighbor cell interference in reuse one systems. The potential of antenna tilt optimisation is visible for the extreme case where one sector fails or is switched off temporarily for power saving reasons and the coverage in the affected area has to be overtaken by neighbor cells.

Several studies have been carried on the effective self- optimisation of the antenna tilt.

In [31], optimisation of the antenna tilt has been carried out with two optimisation targets. The first is to provide continuous coverage in which connections can be established with acceptable service quality, and the second is cell capacity. Cell capacity has been chosen as a target since we know that SINR distribution over the cell area depends again on antenna tilt. The simulation studies incorporate these targets with two metrics: the cell throughput under full buffer assumption and the 5th percentile of the throughput CDF, the latter reflecting cell edge performance. The optimisation was carried out for 19 tri-sectorized base stations which have been located on the basis of a hexagonal cell layout with 500 m inter-site distance. The spatial distribution of SINR values has been collected from a UE performing a random walk through a simulation area.

Most technical papers optimize both antenna tilt and CPICH power together. In [42], optimisation in UMTS network is achieved using an iterative optimisation process. Each loop has two steps: in the first step the parameters are changed according to a rule based optimisation technique, and in the second step, the network is evaluated.

[43] proposes an optimisation framework which is based on regular terminal measurements instead of specialized test measurements to track the state of the radio network. The results show that choosing antenna tilts according to straightforward geometry based setting results in very poor overall performance, while the used method based on simulated annealing technique finds comparing solutions to the one obtained by an exhaustive search, and it remains applicable to larger networks as well, where the exhaustive search would be infeasible.

A heuristic algorithm for tilt optimisation was found in [44] which is intrinsically linked to the pilot power in the network. In each iteration, the algorithm examines the current antenna tilt setting and calculates the optimal uniform pilot power level for the same. The aim of the algorithm is to provide full coverage in the network. The algorithm iterates over the number of all possible tilt angle configurations and changes the antenna tilts on a cell-by-cell basis.

[45] uses an algorithm that is an heuristic variant of the so-called 'Gradient Ascent Method' and defines a utility metric using spectral efficiency. Weights are assigned to the cell edge users. Each antenna is a part of a set and has an individual tilt value which is stored in a tilt vector. All angles are initialized to 11 degrees at the beginning. The algorithm picks a sector at random and makes it the center sector and creates a cluster with its neighbouring cells. It does this over and over till all cells have an optimal tilt setting.

A network level LTE downlink simulator is constructed and evaluations are performed using static snap-shots in [46]. The paper also takes into account handovers and mobility. However, it doesn't serve as a good basis for our optimisations since it needs too many inputs. In addition, it doesn't allow any flexibility to control the time window of optimisation and does not define how each step of the antenna tilt is achieved.

[47] considers two simulation cases: one with a fixed tilt, where a fixed angle of tilt is calculated for 90% coverage of the cell, and the second with a variable tilt which tilts in steps between a minimum and maximum value. The paper combines antenna downtilting with adaptive beam forming. The angle of the downtilt depends on the position of the user and adjusts the beam according to the user position. Timing advance information has been used to approximate mobile distribution in cells. The proposed system does not modify the covered area. A serious drawback of the paper is that while it proposes an interesting concept, it does not present a clear algorithm.

In [48], self-optimisation of antenna tilt has been carried out using two phases. The first phase needs to be performed quickly, and a method based on the Golden Section Search algorithm is used to find a near-optimal tilt angle. The first phase is carried out by creating a fitness function using the average and 5th percentile spectral efficiency. In the second phase, the tilt angle is fine-tuned by frequent explorations of the near-optimal region. Changes are made in steps of 0.2 degrees of tilt. Certain aspects of this paper were used to shape the current algorithm being used in this thesis.

DISCUSSION

The above section contains a comprehensive overview of the most relevant fraction of literature reviewed for the optimisation of antenna tilts. It was observed that a wide variety of optimisation algorithms have been used, mostly heuristic, all with good results. In addition, mostly algorithms optimize in steps, within a lower and upper limit of tilt. Other than technical papers, literature and reports from within KPN were also studied, which included antenna tilt optimisations carried out in Mentor.

As seen with the pilot power study, the literature for antenna tilt optimisations also fails to look at optimisations at varied time scales and thus presents no recommendations for a suitable time interval or an analysis of the effect of time intervals on the self-optimisation of the network. This indicates a clear opportunity for innovative research and analysis, as undertaken by this thesis project.

SELF-OPTIMISATION OF CELL SELECTION THROUGH CIO MODIFICATION

Most of the literature found on CIO modification focusses on Handover (HO) Optimisation. A handover decision is made based on three parameters- Time to trigger, Hysteresis and CIO, and thus, CIO modification forms a large part of HO advancing or delaying. Handover optimisations form an integral part of several SON use cases such as Mobility Load Balancing (MLB) and Mobility Robustness Optimisation (MRO), and thus the literature available on the same is vast [21] [19] [49] [50]. CIO can be modified for two purposes: to facilitate a handover in the network, or to

select a serving cell. The scope of this thesis is limited to the latter because handovers have not been dealt with in this thesis.

The literature available for self-optimisation of cell selection through CIO modification was extremely limited. The following section includes a discussion on the same.

A patent has been filed under 'Using a cell individual offset to bias user equipment towards a cell and provide cell range expansion' - [51], and discusses the use of CIO in biasing a user towards using a small cell or 'low power node' over a base station/macro cell. It aims at a decentralised biasing method according to which the amount of bias/CIO to be applied by user equipment can be changed in a semi-dynamic way based upon the loading of a cell or cells of the network. The patent provides a network node that offers several different potential offset cell bias values for a cell and allows a user equipment to select one in dependence upon its current antenna configuration. Alternatively, the UE can also decide the suitable CIO and signal that to the network.

[29] is a paper that handles cell reselection with the help of CIO modification. The paper discusses the clash between the two SON cases of MRO and MLB, and how simultaneous execution of the two in a network may alter the HO parameters in conflicting ways, and thus, either degrades the HO performance or does not achieve load balancing gains. The paper aims to resolve this dispute by balancing loads by cell reselection by the UEs in RRC idle mode. A cell is made to seem more desirable by the addition of an offset value. While this is one of the few papers that handles cell selection by CIO modification, it does not explicitly list any algorithm. Moreover, the cell reselection is working in conjunction with MRO in the network.

DISCUSSION

The section above summarizes the literature available pertaining to cell selection by a UE by modification of the CIO parameter. As observed, the literature available is not sufficient. In addition, no documentation could be received from KPN on the same as they do not modify CIO offsets or use them for load balancing in a significant way.

There is evidently a knowledge gap in the literature openly available, and the best approach for optimisation in this thesis would be the development of a simplistic algorithm based on already gained knowledge of how the CIO impacts cell selection. The optimisation can then be analyzed for results based on the KPIs.

Chapter VI MODELLING

Cellular system-level simulations have a list of elements on which they are built, and which determine the overall network performance, as they are related to the simulation methodology. These elements are: traffic service type (data session), service characteristics (session size or duration distributions), radio wave propagation models, RAT-specific parameters and network layout.

To carry out the research goals of this thesis, it was decided to build on the system-level simulator created in [1] and run the optimisations in MATLAB. This chapter discusses the implementation of the simulator, details of the radio wave propagation characteristics and traffic modelling. It also discusses the SINR and bit rate equations, and the calculations of the antenna gain and RS power.

The goal of the thesis is to keep the implementation as realistic as possible, thus all data used in this thesis has been sourced from the KPN network, and described in the report for the understanding of the reader.

NETWORK LAYOUT

The areas chosen for this study are Friesland and Purmerend. Friesland is a province in the north-east of the Netherlands and can be classified as rural, while Purmerend is a city in the north-west of the Netherlands, also a part of the Randstad, and can be classified as sub-urban. The data collected from KPN for Friesland contains 33 cells, while that for Purmerend contains 24. Figure 11 shows the two selected areas marked on a map of the Netherlands.

The technology used in this thesis project is LTE in the 800 MHz band, with an assigned bandwidth of 10 MHz. There are two transmit antennas per sector, with 20 W available per antenna port. The initial RS power has been set at 18.2 dB for each cell, while the initial antenna tilts vary per cell. Cells at the boundary of the selected simulation areas do not have interfering cells on all sides, and thus their performance statistics will be too optimistic. These cells are said to have boundary effects, and are usually not picked to study the performance of the network. Figure 12 shows a layout of the simulated cells in Friesland, and Figure 13 zooms into the center of the city of Sneek, to give a clearer view of the cells there. Figure 14 is a layout of the simulated cells in Purmerend. Figure 15, 16 and 17 present the best server area maps for Friesland and Purmerend.



Figure 11: Representation of selected areas [52]

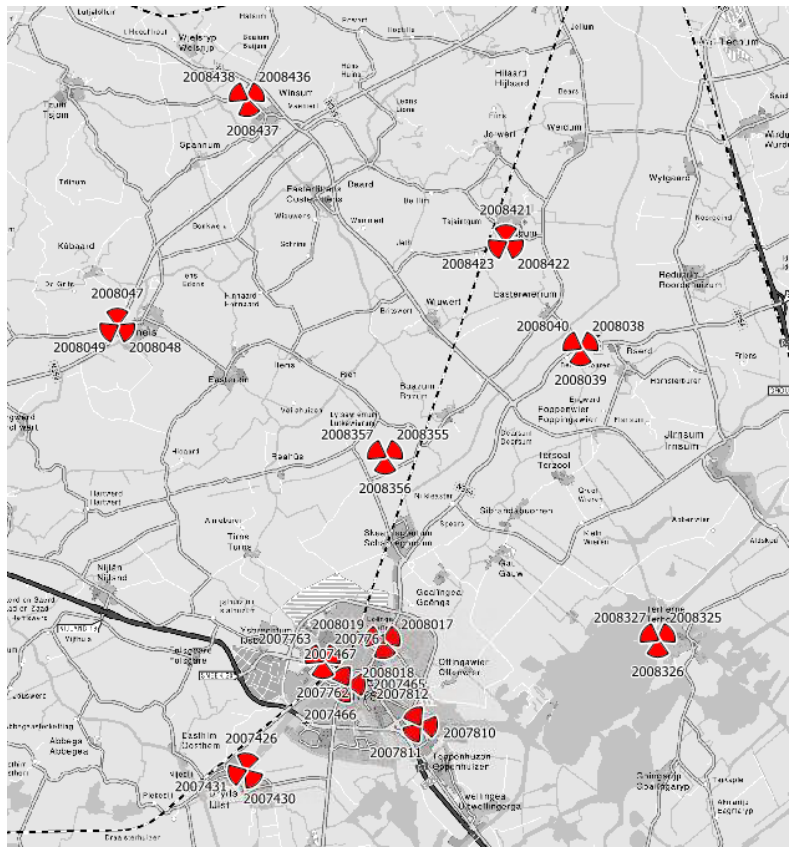


Figure 12: Simulated cells in Friesland



Figure 13: Simulated cells in Friesland (zoomed in view of Sneek)

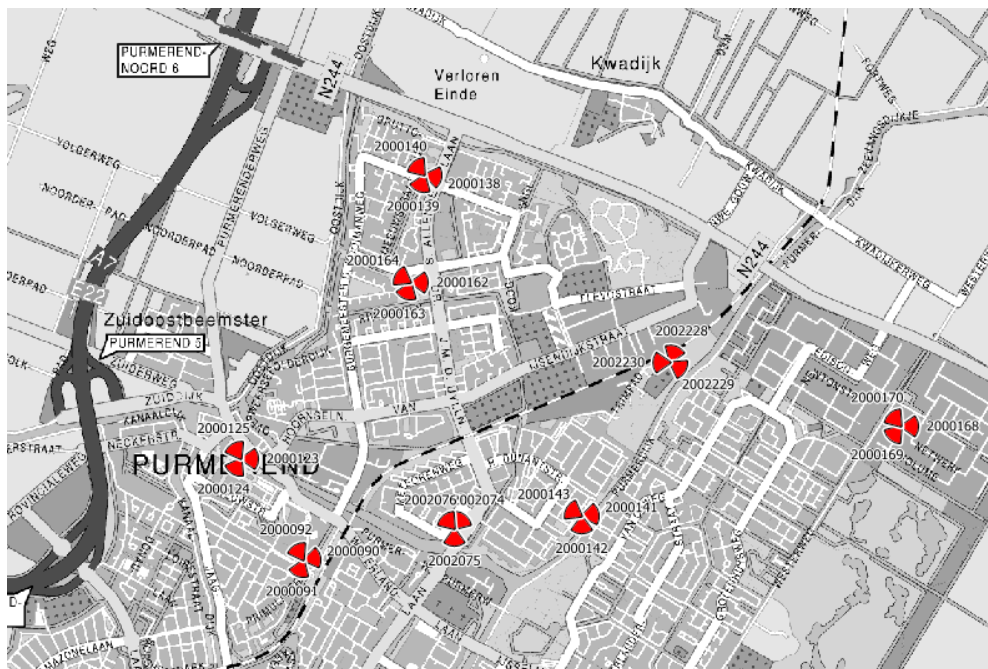


Figure 14: Simulated cells in Purmerend

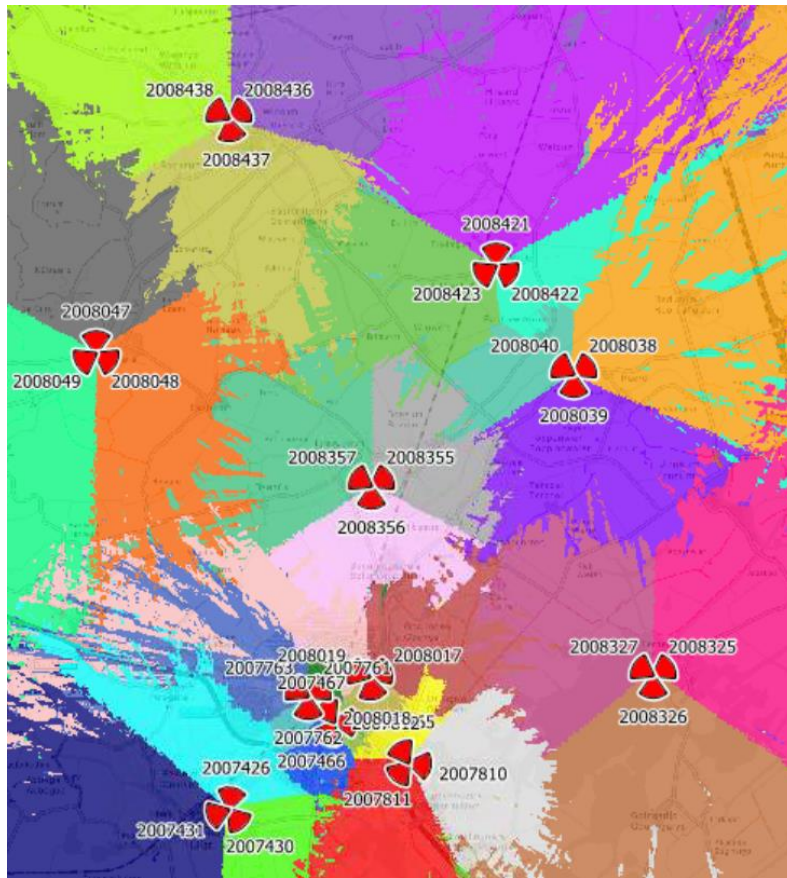


Figure 15: Best server area map for Friesland

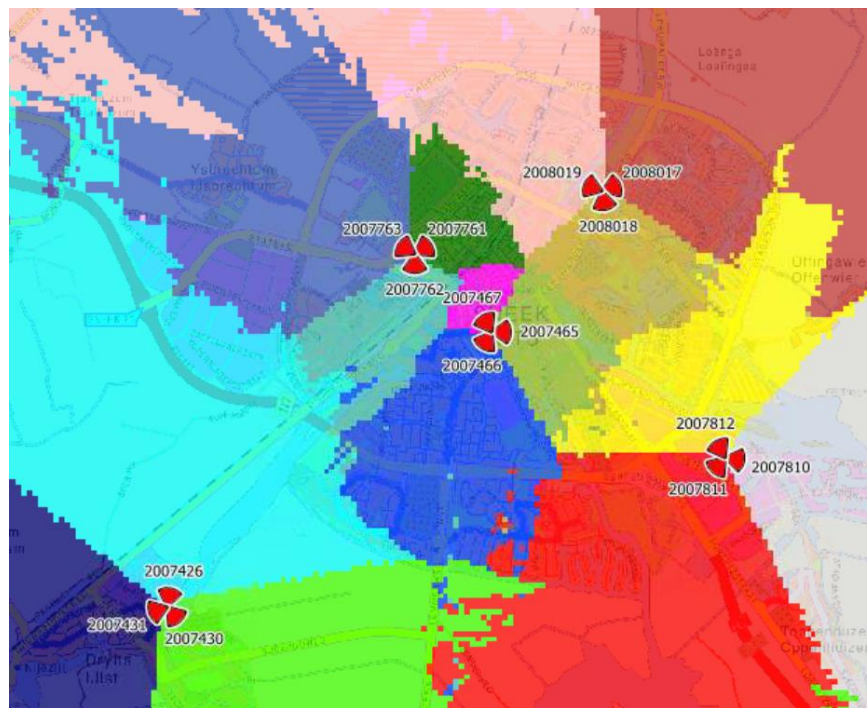


Figure 16: Best server area map for Friesland (zoomed in)

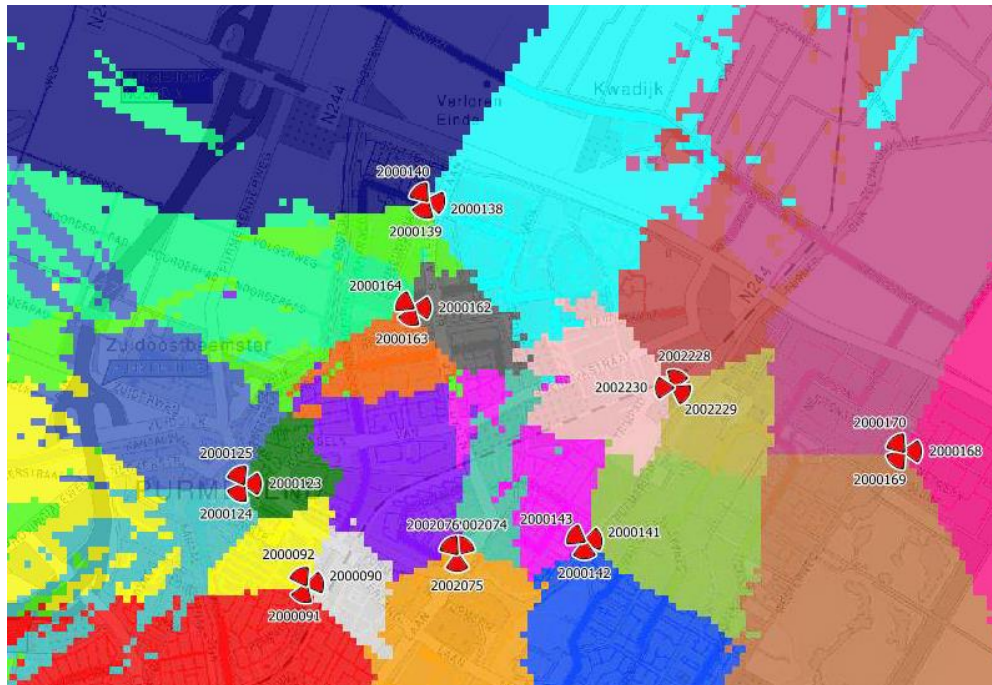


Figure 17: Best server area map for Purmerend

RADIO WAVE PROPAGATION CHARACTERISTICS

One of the essential building blocks of simulation is radio wave propagation modeling. Due to a critical influence of SINR on the communications link performance, as well as coverage assessment, realistic propagation modeling is essential when simulating cellular networks. After interference effects are taken into account, SINR values translate into user experienced bit rate values with the help of link-to-system level interfaces (mapping of SINR to bit rate values).

The simulations did not need to perform path-loss calculations, as propagation maps validated and provided by KPN were used instead. The key advantage of such maps is that they are realistic.

Propagation maps are in the form of pixel matrices, where each pixel represents a 40 m by 40 m geographical area. Each pixel has a propagation loss value associated to it, that corresponds to a radio link to the best serving cell. Propagation losses of nine strongest interferers (neighboring co-channel cell transceivers) for the particular pixel are included too. Propagation loss values involve path loss, slow fading effects, transmitting antenna characteristics (tilt, azimuth, gains, etc.), losses in an antenna feeding line and combiner (diplexer). Since the values of propagation losses made available by KPN are based on the initial tilt setting of the network, the values used in the study exclude the effects of antenna gains, and the gain values are added again at the time of RSRP recalculation using the tilt setting of the network at that instant. Figure 18 plots the initial RSRP values for all pixels in Friesland, in relation to cell 2007763, as received in the propagation maps from KPN. Since each pixel stores only the path loss values corresponding to the ten strongest cells, certain pixels in the area do not contain an RSRP value from cell 2007763, and are thus white. The colourbar on the right denotes the RSRP in dBm, while the x and y coordinates are distance in meters, according to the Rijksdriehoek coordinates.

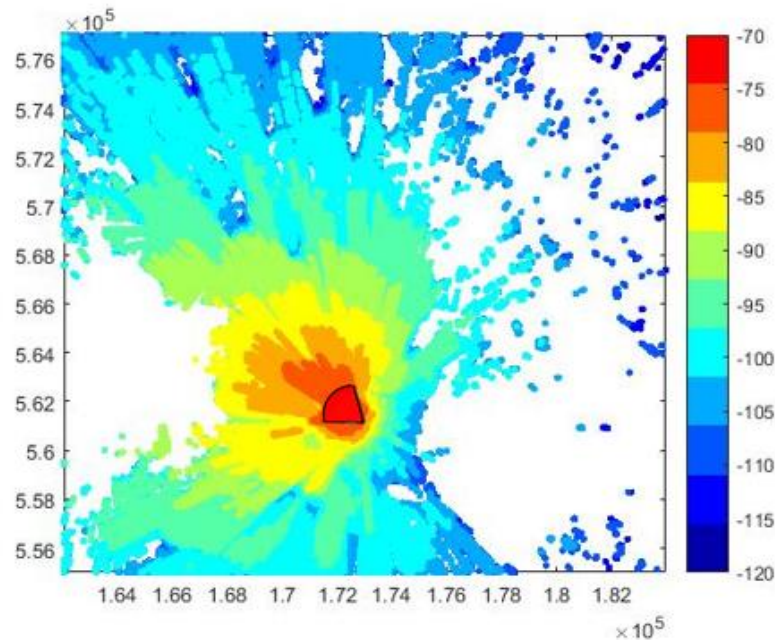


Figure 18: RSRP value plot for cell 2007763 in Friesland

The values in the propagation maps are for outdoor areas, however, in the simulations of this project, it is assumed that all sessions originate from indoor locations, hence Building Penetration Loss (BPL) has been taken into account when determining the total propagation loss. The characteristic area mean BPL value is based on measurements done by KPN, and is a deterministic value of 11 dB for the areas of our study.

SESSION ARRIVAL TIME MODELLING

The data used in this thesis is that of LTE in the downlink, and is limited to data calls only. To simulate a realistic traffic load, data session arrival rates were collected from the live network for a particular day, for both Friesland and Purmerend. This data provided by KPN consists of a continuous stream of data collected over 24 hours, at 15 minute intervals, with an indication of how many users are connected to each cell in a certain 15 minute period, and the total data traffic volume handled by that cell in the period. A full log trace consists of 96 periods in total, and in order to make any use of these values in our simulation, we use a stochastic point process, the Poisson process, to sample individual call arrival instants based on these 15 minute averages over the whole period. A detailed explanation of the same can be found in [1].

The following figures help us to visualize the load intensities in the chosen simulation areas. The colourbar on the right denotes the offered traffic load in Mbit/s, while the x and y coordinates are distance in meters, according to the Rijksdriehoek coordinates.

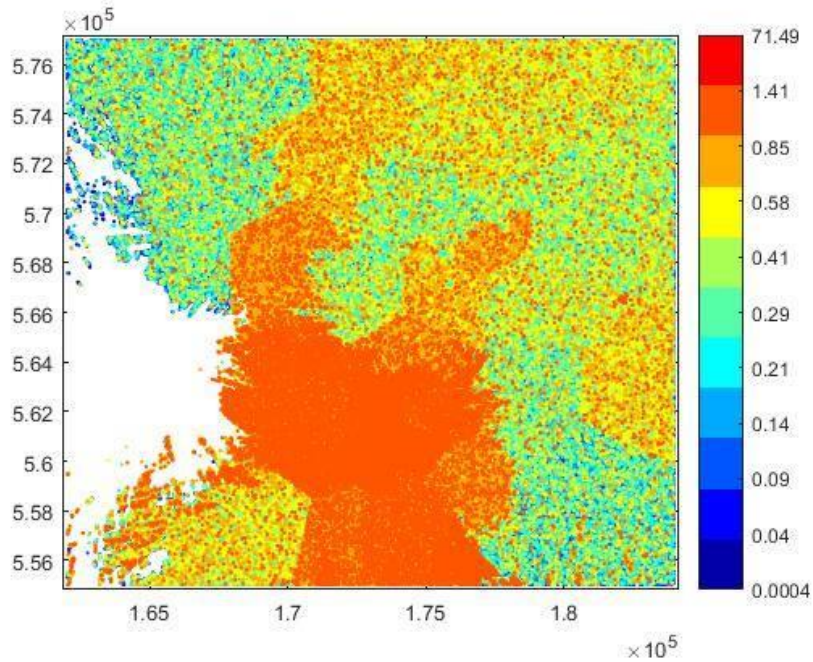


Figure 19: Load intensity visualisation for Friesland

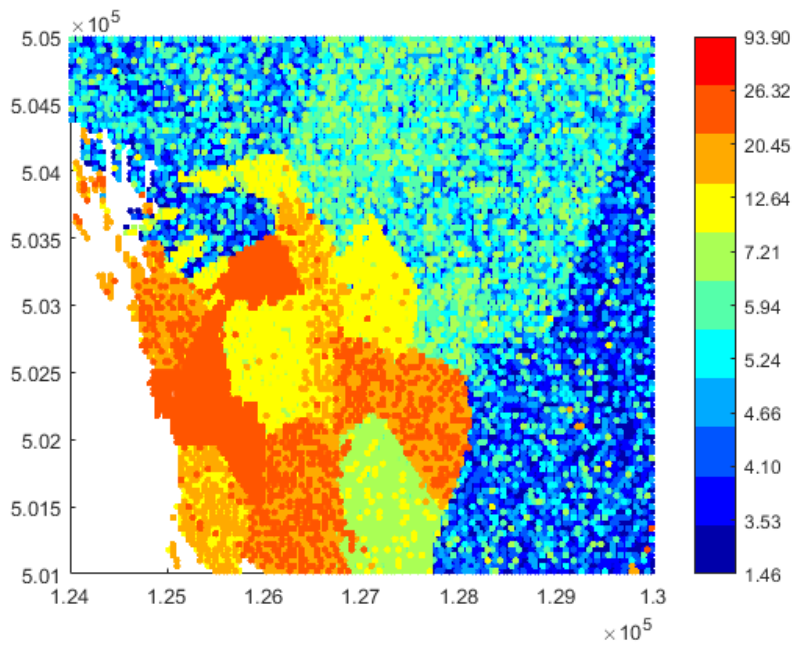


Figure 20: Load intensity visualisation for Purmerend

SERVICE MODELLING

The data available for the 15 minute intervals contains the total number of sessions being served by the cell and the amount of total data downloaded during that interval. Service modelling of the sessions involves sampling this data as a Poisson process, in order to obtain individual sessions

which have an arrival time and a session size (in Megabits) associated with them. The session sizes are assigned using a lognormal distribution with a mean of 0.897 for Friesland and 0.825 for Purmerend. This way a trace of session arrivals for an entire day is compiled, including corresponding sizes [1]. In the initial data made available by KPN, each of these sessions are associated with a certain cell, however, after the full trace of sessions has been created for the whole day, each session is allotted a pixel within that cell, and the session becomes delinked from the cell from this point on. Each session now originates in its allotted pixel, and is served by a cell depending on the strongest RSRP for the session, depending on the actual tilt, RS and CIO setting. Each session experiences an SINR, and along with the channel sharing factor, can be used to derive the throughput, which ultimately helps to determine the session duration.

The simulation considers all sessions to be indoors, and with no mobility.

SIMULATION METHODOLOGY

The simulator for the thesis research was built using MATLAB computing environment. MATLAB was chosen because it provides a vast computational function library, high speed of development and convenient debugging features.

The code implements an event-based simulation flow. As described previously, a trace of events for a full 24 hour day have been generated. Going through a list, event by event, makes up a simulation time flow. Each session in this list has ten possible serving cells – the UE will select the one with the strongest RSRP as its serving cell, and the rest nine will become interfering cells. Before simulation starts, each event (session) in the list is associated with a random propagation map pixel in a cell coverage area, which in effect assigns it a certain path loss value with respect to each of the ten possible serving cells. This pathloss value includes shadowing effects as well, and stays constant for any given pixel-cell pair.

As mentioned above, the propagation maps received from KPN contain the RSRP values for the ten strongest cells, based on the initial configuration of the network. These RSRP values are recalculated depending on the tilt value and RS power of the cells at that instant in the simulation. Since the purpose of this study is to facilitate load balancing and ameliorate the KPIs (discussed in the next chapter) by constantly changing the configuration parameters, it is important that the UE not be associated with any cell in advance, and chooses its serving cell based on the current RSRP values. When a new session arrives, RSRP values from all ten possible cells is recalculated, and the cell providing the strongest signal is chosen as the serving cell. At this point a coverage check is introduced – if the RSRP of the strongest cell is less than -124 dBm, there is said to be a coverage failure and the session is not served by any cell. This session is then logged into a new table which consists of all coverage failures, and ultimately helps us calculate the coverage failure probability of the network.

Once a session has been assigned a cell, the SINR values are calculated. The number of people sharing the channel at that instant is determined, and this channel sharing factor along with the SINR is used to calculate the bit rate experienced by the session. An arrival or departure of a session triggers a system interference state recalculation for all parties as interference and SINR levels change, along with the channel sharing factor. Such alterations stipulate changes in user

achievable bit rates, therefore projected data session departure times must be re-evaluated, session dropping criteria checked, statistical measures logged, etc. During the time when no sessions arrive or depart, system state stays frozen and user achievable bit rates do not change. However, if during the lifetime of a session, a change is introduced into the system by changing one of the optimisation parameters, a similar approach is adopted as the user will no longer experience the same SINR and bit rate, and may not even be served by the same cell any longer. If an optimisation change is introduced during the lifetime of the session, the RSRP experienced by the UE is recalculated, a new cell is selected, and the remainder of the session is completed in the new cell using a fresh SINR value and channel sharing factor, which determines the bit rate value.

The data available for the simulations is for a period of 24 hours. However, the simulations are run for ten days, using the same 24 hour data for each day. When the simulation is started on day one, the network is in its initial configuration i.e. using the initial tilts, RS power and CIO values set by KPN. However, once the network starts to self-optimize, the values for these parameters change, depending on the parameter optimised in that particular simulation run. Thus, when the simulation is run with the same data for a second day, the antenna tilt, RS power or CIO values are different than they were on day one, and have been selected by the self-optimisation algorithm, based on the state of network at that time. Since the data is the same for each 24 hour period, it is expected that at some point the network will converge to an optimal state, i.e., the values of antenna tilt, RS power or CIO will start to repeat themselves for each day. This is because the network slowly moves closer to an optimal state, and the optimisation converges after the warm-up period is over. However, at this point it is important to mention that the network will never entirely converge. The best we can expect is an almost converged network. This has been explained and discussed further along with the results, presented in Chapter 8.

SINR CALCULATION

Downlink SINR calculation follows a standard approach. The received power of a signal of interest for a UE is calculated by taking serving PDSCH power and applying propagation gain and BPL values. A similar approach is also followed for the received power from the interfering cells. Propagation gain (or loss) values are taken from the radio wave propagation map, after excluding the antenna gain. The terms for the propagation gain, G_{Tx} and G_i , also include the BPL. Thermal noise power N is evaluated at the temperature of 290 K, using the following formula

$$N = K * T * B$$

where,

- K- Boltzmann's constant, in Joules per Kelvin
- T- Temperature, in Kelvin
- B- Bandwidth, in Hertz

Hence, SINR for the given UE is calculated according to the following formula

$$SINR [dB] = 10 * \log_{10} \left(\frac{P_{Tx} * G_{Tx} * AG}{\sum_{i=1}^9 (I_i * G_i * AG_i) + N * NF} \right)$$

Where, in linear units,

- P_{Tx} - transmit power of the PDSCH in the serving cell
- G_{Tx} - propagation gain value (including BPL) between UE and serving cell
- G_i - propagation gain value (including BPL) between UE and interfering cell i
- AG - antenna gain value for serving cell
- AG_i - antenna gain value of interfering cell i
- I_i - total transmit power for interferer i
- N - thermal noise power
- NF - user equipment noise figure

BIT RATE CALCULATIONS

Simulation of LTE requires data sessions to be simulated, and resource sharing is assumed to be done in Frequency Domain Packet Scheduling (FDPS) manner. Simplified FDPS modeling is implemented by adding a 2.1 dB gain to session SINR in order to model multi-user diversity gains from channel-adaptive scheduling, which roughly corresponds to 40% throughput gains reported by Holma and Toskala [10] when using FDPS in LTE under low UE velocities. A simplistic 2x2 MIMO antenna modeling is used. There is no admission control, and thus, LTE sessions cannot get blocked. However, a session dropping function is implemented which drops sessions that achieve less than 10 kbit/s throughput over a 5 s period.

A link-to-system interface for LTE bit rate estimations is used, that is a combination of baseline Evolved-UTRA (E-UTRA) model described in Annex A.1 of [53] and Bell Laboratories Layered Space-Time (BLAST) 2x2 MIMO antenna scheme described by Mogensen et al [54]. The resulting formulas, used to approximate the throughput over a channel with a given SINR, when using link adaptation, are the following:

$$R [\text{bps}] = \begin{cases} 0, & \text{if } SINR < SINR_{min} \\ B * \alpha * \log_2(1 + SINR), & \text{if } SINR_{min} < SINR < 10.5 \\ 2 * B * \beta * \log_2(1 + SINR - \gamma), & \text{if } 10.5 < SINR < SINR_{max} \\ B * Thr_{max}, & \text{if } SINR > SINR_{max} \end{cases}$$

where:

- R – Bit rate [bps]
- B – Bandwidth [Hz]
- α : attenuation factor, representing implementation losses: bandwidth efficiency, cyclic prefix, pilot overhead, dedicated and common control channels
- β : attenuation factor used with MIMO
- γ : SINR efficiency of LTE [dB]
- $SINR_{min}$ = minimum SINR of the codeset [dB]
- $SINR_{max}$ = SINR at which maximum throughput is achieved [dB]
- Thr_{max} = maximum spectral efficiency of the codeset [b/s/Hz]

Parameter	Downlink	Comment
α	0.6	System bandwidth efficiency [53]
β	0.56	System bandwidth efficiency [54]
γ [dB]	6.02	SINR efficiency of LTE [54]
$SINR_{min}$ [dB]	-10	Based on Section 7.1.7.2 of [55]
$SINR_{max}$ [dB]	31	Based on Section 7.1.7.2 of [55]
Thr_{max} [b/s/Hz]	9.3	Based on $SINR_{max}$

Table 1: Parameters describing 2*2 MIMO LTE link level performance

In order to understand the terms α , β and γ in the formula above, we briefly discuss the concept from the papers where these formulae have been taken.

The Shannon-Hartley theorem represents the capacity of a channel as a function of the SINR and the bandwidth of the channel. However, The Shannon capacity bound cannot be reached in practice due to several implementation issues. To represent these loss mechanisms accurately, [54] uses a modified Shannon capacity formula, where S represents the channel spectral efficiency in bits/s/Hz.

$$S = \alpha * \beta * \log_2 \left(1 + \frac{SNR}{\gamma} \right)$$

α and β represent the decrease in the system bandwidth efficiency of LTE due to these implementation losses, as listed above. The term γ adjusts for the reduced SNR efficiency in LTE. $SINR_{min}$ and $SINR_{max}$ values are determined using Section 7.1.7.2 of [55]. $SINR_{min}$ value is determined by assuming Modulation and Coding Scheme (MCS) 0 and looking up Transport Block Size (TBS) table for single spatial layer channel. $SINR_{max}$ value is determined by assuming the highest MCS and looking up the TBS table for two spatial layer multiplexing channel. Resulting spectrum efficiency, depending on an SINR, is presented in the figure below. Chosen parameter values are listed in Table 1.

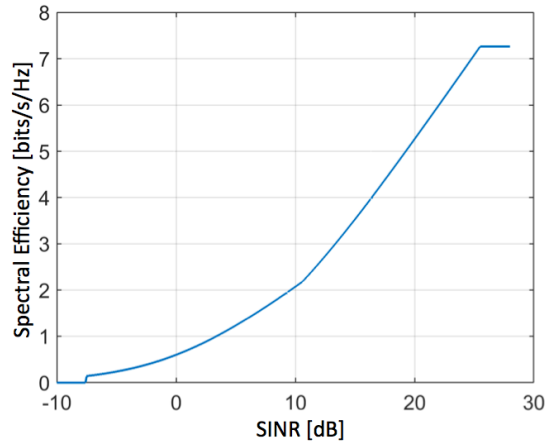


Figure 21: LTE 2*2 MIMO spectral efficiency

CHANNEL SHARING

After a UE picks a serving cell and experiences a certain SINR from that cell, this SINR is mapped into a bit rate using the formula discussed above. However, since the channel is shared among several users, the throughput experienced by the UE is dependent on the number of active users in the cell at that instant. A channel sharing factor has been implemented in this thesis, which is equal to one over the number of users active in that cell at that instant. The throughput experienced by a user at a particular time instant t is equal to the bit rate divided by the number of users being served by the cell at that instant t .

$$\text{Throughput}(t) = \frac{\text{Bit rate}(t)}{\text{Number of users}(t)}$$

However, every time a user leaves or gets added to the cell, the corresponding channel sharing factor goes up or decreases, respectively. This may occur several times during the lifetime of the call, and the experienced throughput would also change, correspondingly. Since the experienced throughput determines the duration of a session, changes in the throughput means recalculating the projected session departure time, depending on the amount of data still left to be downloaded.

ANTENNA TILT CALCULATIONS

This section discusses the recalculation of RSRP values after a change is introduced in the tilt value of the antenna. KPN uses antennas by Kathrein, and the antennas deployed in Friesland and Purmerend allow for a maximum and minimum tilt of 10 degrees and 0 degrees, respectively. The tilt can only be changed in steps of 1 degree, and data sheets for each degree of tilt are available

from the vendor. These sheets contain information about the gain value available in the main lobe, and the relative loss values (in dB) for horizontal and vertical angles of 0 to 360.

```
80010292v3_800_t3 - Notepad
File Edit Format View Help
NAME 80010292v3_800_t3
FREQUENCY 947
GAIN 17.55 dBi
TILT 0
COMMENTS DATE 30.09.2011 +45 degrees polarized system Leven position 3 deg
HORIZONTAL 360
0.0 0.0
1.0 0.0
2.0 0.0
3.0 0.0
4.0 0.0
5.0 0.0
6.0 0.0
7.0 0.0
8.0 0.1
9.0 0.1
10.0 0.1
11.0 0.2
12.0 0.2
13.0 0.3
14.0 0.3
15.0 0.4
16.0 0.5
17.0 0.6
18.0 0.6
19.0 0.7
```

Figure 22: Kathrein Antenna 80010292 horizontal gain offset values

Figure 22 contains the antenna gain offset values for the Kathrein antenna 80010292 version 3 in the 800 MHz band, for a tilt of three degrees. The gain in the main lobe for this antenna is 17.55 dBi. We can see the horizontal offset values for each degree of tilt of the antenna, while Figure 23 shows the vertical gain offset values. The vertical and horizontal gain plots have been shown in Figure 24.

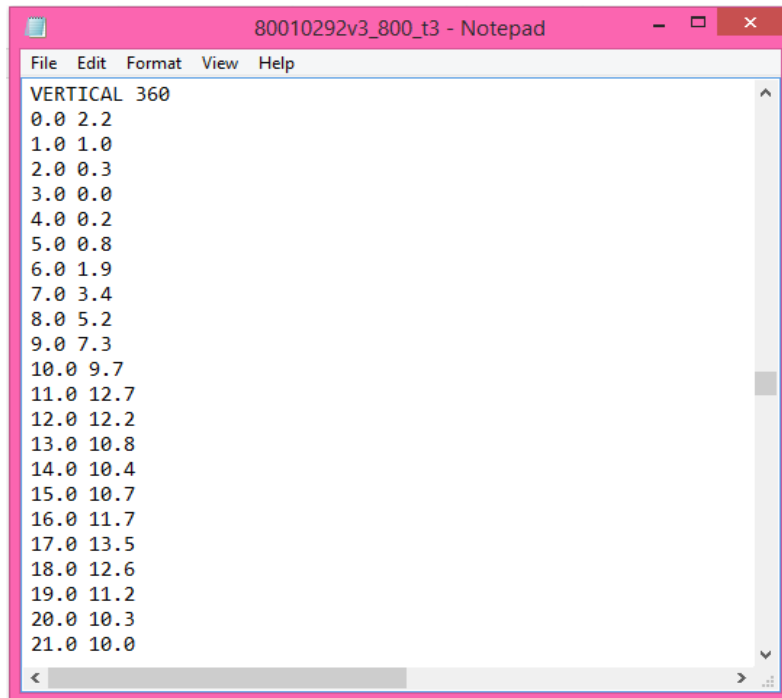


Figure 23: Kathrein Antenna 80010292 vertical gain offset values

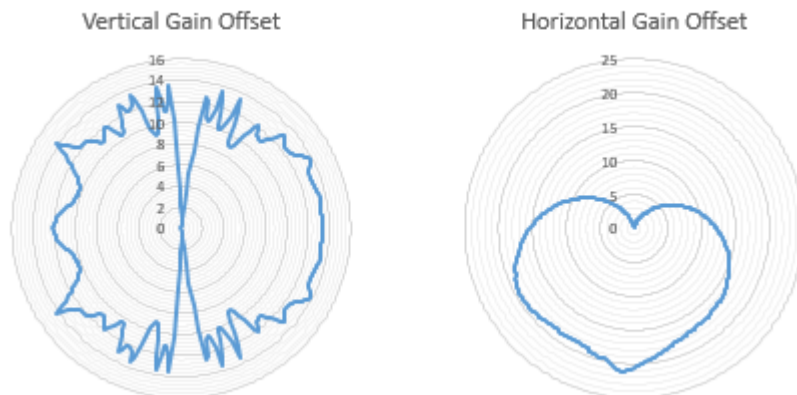


Figure 24: Gain plots for horizontal and vertical gain offsets

The gain in the main lobe is the highest, and the gain value reduces as we move out of the main lobe into the side lobes. As we can see in the figure, the main lobe is the biggest, and thus offers the maximum gain, and gain value gradually reduces as we move away from the main lobe. Commercially deployed antennas, like the ones at KPN, specify the main lobe gain in their documentation. When a user is not in the main lobe, it receives a reduced gain. This reduced gain depends on the horizontal and vertical angles the user makes with the antenna.

As seen from the figure below, the antenna has an initial tilt of θ . Note that initial tilt values for all antenna of concern have been obtained from KPN. The user is on the ground and makes an angle of $\theta + \alpha$ with the horizontal plane. We need to find the vertical angle between the user and the antenna, thus, the angle of interest in this situation is the angle α . The height of the antenna is also known from KPN, and has been denoted as H_a . The height H_u of the UE has been assumed as 1.5 meters. The distance R between UE and antenna can be calculated using standard distance formula.

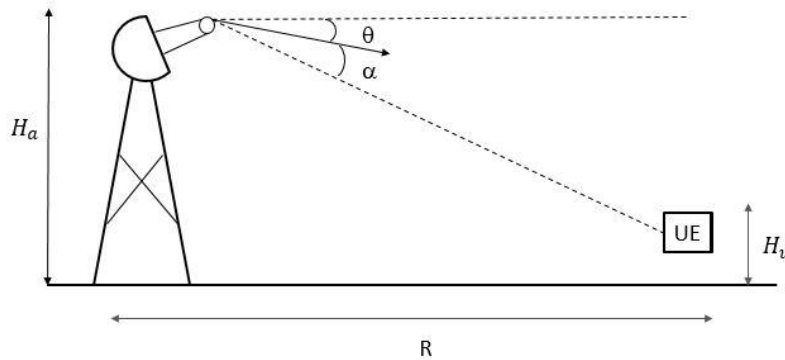


Figure 25: Vertical angle of the UE w.r.t. the antenna

The vertical angle is then calculated using the following formula

$$\alpha + \theta = \tan^{-1} \frac{H_a - H_u}{R}$$

Since the angle we are concerned with is only α , the result of the above calculation is then treated in the following way,

$$\alpha = \tan^{-1} \frac{H_a - H_u}{R} - \theta$$

The above holds true only if the angle the UE makes w.r.t the antenna is greater than the tilt of the antenna. In case the antenna tilt is greater, the subtraction needs to be reversed. A modulus operator takes care of that.

$$\alpha = \left| \tan^{-1} \frac{H_a - H_u}{R} - \theta \right|$$

Similarly, refer to Figure 26 for *horizontal angle* calculation. The figure shows us a top view of the antenna pattern space. The azimuth of the antenna is the orientation of the main lobe of the antenna, with respect to the north, measured in clockwise direction. The azimuth angle values for all antennas have been obtained from KPN and stay constant throughout the optimisations. The angle of interest here is β and gives us a measurement of how shifted the user is out of the main lobe. This angle is called the horizontal angle.

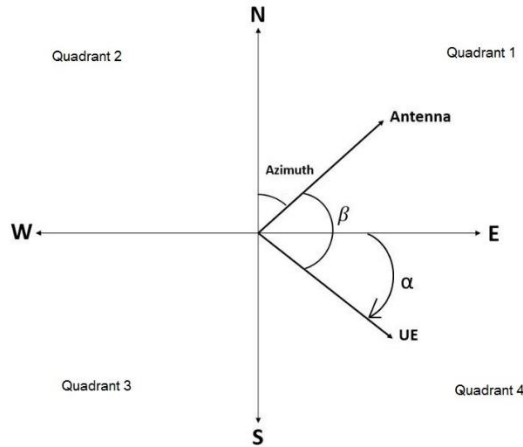


Figure 26: Horizontal angle of the UE w.r.t the antenna

Let the position of the antenna pixel be (x_a, y_a) and that of the user pixel be (x_u, y_u) . Preliminary angle α can be calculated as follows

$$\alpha = \tan^{-1} \frac{y_u - y_a}{x_u - x_a}$$

The Cartesian coordinate system measures angles in an anti-clockwise direction with respect to the x-axis, while KPN measures its azimuth values in a clockwise direction with respect to the north. Thus, corrections need to be applied to the value obtained for angle α above, in order to correctly calculate the horizontal angle β . In order to estimate β , an intermediate angle γ is calculated, which is needed to reconcile the differences between the KPN system and the Cartesian system. This is done by assigning the UE to a quadrant, based on its position relative to the antenna. The corrections are also quadrant specific, and are as follows:

$$\begin{aligned} \gamma &= 90 - \alpha, & \text{Quadrant 1} \\ \gamma &= 270 - \alpha, & \text{Quadrant 2} \\ \gamma &= 270 - \alpha, & \text{Quadrant 3} \\ \gamma &= 90 - \alpha, & \text{Quadrant 4} \end{aligned}$$

Since the angle needed is only between the azimuth and the user, the following is then implemented,

$$\beta = |\text{azimuth} - \gamma|$$

As a user moves away from the main lobe both in vertical and horizontal angles, the relative gain experienced by it reduces. The angles calculated above help us ascertain the corresponding gain offset values using the files received from KPN. The gain offset value obtained from the horizontal angle is called the Horizontal Offset (HO), and that obtained from the vertical angle is called Vertical Offset (VO). The final antenna gain value can be calculated as follows

$$\text{Antenna Gain} = \text{Main Lobe Gain} - \text{HO} - \text{VO}$$

RSRP CALCULATION

For each pixel in the propagation map, there are ten path loss values available, from ten possible cells. However, each time a change is made in one of the optimisation parameters, the RSRP changes and needs to be recalculated. This is done using the following equation

$$RSRP_{perceived} = RSRP_{actual} + CIO$$

$$RSRP_{perceived} = RS \text{ power} + \text{Antenna Gain} - \text{Feeder loss} - \text{Path loss} - BPL$$

The path loss values include slow fading as well, and stay constant for a certain pixel-cell pair. The feeder loss values are also constant. The building penetration loss values are also subtracted since all sessions are assumed to be indoors.

When changes are made to the tilt of an antenna, the antenna gain values change, due to the change in the horizontal and vertical offset values. Thus, for tilt optimisations, keeping all other terms on the right constant, only the antenna gain is changed, and RSRP is recalculated. In case of RS power optimisations, only the RS power term changes, while all other terms on the right stay constant. For both, antenna tilt and RS power optimisations, the value of CIO is set to 0 dB. When optimising using cell individual offsets, the CIO term on the left assumes a value other than 0 dB, which modifies the RSRP *perceived* by the UE, however, does not change the *actual* RSRP. This modified value of the RSRP is used to impact cell selection by the UE. Thus, CIO is used in this thesis as a method of changing the cell size, by impacting the cell selection by the UE. Once the UE selects a cell, it has to perform a coverage check. This is done by comparing the actual RSRP of the cell with the coverage threshold (-124 dBm), and determining if the UE can indeed be served by this cell

PDSCH POWER CALCULATION

As discussed earlier (Chapter 2) and visualised in Figure 1, each PRB is made up of 12 subcarriers across 7 symbols, which results in 84 resource elements. 5 symbols out of the 7 are dedicated to the PDSCH, while the other two symbols are shared between the RS and the PDSCH. Since we have 20 W in each antenna port, it makes up for 40 W in total. A fraction 5/7 of this 40 W is dedicated to the PDSCH, which is equal to 28.57 W. The total power available in the other two

symbols is 11.43 W, and this power is shared between the RS and the PDSCH. Given a uniform distribution of energy across all REs, the unused energy from the silenced REs is used for PDSCH boosting. This explains why an increase in the RS leads to a decrease in the SINR, because the power available in the PDSCH decreases.

SUMMARY

A summary of the modelling details has been presented in the table below.

Environment	Rural and sub-urban
Type of users	Indoor
Carrier frequency	800 MHz
Bandwidth	10 MHz
Cell layout	Real network based
Cell selection	RSRP +CIO based
Traffic load	Time-varying, based on collected logs
Session size	Empirical distribution based (lognormal) $\mu = 0.897$ for Friesland and 0.825 for Purmerend
Scheduler	FDPS
Propagation modelling	KPN proprietary
Multipath fading	No
Building penetration loss	11 dB
Feeder loss	2 dB
Mobility	No
Initial RS power	18.2 dBm
Initial tilt angle	Varying, based on antenna
Initial CIO Value	0 dB
Noise figure	9 dB
Call dropping	<10kbit/5s
Coverage threshold	-124 dBm

Table 2: Summary of modelling

Chapter VII SELF-OPTIMISATION ALGORITHMS

The optimisation algorithm used in this study has been inspired by [42] and [48]. Since the data used for this study has been extracted from the live network at KPN, an algorithm had to be designed which was able to exploit the data to our advantage. Algorithms available in literature often used methods which needed more data for calculations than was available to us, such as number of successful handovers, ping pong handovers, handover failures [35] or uplink cell load conditions [42]. The following section discusses the parameters used for optimisation, the key performance indicators (KPI) used to assess the performance and feed the algorithm, and the algorithm itself.

OPTIMISATION PARAMETERS

- 1) **Antenna tilt:** Antenna tilt as a method of optimisation is fairly common. When the tilt of an antenna is changed, the antenna gain changes, due to the change in the horizontal and vertical gain offsets for the UE. An increase in the downtilt of the antenna means that the BSA of the cell reduces, while the SINR will improve for those users which are now in its BSA. Similarly, a decrease in the downtilt means the BSA will go up, cell boundary will increase, which will attract more users to this cell. This will lead to an increase in the channel sharing factor, and thus lower user experienced throughputs.

The tilt values for this study range from 0 to 10 degrees, which is a constraint imposed by the Kathrein antennas used by KPN.

- 2) **RS power:** As discussed earlier, RS power is another method used to self-optimize a network. An increase in the RS power leads to an increase in the RSRP for the UE, which makes the cell more suitable and has a greater chance of being selected as the serving cell. This is a method of attracting more users into a cell, which essentially means increasing the cell coverage and extending the cell boundary, since a larger number of users now receive a strong signal from this particular cell.

However, on the downside, since the power in a PRB stays constant, the more power available to the reference signal, the lesser power remains for the PDSCH. Thus, an increase in RS power means a decrease in the SINR, and an increase in the channel sharing factor, and consequently, the bitrate decreases. In essence, increasing the RS power will lead to more users being served by the cell, however, in the classic trade-off between coverage-quality, the quality will go down.

The initial RS power in the KPN network is 18.2 dBm, and we vary the RS between the ranges of 13.2 and 24.2 dBm, in step sizes of 1 dB.

- 3) **Cell Individual Offset (CIO):** Cell individual offsets make the perceived RSRP value go up for the UE, however, it does not change the actual RSRP value. Since the actual RSRP value

stays the same, the power available to the RS and the PDSCH in the PRB does not change. A positive CIO leads to the attraction of more remote users to the cell, i.e. users with lower SINRs, causing the SINR statistics of the cell to worsen. The CIO is varied in steps of 1 dB, from -6 to +6 dB.

SON-DRIVING KEY PERFORMANCE INDICATORS

Key performance indicators are quantifiable metrics used to evaluate the performance of the network and steer the SON algorithm. Telecom operators use several metrics to measure the performance of a network, such as loads, throughput, SINR, call drop rate, coverage failure probability. However, KPIs can be divided into two categories- the ones that are used to steer the SON algorithm, and the ones used to evaluate it. In this section we discuss the KPIs used to steer the SON algorithm. The KPIs used to evaluate the performance of the network are discussed in the next section.

10th throughput percentile

This has been used to drive our optimisation algorithm and is an indicator of the throughput experienced by the users at the cell edge.

The throughput experienced by a certain session can change multiple times during its lifetime, thus, the average throughput for a session is calculated. The throughput of a session is calculated using the following formula

$$\text{Throughput} \left(\frac{\text{bits}}{\text{s}} \right) = \frac{\text{Size of the session (bits)}}{\text{Total duration of the session (s)}}$$

Based on these throughput values, a CDF is made, and the 10th percentile value is selected. Calls that are dropped retain the throughput value they experienced up till the moment the call was dropped. This is done because if a user was, for example, streaming a Youtube video, the amount of video that was streamed/buffered in the UEs playout buffer at application level before the session ended, can still be viewed after the session has been dropped.

The 10th percentile throughput is calculated for each cell, for the given optimisation interval, and this has been used as the primary optimisation criterion. In addition to feeding the SON algorithm, throughput has also been used to evaluate the performance of the network. Since the optimisation time intervals vary, a standard performance logging interval needs to be maintained, so as to compare the performance of different time intervals. These performance logging intervals are chosen as one hour and one day. This is done so that we can study the performance of the busy hour, as well as of the whole day (discussed in Chapter 8).

EVALUATION KEY PERFORMANCE INDICATORS

As mentioned earlier, KPIs can be used both to drive the algorithm and to evaluate the performance. This section discusses the KPIs, which along with the 10th throughput percentile, are used to evaluate the performance.

- **Load:** Since the network is dynamic, the best way to observe the 10th throughput percentile metric is to observe it in comparison with the loads in the cell. This is done because an increase in the load leads to a decrease in the throughput, and vice versa, and studying the loads and throughput together helps us to understand the network better. The loads have also been logged for the chosen performance logging intervals, i.e., one hour and one day, for each cell. Thus, the final graphs contain the throughput metric plotted alongside the loads experienced by the cell over the same period.
- **Call drop rate:** The call drop rate indicates how many users experience extremely low throughputs for long periods, i.e., a bit rate lower than 10 kbit/s over a 5 second period, and thus could not support the session. It is calculated per cell per hour, and per day, using the following formula,

$$\text{Call drop rate} = \frac{\text{dropped sessions}}{\text{total sessions}} * 100$$

The call drop rate is also observed in relation with loads in the cell, for a better understanding, although a low throughput is more likely due to a poor SINR than due to a high cell load.

Call drop rate is not a part of the SON algorithm explicitly, however, the throughput experienced by dropped calls is included in the throughput CDF and hence is also implicitly factored into the 10th throughput percentile, as explained above.

- **Coverage failure probability:** The UEs which do not receive a strong enough RSRP (greater than -124dBm) from any of the ten candidate cells, are termed as a coverage failure. The coverage failure probability is calculated per hour, and per day, by observing the total number of sessions arriving, and the number of sessions unable to find a serving cell. Coverage failure probability is calculated using the following formula:

$$\text{Coverage failure probability} = \frac{\text{sessions without any coverage}}{\text{total sessions}} * 100$$

Coverage failure is not a part of the algorithm, and is only used for the assessment of the network performance.

- **PRB utilisation factor:** A bandwidth of 10 MHz corresponds to 50 PRBs. In the cell, even if only one user is served, all PRBs are used. Thus, either all PRBs are used or none are used, corresponding to the presence of one or more users, or no user at all, respectively. The PRB utilisation factor is a value between 0 and 1, and helps to understand the duration of time for which a cell is serving users, in a given time interval, or equivalently, gives the time-average of the number of utilized PRBs. The PRB utilisation factor is calculated for every cell, per hour, using the following formula:

$$PRB \text{ utilisation factor} = \frac{t_1 + t_2 + t_3 \dots \dots + t_n}{\text{Total time (in secs)}}$$

where t_1, t_2, \dots, t_n are the time periods in which the cell is serving calls

PRB utilisation factor is neither a part of the algorithm, nor a conventionally used KPI. It is an indicator of the load of the cell, and in this thesis has been used to understand the difference between the two areas of simulation. Rural areas typically experience lower PRB utilisation factors than sub-urban (or urban) areas.

OPTIMISATION ALGORITHM

The research conducted for this thesis study is a temporal study of the self-optimisation of a network. Thus, the optimisation is repeated for several different time intervals, in an effort to ascertain the most suitable time interval for optimisation. The table below lists the different time intervals considered in the project. In addition to the below listed intervals, a reference case is also run for each area, with no self-optimisation, maintaining the initial settings of the network received from KPN.

Time intervals for self-optimisation
1 min
15 min
2 hours
4 hours
8 hours

Table 3: Time intervals for self- optimisation

The first iteration of the simulation uses the initial settings of the network, and runs the simulation for it, for example, in case of a 15 min time interval, the time from 0 to 15 minutes counts as first iteration. At the start of the second iteration, a change is forced upon all cells in the simulation simultaneously; in case of tilt optimisation that is an increase in 1 degree of tilt, for RS optimisation an increase of 1 dBm of RS power, and for CIO optimisation an increase of 1 dB of CIO, for all cells. After this step, no more such arbitrary changes are made to the network, but it is up to the SON algorithm to decide the direction of change and the applied step size. This has been illustrated in the figure below.

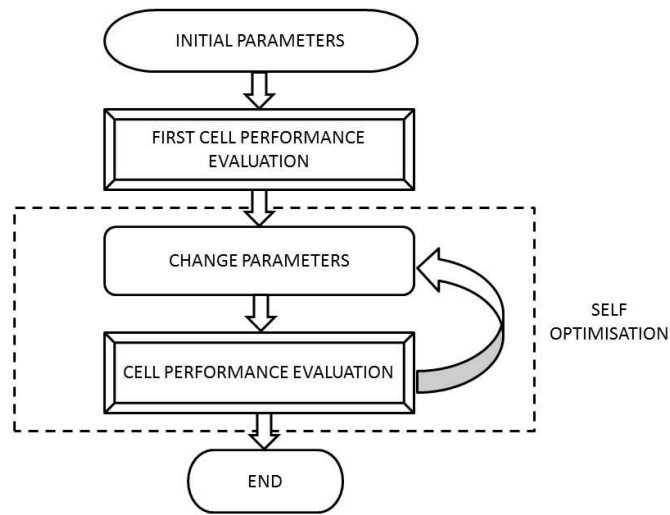


Figure 27: Structure of self-optimisation process

At the end of each iteration, the network logs the 10th throughput percentile for each cell. This throughput is then compared to the throughput value observed over the previous interval. Several cases are distinguished:

- If an *increase* (hence improvement) in the cell's 10th throughput value *greater than 5%* is observed, then the previous radio parameter change is interpreted as fruitful, and the cell further adapts the radio parameter *in the same direction*. For example, if by increasing the tilt by one degree, the 10th throughput percentile is increased by more than 5%, then in the next iteration we increase the tilt by another degree (bounded by the maximum feasible tilt value)
- Alternatively, if a *decrease* in the cell's 10th throughput value *greater than 5%* is observed, then the previous parameter change is interpreted as having been *not* a good idea, then the radio parameter is changed *in the opposite direction*. Continuing the previous example, we would then decreasing the tilt value by one degree.
- If the observed change is less than 5%, the value of the parameter is kept the same for the next interval.

Hence the basic idea is to always change the considered radio parameter in the direction where we observe a positive change in the 10th throughput percentile, unless the observed throughput effect is considered small and the parameter is not changed. The 5% threshold for the 'change percentage' is applied so as to avoid too frequent or unnecessary changes in the parameters. Herein the change percentage is defined as the percentage of change in 10th percentile throughput between the last iteration and the current one:

$$\text{Change\%} = \frac{\text{Current throughput} - \text{previous throughput}}{\text{previous throughput}} * 100$$

The same algorithm is observed for tilt, RS power and CIO optimisations. All optimisations are done independently on a cell-level basis, and are carried out simultaneously over all cells. The algorithm has been illustrated by a flowchart below, where P represent the value of our optimisation parameter, P_2 denotes its value in the current iteration and P_1 denotes its value in the previous iteration.

The algorithm has been illustrated by a flowchart.

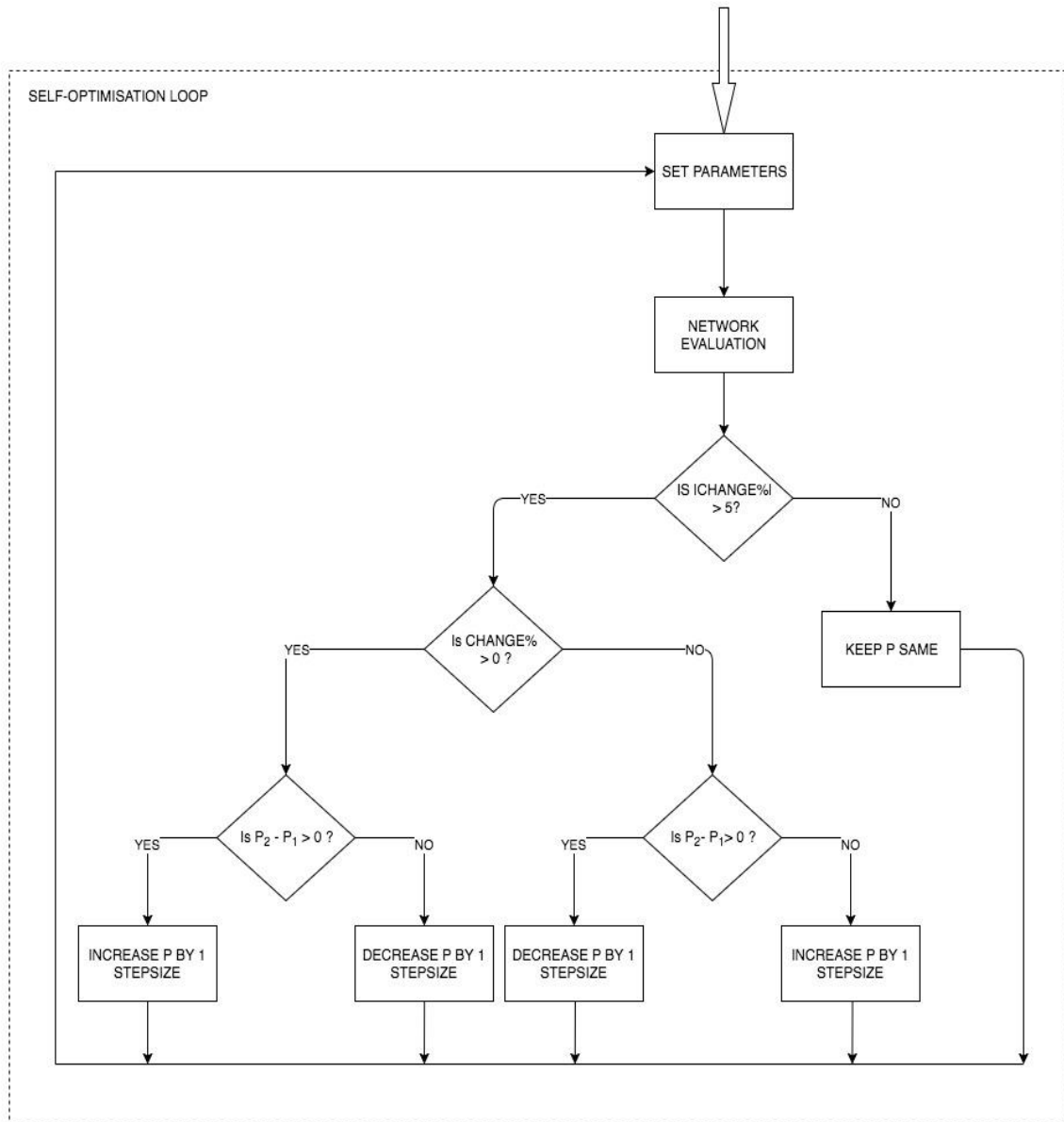


Figure 28: Flowchart for optimisation

Chapter VIII RESULTS AND DISCUSSION

INTRODUCTION

The thesis includes a temporal study, i.e., studying the performance of the network by self-optimising it over several different time scales, and a spatial study, i.e., studying these effects for two different areas in the Netherlands. In addition, this spatio-temporal study has been carried out using three different optimisation parameters. Thus, the results need to be presented in such a manner that all these aspects of the thesis can be studied in correlation with each other.

This chapter has been arranged as follows: the remainder of this section introduces the basics for understanding the results, and explains each case. In the next section, detailed optimisation graphs have been discussed for each optimisation parameter. The section that follows it contains the main plots which will be used to evaluate the impact of the time interval on self-optimisation, and the relative performance of the three parameters. The chapter is concluded by comparing the results in the two simulation areas, and by giving a summary of the results.

The results in the third section have been presented by plotting the 10th throughput percentile against the optimisation time interval, and by plotting the coverage failure rate against the optimisation time interval. This has been done for both the areas and all three parameters, using the following cases:

1. All day - Bottleneck cell: The 10th throughput percentile values for all cells in the network are plotted and the bottleneck cell is picked out. The bottleneck cell is said to be one that experiences the minimum throughput. As mentioned earlier, the optimisation has been run for 10 days of data, and the throughput values for the last 5 days, i.e., day 6- 10 have been averaged for these plots. This is done because the first 5 days have been treated as a warm-up period and the network is considered optimised after the 5th day. The graphs below show these plots for Friesland and Purmerend, when the simulation is run for the non-optimised case, i.e., 'No SON'.

When the bottleneck cell is selected, it is ensured that it does not lie at the boundary of the simulation area. Boundary cells do not have interfering cells on all sides, and thus their performance statistics are optimistic, and not representative of the actual network performance. From Figure 29 and 30, we see that the bottleneck cell for Friesland and Purmerend is cell 2007763 and cell 2000090, respectively. The cells for neither area lie at the boundary.

Once the bottleneck cell is selected, the 10th throughput percentile values for that cell are averaged for the last five days, and plotted against the time interval of the optimisation.

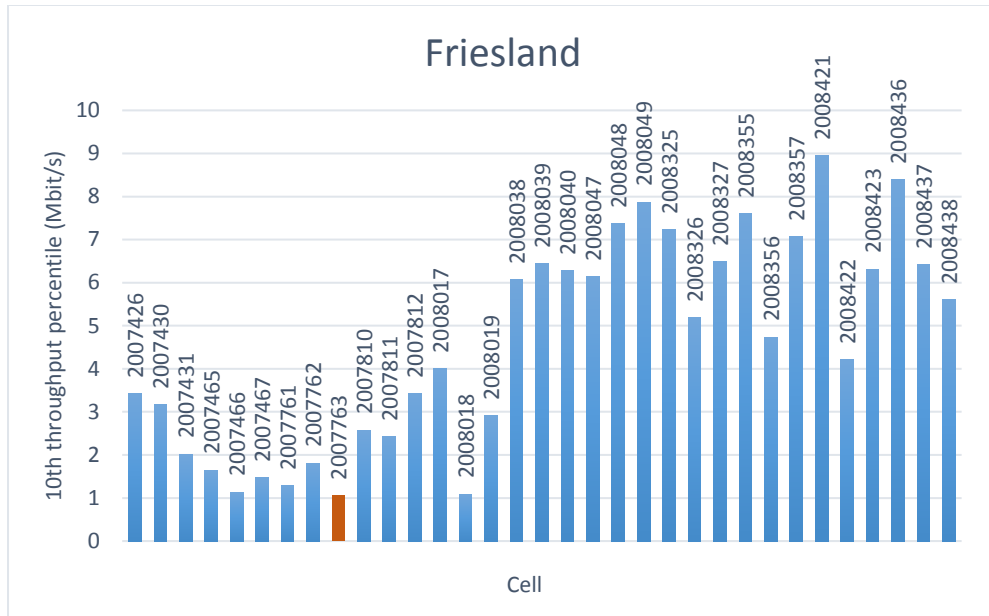


Figure 29: Plot to determine the bottleneck cell in Friesland

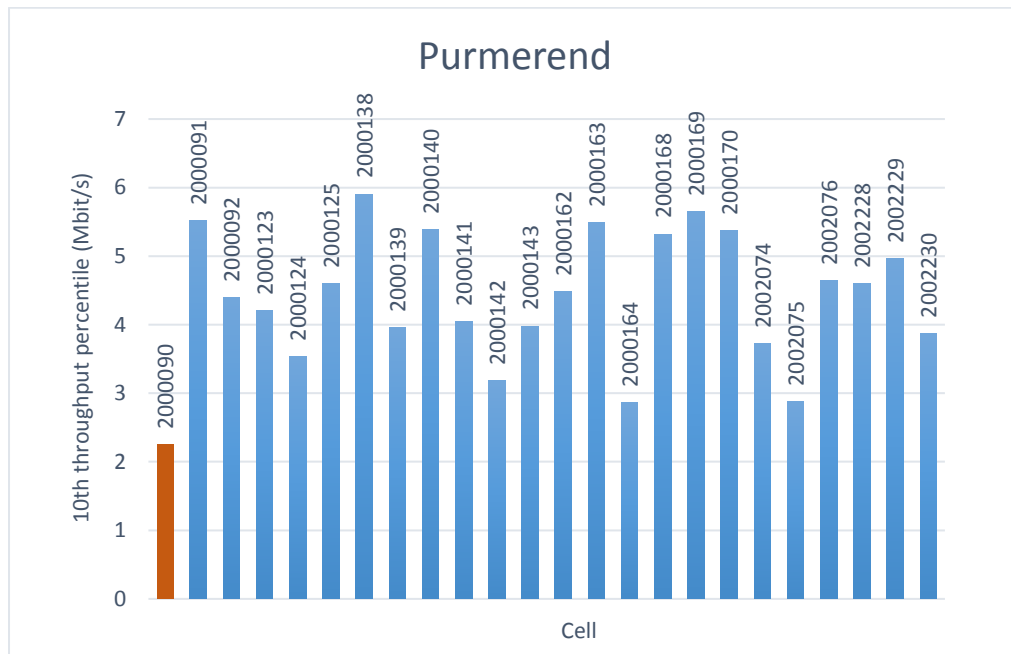


Figure 30: Plot to determine the bottleneck cell in Purmerend

2. All day - Whole network: This calculates the 10th throughput percentile value for the whole network observed over the whole day. This is one value for each day, and as earlier, the values for the last 5 days have been averaged.

- Bottleneck hour- Bottleneck cell:** Once the bottleneck cell in the network has been ascertained, the 10th throughput percentile values for each hour of the day are plotted, in order to determine the hour in which it experiences minimum throughput. This is known as the bottleneck hour of the bottleneck cell, and will help to study the performance of the network when it is experiencing the lowest throughputs. The following plots show the bottleneck hour for the bottleneck cells in Friesland and Purmerend.

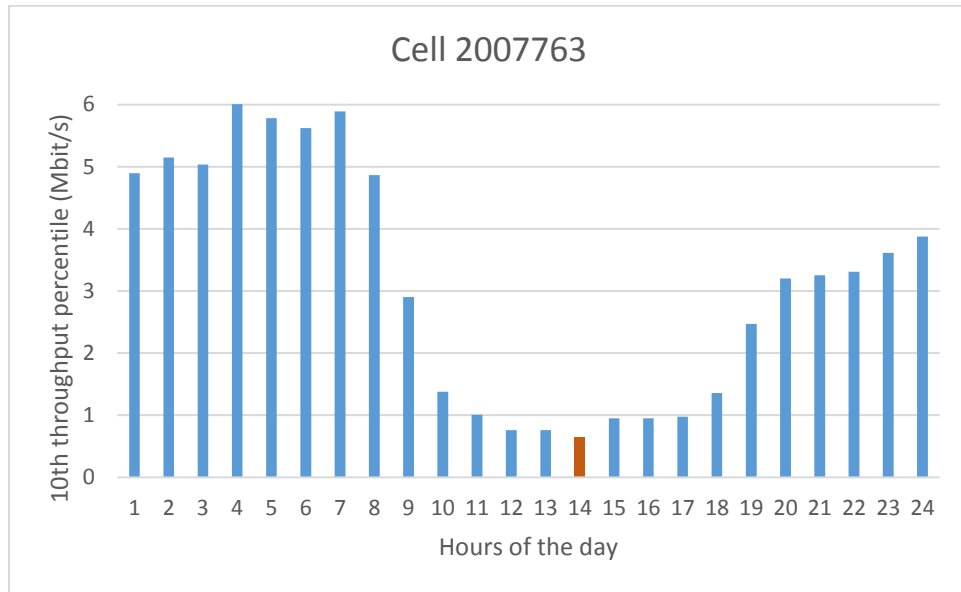


Figure 31: Plot to determine the bottleneck hour of cell 2007763 in Friesland

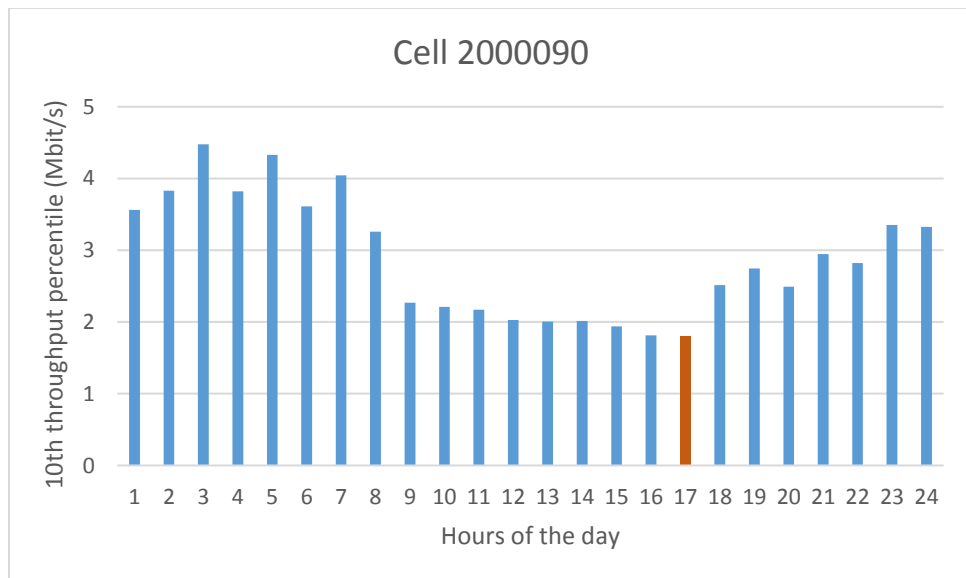


Figure 32: Plot to determine the bottleneck hour of cell 2000090 in Purmerend

As we can see from the plot, the bottleneck hour for the bottleneck cell in Friesland is at 14, which is the duration between 13:00 – 14:00, while for Purmerend it is at 17, which is the duration between 16:00 – 17:00.

4. **Bottleneck hour-Whole network:** The bottleneck hour of the whole network is determined by plotting the 10th throughput percentile values for the whole network, for each hour of the day. This case is important to plot because the network and the cells may not experience a bottleneck during the same hour of the day.

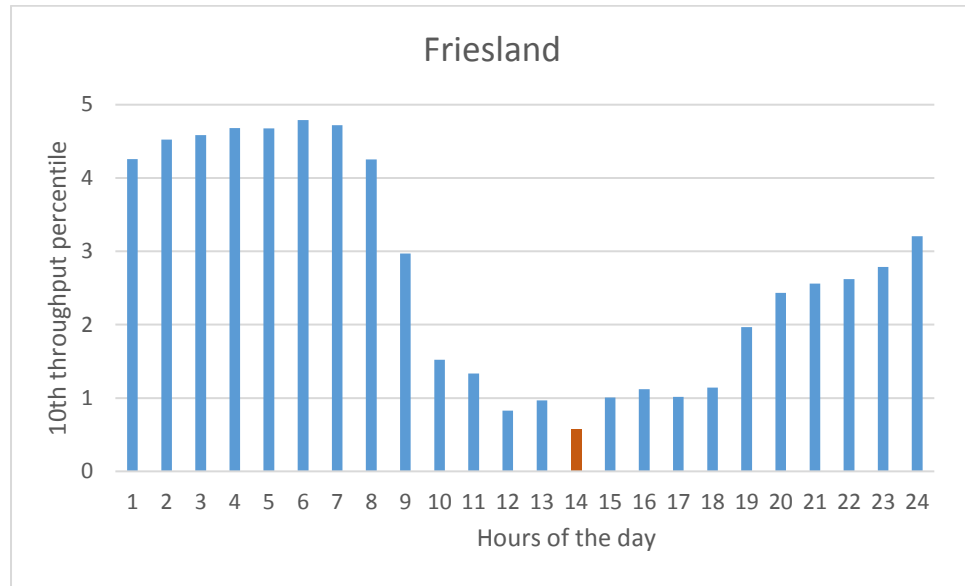


Figure 33: Plot to determine the bottleneck hour of the network in Friesland

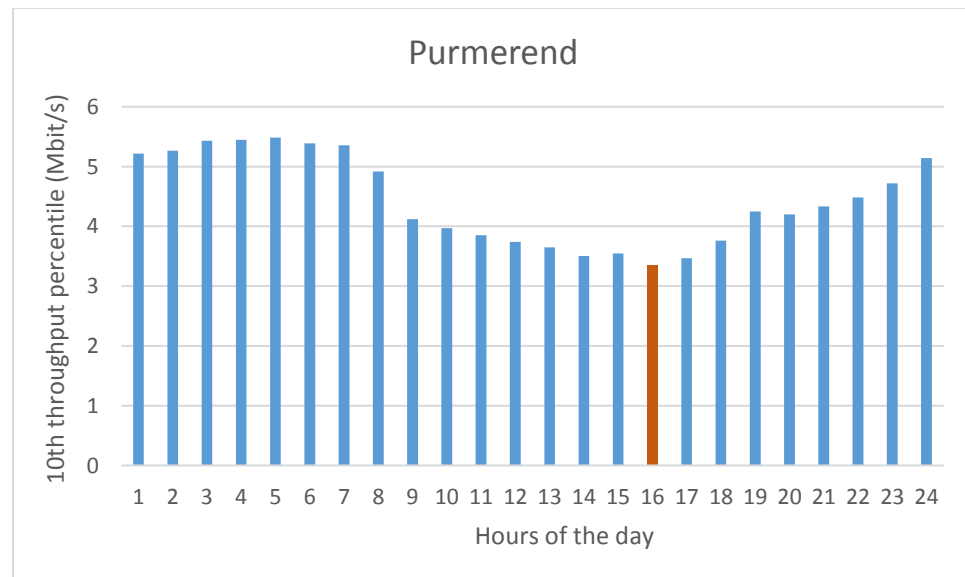


Figure 34: Plot to determine the bottleneck hour of the network in Purmerend

Figure 33 and 34 are used to ascertain the bottleneck hour for the network in Friesland and Purmerend, respectively. As we can see, the bottleneck hour for the network and the cell is the same in Friesland, i.e., the interval between 13:00 – 14:00. However, this is not the case for Purmerend, and the bottleneck hour for the Purmerend network is at 16, the interval between 15:00 – 16:00.

The four cases discussed above are used in the plots of 10th throughput percentile versus optimisation time interval. Since coverage failures are not cell specific, only cases two and four are relevant for the plot of coverage failure rate versus optimisation time interval.

DETAILED OPTIMISATION GRAPHS

When the simulations are run, detailed graphs are created in order to understand the working of the optimisation algorithm and the subsequent performance of the network. Each graph contains five subplots, containing the following: the 10th throughput percentile, the load of the cell, the optimisation parameter (tilt/RS/CIO), the call drop rate, and the PRB utilisation factor. In this section, I present and discuss one graph for each optimisation parameter, optimised for an interval of 60 minutes. All the five subplots in the figures are at a granularity of 60 minutes. The plots are discussed for the bottleneck cell in Friesland, cell 2007763.

RS Power

The graph below shows the detailed optimisation plot created when the network is self-optimised using RS power. The first subplot visualizes the 10th throughput percentile, the second one visualizes the changes in the RS power, and the third one visualizes the loads of the cell. The tilt and CIO in this case are fixed at 2 degrees and 0 dB, respectively. As we can observe, the load graph and the throughput graph have an inverse relation, i.e., at the points in the load graph where the load is too high, the corresponding points in the throughput graph exhibit low throughput values. This is an expected outcome, as an increase in the loads in the cell lead to an increase in the channel sharing factor, and thus a decrease in the throughput. The idea of the optimisation is to constantly improve the throughput performance by changing the RS power. Thus, when the throughput observed during a certain optimisation interval decreases w.r.t. the throughput of the previous optimisation interval, the RS power of cell is decreased. This is done to decrease the cell size, and reduce the cell load, so as to improve the throughput. In addition, as discussed in the previous chapters, decrease in the RS power will allow the power available in the PDSCH to increase, thus also improving user throughput. Since the network is dynamic, the RS power also changes constantly in accordance with it, so as to keep the network as optimised as possible, at all times. As we can see from subplot 2 of the graph, the initial RS power in the network is 18.2 dBm, but gradually decreases. Since cell 2007763 is a bottleneck cell as well as a highly loaded cell, a lower RS power is indeed advisable.

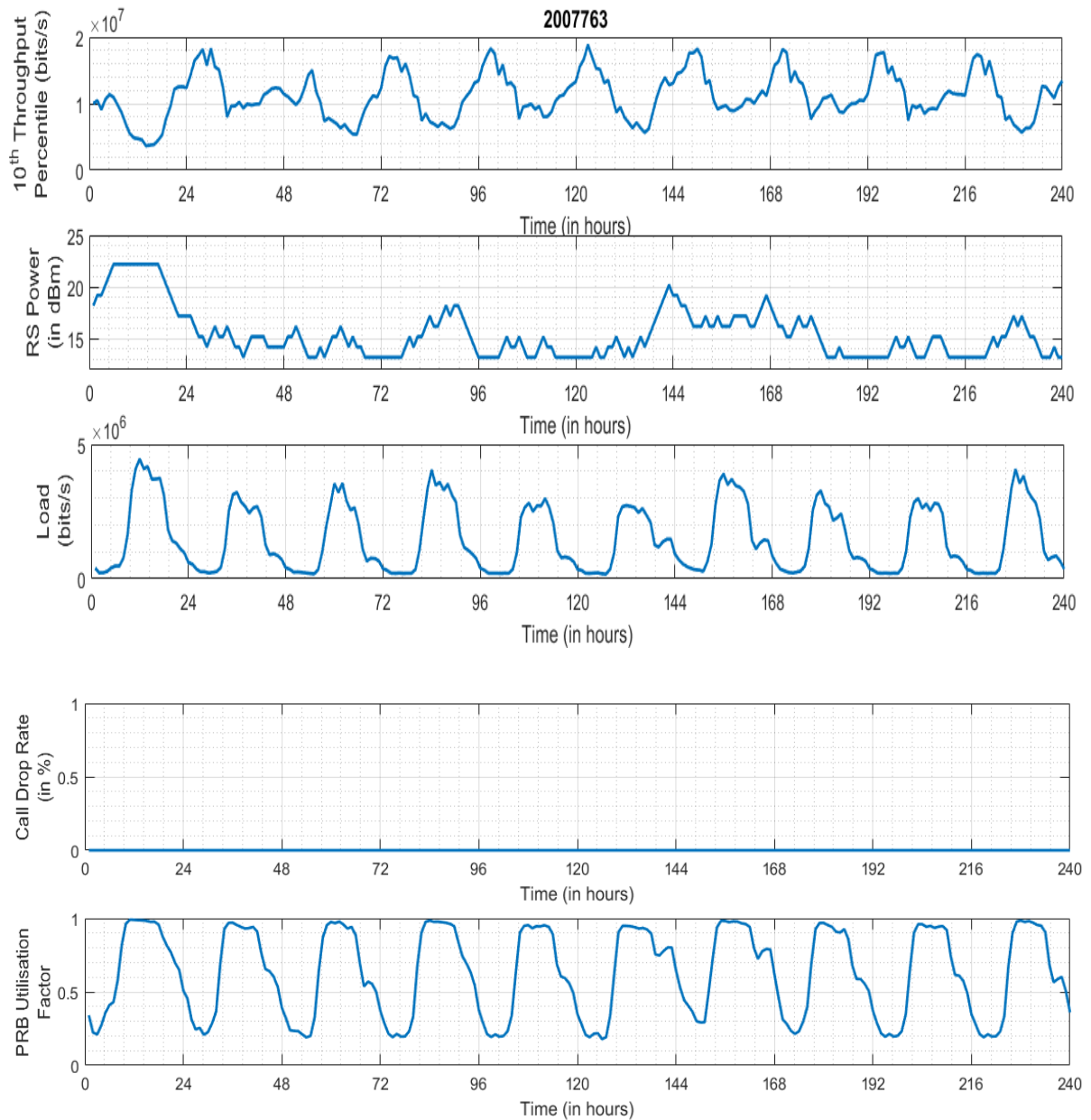


Figure 35: Self-optimisation of cell 2007763 in Friesland using RS power

The last two subplots indicate the call drop rate and the PRB utilisation factor. As we can observe, no calls are dropped in this simulation run, and the PRB utilisation of the cell indicates a moderately loaded cell, and is mostly between 20-80%.

As we can see, even after the network is optimised, the RS power values are not identical for each day, and there is still a slight variation in the RS values of each day. This is expected to remain and can be attributed to the following reason. When a cell takes on a certain RS value, it leads to certain amount of load in the cell, and thus, an experienced user throughput, which determines

the duration of each session that the cell serves. A slight variation in the throughput between two days can lead to a different session duration for the exact same session on the two days. Moreover, if a session gets carried over into a new optimisation interval (in our case, the next hour), or into a new day (for sessions which originate just before midnight), this would lead to a slight change in the load of that interval or that day, and would affect the resulting throughput, and hence the RS power value of the next interval. Moreover, due to the fact that not all days start with the same RS setting across all cells, this affects the resulting inter-cell load balance and interference effects. These factors lead to a similar, yet not identical, performance of the network for consecutive days in an optimised network. This can be expected for optimisations done using all three parameters.

CIO

In this section we discuss an optimisation run carried out using cell individual offset. The tilt and RS power in this case is fixed at 2 degrees and 18.2 dBm, respectively. As discussed in the previous chapters, CIO is used to make a cell seem more (or less) desirable to a UE, by adding (or subtracting) a CIO value from the RSRP. In Figure 36, we see the CIO values added to the RSRP. This will affect the cell size, and thus, the loads in the cell. The simulation starts off with a value of 0 dB, however, slowly converges to a negative CIO value between -5 and -1. This is in line with the fact that cell 2007763 is a bottleneck cell as well as a highly loaded cell, and making the RSRP seem less strong will allow the load of the cell to reduce. In addition, if we observe the load and the CIO subplots, we see that at each moment that the CIO increases (takes on less negative value), the load of the cell also increases at that point. This validates our correlation between the CIO value and the load.

As discussed in the previous example (RS power), the load and throughput are expected to have an inverse relation with each other, and that can be observed in this graph as well. When the throughput starts to deteriorate, the perceived RSRP of the cell is lowered by adding a negative CIO value, in order to reduce cell size and cell load. Another important point to note here is that, while in the case of both RS power and CIO optimisations that have been discussed, we have reduced the cell size, the throughputs experienced in RS power optimisations (previous case) are higher than the throughputs experienced in the CIO case. This is due to the fact that while the cell load may be decreasing here due to a lowered RSRP (perceived), the power available in the PDSCH stays constant, since the RS power is staying constant. Contrast this to the previous example where the PDSCH increases as a result of lowered RS power, thus delivering higher user throughputs as compared to a CIO based self-optimisation.

The second subplot shows that no calls have been dropped in this optimisation run. The last subplot contains the PRB utilisation factor, and mostly stays between the values of 20-70%.

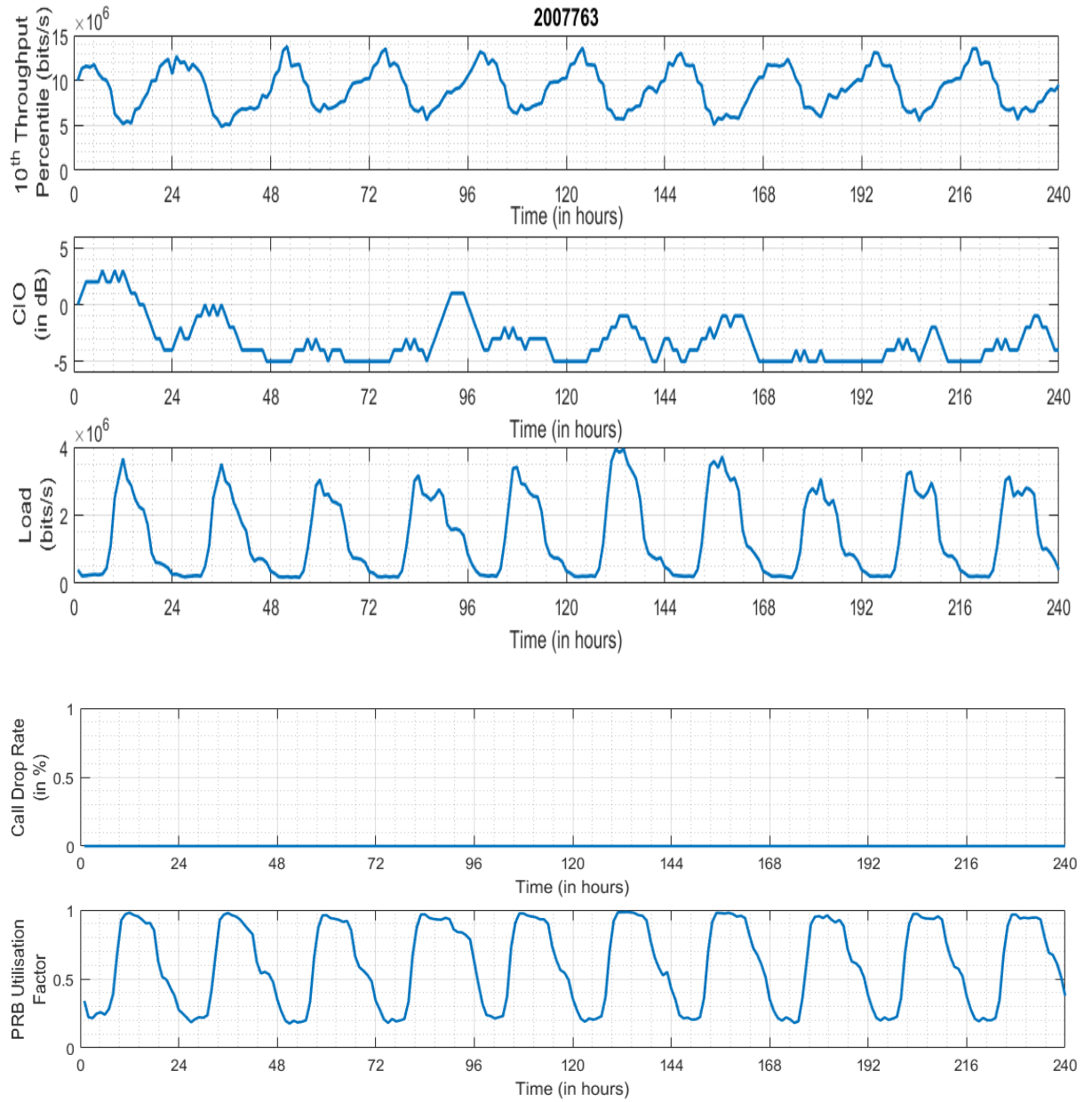


Figure 36: Self-optimisation of cell 2007763 in Friesland using CIO

Antenna Tilt

Antenna tilt is considered to be one of the strongest methods of self-optimisation of a network. This is because changing the antenna tilt has a greater impact on the cell size, as well as the load distribution and SINR statistics, than any of the other methods considered in this thesis. When the throughput of the cell deteriorates, the tilt of the antenna is increased in order to downtilt the antenna more, and decrease the cell size, in an attempt to decrease the load.

However, in this case, the antenna tilt does not perform very well. As we can see from subplot 1 and 2 in Figure 37, when the throughput of the cell falls to its lowest, the tilt of the antenna is initially increased. However, the algorithm expects this increase in the tilt to bring about an amelioration in the throughput, which does not happen, since the load values stay at a peak for almost 10 hours of the day. When the algorithm introduces a change in the tilt, but does not experience an ameliorated throughput, it reverses the direction of the change, hoping that the reversed change will improve the throughput. This ping-pong continues till the load of the cell goes down which consequently brings up the throughput. *This is a flaw in the algorithm.* When the tilt angle was initially increased to accommodate for the increased load, the algorithm should have continued to increase the tilt angle despite the deteriorating throughput. The reason the throughput deteriorates even upon increasing the tilt is not because the tilt has been increased, but because the tilt has not been increased enough.

This may seem like an error in the implementation of the simulation, but this is actually a failure of the algorithm (discussed in the previous chapter). Since in high loaded cells, loads increase sharply and rapidly, small tilt changes, such as that of 1 degree, which the algorithm introduces are not enough. A suitable tilt change for such cells would be higher than 1 degree, and would need to be decided based on the load in the cell.

As mentioned earlier, we have chosen the bottleneck cell in Friesland for this discussion, which also happens to be the highest loaded cell in the network. This problem occurs only in cells with extremely high loads (as in this case). In addition, as mentioned earlier, tilt angle is a more effective method, and thus in our case it manages to pull in much more load into the cell, as compared to the other two methods. The high loads also lead to poor throughputs. Throughput for tilt optimisations caps at 4 Mbit/s, while in case of CIO and RS power optimisations the throughputs go up to 15 and 20 Mbit/s, respectively. The low throughputs also lead a large number of calls being dropped, and a high call drop rate consequently leads to a low 10th throughput percentile. In this case, call drop rate can be seen to go as high as 40%.

A suitable way to fix this flaw is to change the algorithm used in this thesis from an incremental to an adaptive one, i.e., currently the algorithm changes the tilt value in increments of 1 degree at a time, however, it should be adaptive such that it recommends a tilt change based on the load in the cell. For example, when the load in the cell is higher, the tilt change could be 4 degrees, while for low loaded cells, a tilt change of 1 degree is suitable. The current algorithm does not factor in the load of the cell while recommending a change in the tilt, however, it should, and the change value should be adaptive and not incremental.

However, the optimisation still retains the basic characteristics of network performance, such as an inverse relation between the load and throughput. We also notice that while the optimisation

starts with an initial tilt value of 2 degrees, it converges towards a much higher value and mostly stays between 5 and 10 degrees. Since the above discussed problem with the algorithm is only present in case of high loaded cells, we discuss the graph for a lightly loaded cell in Figure 38 in order to understand the functioning of the tilt optimisations. The graph is for cell 2008355, which is a lightly loaded cell in the interior of Friesland (non-boundary cell).

We can observe that there are no dropped calls in this cell, and the throughput values are significantly high. The load values are relatively lower, and the PRB utilisation factor is fairly low, between 5-25%. Upon studying the load and the throughputs, we notice that the load values change frequently and lead to a change in the throughputs. The peaks in the loads correspond to the lows in the throughputs. When the throughput value deteriorates, the tilt value increases in order to reduce the load. At several points in the graph we see that while the throughput values change, the tilt is staying constant. This is because the algorithm only introduces a change in the

optimisation parameter (tilt/RS/CIO) if the change in throughput is more than 5%. For a change lower than 5%, the value of the optimisation parameter is retained (tilt/RS/CIO).

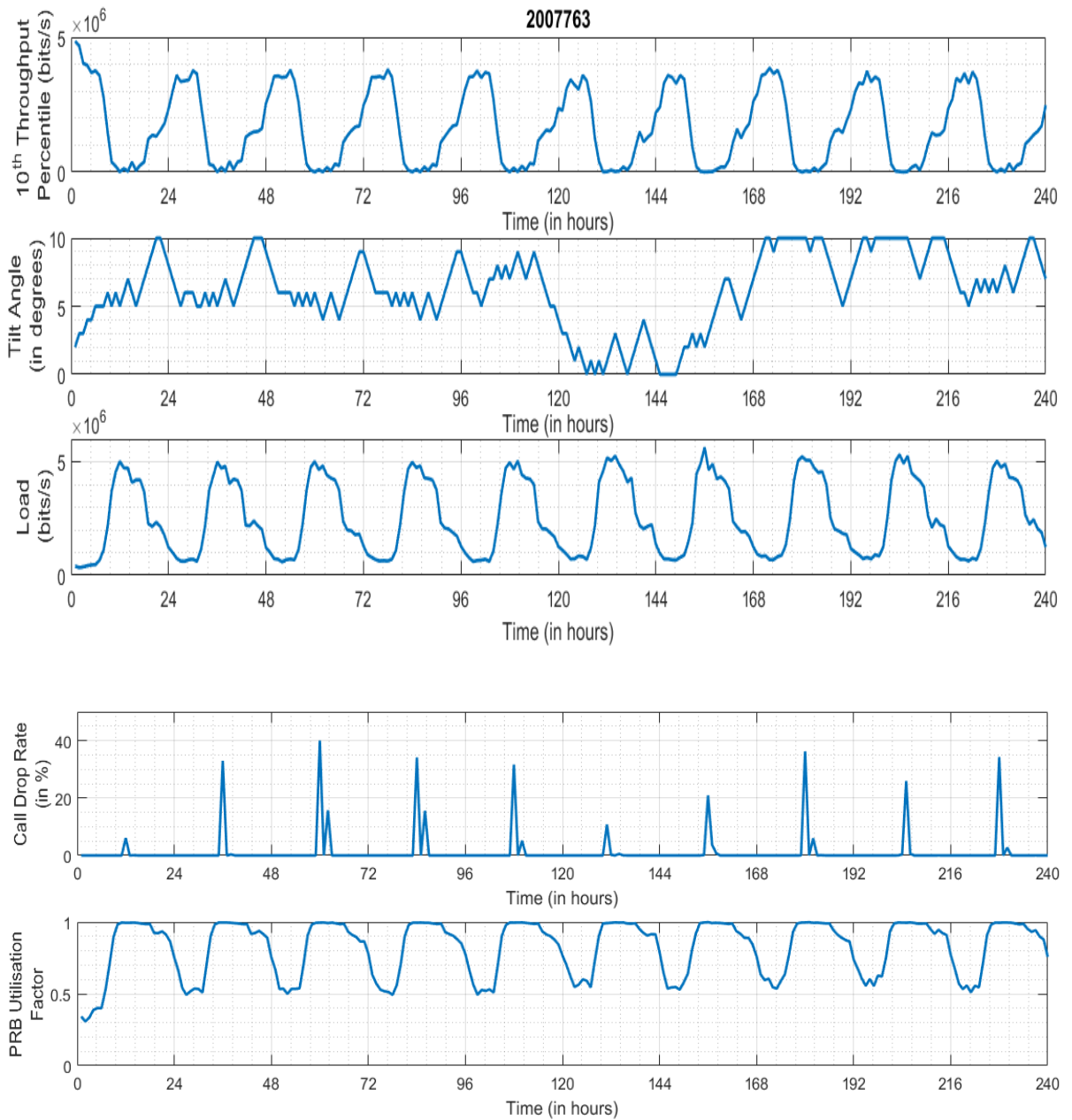


Figure 37: Self-optimisation of cell 2007763 in Friesland using antenna tilt

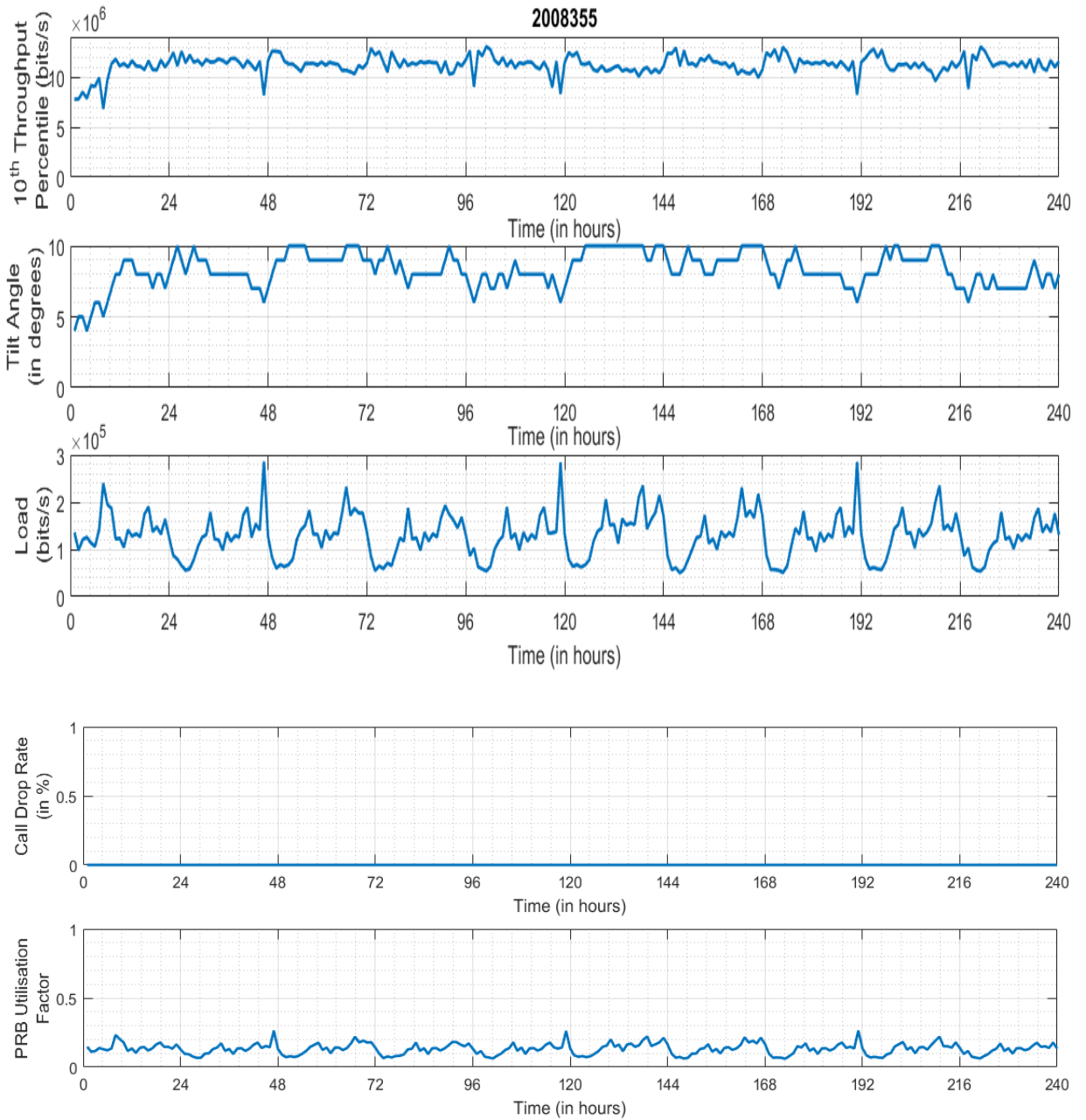


Figure 38: Lightly loaded cell 2008355 in Friesland self-optimised using antenna tilt

TIMESCALE ANALYSIS PLOTS

In this section the main plots are presented, which will be used to study the effect of the self-optimisation timescale on the performance, as well as the relative performance of the three methods. The plots are presented area-wise, first for Friesland, and then for Purmerend. The plots on the left side are for the bottleneck hour, where the first plot is for the throughput performance of the bottleneck cell, the second plot is for the throughput performance of the network, while the last plot is for the coverage failure rate. The right side contains plots for all-day, with the first, second and third plots representing the throughput of the bottleneck cell, the throughput of the network, and the coverage of the network, respectively. The plots for Purmerend are arranged in the same fashion.

FRIESLAND

The plots for Friesland have been shown on the next page. The most obvious result from the plots is that the throughput performance of the network for an optimised network is significantly better than that of a non-optimised network, except in the case of tilt optimisations. This is a successful result, since self-optimisation is aimed at improving the quality delivered by the network.

Comparison of the methods

As discussed in the earlier section, the tilt optimisations for Friesland do not work. This can also be seen from the graphs, as the optimised network performs worse than a non-optimised network. Thus, no reasonable inferences can be made for tilt optimisations, and must be disregarded.

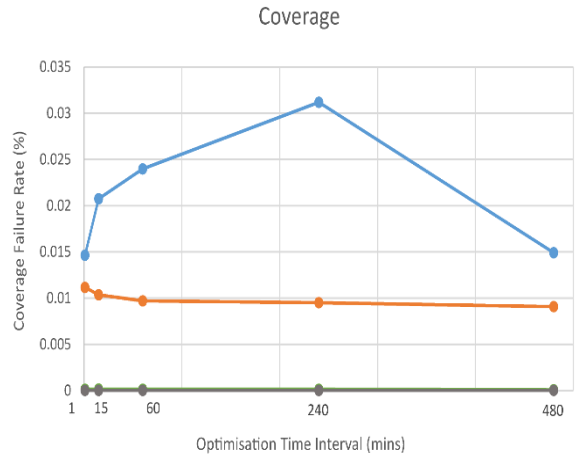
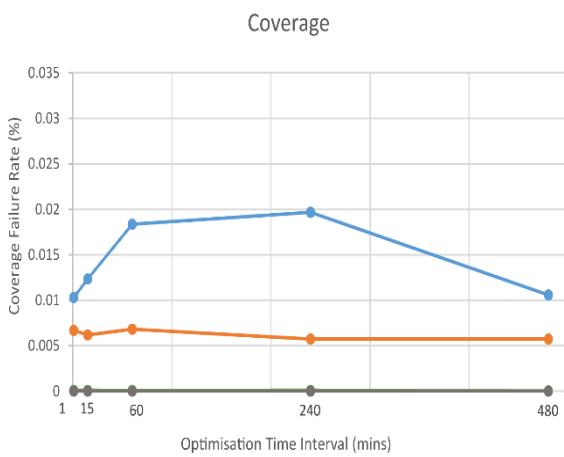
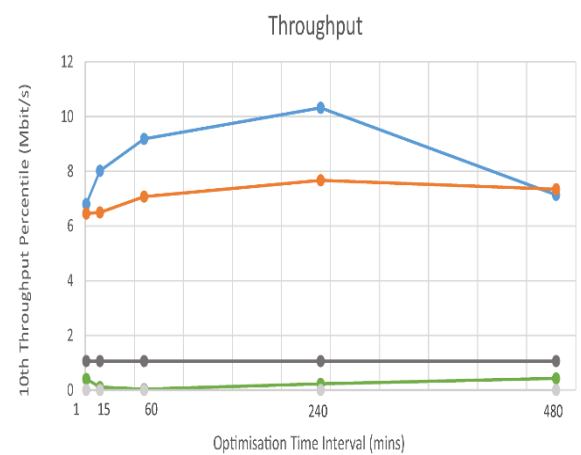
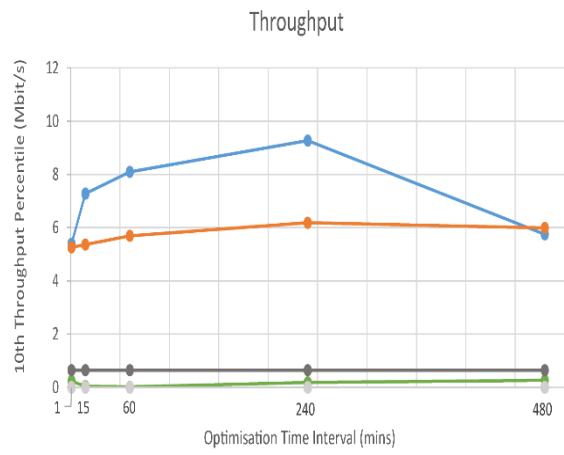
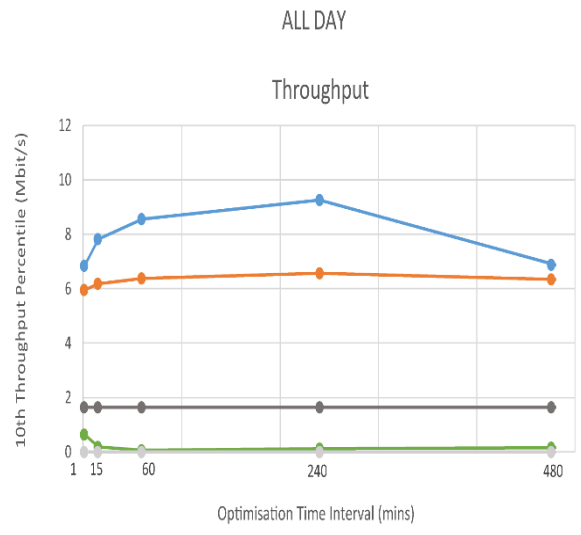
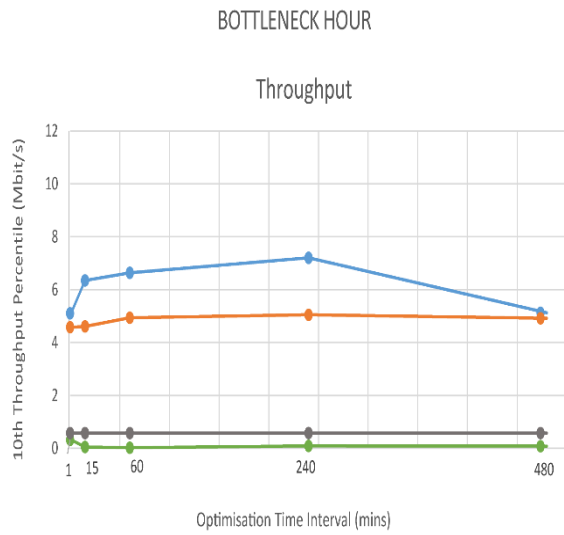
From all the four throughput graphs, we can see that RS power optimisations perform better than CIO optimisations, for all cases. This is in line with the detailed graph discussion in the previous section, where we observed that the throughputs for RS optimisations were higher than that for CIO.

The coverage graphs for both, the 'bottleneck hour' and 'all day', show the coverage failure in the case of RS optimisations to be the highest. Since every network has an intrinsic trade-off between coverage and quality, we can attribute the higher coverage failure rate to improved quality of the network. However, the coverage failure rate goes up to a maximum of only 0.035%, which means a coverage of at least 99.965% at all times, which is an extremely good coverage performance.

Comparison of the time intervals

The optimisation time interval analysis reveals that there is indeed an optimal time interval for self-optimisation of the network, and in Friesland, this interval is 240 mins or 4 hours. Both RS power and CIO optimisations have their throughput values peaking at 240, while other timescales can be seen to perform worse than this time interval. The trends of all four throughput graphs are more or less the same.

We also notice that the throughput values for 'all day' are higher than that for 'bottleneck hour'. This is because the bottleneck hour usually experiences low throughputs, while the throughputs for the whole day also contain the effects of the less busy hours, and thus are better.



— RS — CIO — Tilt — No SON

Figure 39: Friesland results

The throughput values for the network are higher than that of the bottleneck cell. This is expected, and follows the same reasoning as above. The throughput of the network includes the effects of both lightly loaded as well as highly loaded cells, and thus tends to be higher.

The coverage plots for Friesland show that the RS power optimisations have the highest coverage failure rate at 240 min. As discussed earlier, since throughput performance peaks at 240 min, this can be considered a coverage-quality trade-off. The coverage failure rate trendline for CIO is almost flat. However, since the actual values of the coverage failure for all methods are very low, this result does not hold much significance.

PURMEREND

The results for Purmerend have been shown on the next page. Overall, we observe a lesser impact of SON in Purmerend, as compared to Friesland.

Comparison of the methods

An interesting observation from the plots is that the tilt optimisations perform the best in case of the bottleneck cell, both for the 'bottleneck hour' and 'all day'. This is because while our chosen bottleneck cell has low throughputs, it is not among the highest loaded cells, and definitely has much lower load than the bottleneck cell for Friesland. The load for cell 2007763 in Friesland is 6 Mbit/s, while that for cell 2000090 in Purmerend is 2 Mbit/s. This validates our interpretation that the assumed tilt angle optimisation algorithm only fails in case of heavily loaded cells. The throughput performance of the network in case of tilt angle optimisations is expected to be lower than that for the bottleneck cell, as it would incorporate the effects of heavier loaded cells. Unfortunately, the throughput for the network in this case turns out to be lower than that of a non-optimised network.

RS power optimisation performs consistency well for all the cases. The CIO optimisations do not perform as well as in the case of Friesland, and its throughput performance stays fairly similar to that of a non-optimised network.

Since the coverage failure rate for all the three methods is almost zero, and thus negligible, no comparison can be drawn between the relative performance of the methods for coverage, and the results for coverage failure rate can be ignored.

Comparison of the time intervals

The throughput performance for both tilt and RS optimisations for Purmerend peaks at an optimisation interval of 240 mins or 4 hours. Since the throughput performance trendline of CIO optimisations is almost flat, i.e., all time intervals present almost similar throughput performance, no inference can be drawn about a suitable time interval for CIO optimisation.

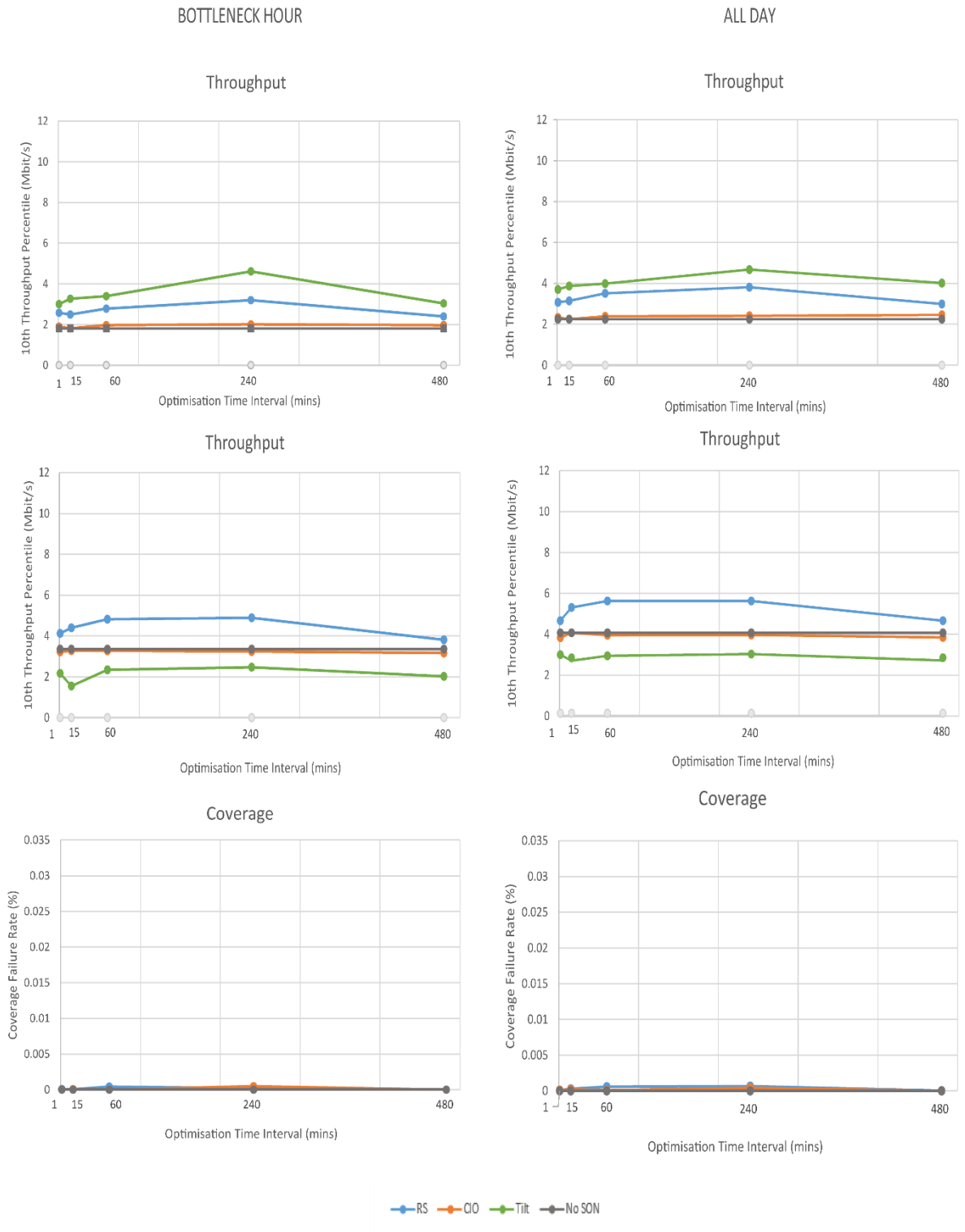


Figure 40: Purmerend results

As in the case of Friesland, the 'all day' exhibits higher throughput performance than the 'bottleneck hour', and the network exhibits a higher throughput performance than the bottleneck cell.

The coverage failure rate is almost zero, for both the busy hour and the whole day, and thus, no analysis needs to be made regarding the effect of the time interval of optimisation. The highest coverage failure rate for Purmerend is .00067, which means a coverage of at least 99.9993% at all times, which is extremely good.

COMPARISON OF THE SIMULATION AREAS

The results discussed above show us that an optimal time interval for self-optimisation does exist, and it is consistently 240 minutes, for both the areas. A comparison of the optimisation parameters tells us that RS power performs consistently well in both areas. In some cases in Purmerend, tilt optimisation is seen to perform the best. However, given the evident flaw in the algorithm, tilt optimisation cannot be considered as a suitable method of optimisation using the current algorithm. Nevertheless, we can conclude that antenna tilt has the potential to be an excellent optimisation parameter, provided the flaw in the algorithm is fixed.

Overall, we notice lesser gains with self-optimisation in Purmerend, as compared to Friesland. However, it can be observed is that the 'No SON' case for Purmerend performs better than the 'No SON' case for Friesland. The 'No SON' case for each area has been run by retaining the initial configuration for all three optimisation parameters, as was obtained from KPN. While the RS power and CIO for both the areas were fixed at 18.2 dBm and 0 dB, respectively, the tilt angle for the bottleneck cell in Friesland is 2 degrees, while that for the bottleneck cell in Purmerend is 6 degrees. Hence, it can be said that the initial network configuration received for Purmerend was 'more optimal' than that for Friesland, which leads to the reference case of 'No SON' performing better in case of Purmerend. This allows us to speculate whether the optimised network is not performing so well, or if the reference case is performing too well, thus making the optimised cases' performance seem not so optimistic.

Upon studying the Friesland map, it was discovered that the neighbouring cells to cell 2007763 also have low tilts- cell 2007761 has a tilt of 2 degrees, while cell 2008019 has a tilt of 5 degrees. Friesland is a large area, and the KPN cellular sites are not so many, and thus the cells cannot have high antenna tilts, as that would lead to coverage gaps.

SUMMARY AND RECOMMENDATIONS

In this chapter, we discussed the results of this thesis project. The first section familiarized the reader with the basics needed to understand the plots, and introduced and explained the cases of bottleneck cell and bottleneck hour. The second section discussed the detailed optimisation plots for each method, and explained using a 5-in-1 plot of 10th throughput percentile, optimisation parameter, load, call drop rate and PRB utilisation factor. It also explained why the assumed optimisation algorithm is not suitable for tilt angle optimisations, and where it fails. Subsequently the final section discussed the main plots and drew an analysis on the relative performance of the methods and the time intervals. A comparison between the two simulation areas has also been presented.

The results exhibit best throughput performance in the case of RS power optimisations, while the optimal time interval has been observed as 240 minutes.

The optimisation algorithm used in this thesis project is incremental, i.e., change is introduced in step sizes and a change of only one step size can be introduced in one go. However, the results suggest that an adaptive algorithm may be more suitable, where the amount of change to be introduced is decided by factoring in the load of the cell, and a change of several step sizes can be introduced in one go.

The results also exhibit an extremely good performance of the coverage of the cells. Since there is always a trade-off between the capacity and quality in a mobile network, the coverage can be sacrificed to a small extent, in order to boost the quality. The coverage could be brought down to 99.5%, and that would still be a good value, and this sacrificed performance could be used to bring about an improvement in the quality.

CONCLUSIONS

In this thesis, the goal has been set to examine the effect of different optimisation time intervals on the self-optimisation of KPN's mobile network, and to determine if a suitable time interval exists. In addition, this temporal study has to be carried out using three different optimisation parameters – antenna tilt, RS power and Cell Individual Offset, and two different simulation areas – Friesland and Purmerend. Ultimately recommendations need to be made about the suitability of the parameters, and a suitable optimisation time interval, for each simulation area. The preparation for the project includes a qualitative analysis of all three optimisation methods (parameters), and a study of related literature to understand the current research in the field and determine a suitable optimisation algorithm.

The undertaken thesis project is performed by creating a simulation study in MATLAB. The input for the study is taken from the KPN network, and includes data traffic for LTE in the downlink for the 800 MHz band. The data received from KPN is for a period of 24 hours, and has been looped for several days in order to run the optimisations. The optimisations for each case (timescale, parameter, area) were run for a period of ten days, and the first five days have been treated as the warm-up period. The performance results for the last five days have been averaged, and are used to study the results. The final results plotted consider four cases: the bottleneck hour performance of the bottleneck cell, and that of the whole network, and the all-day performance of the bottleneck cell and the network. These cases help to study the network at its lowest throughput performance, as well as overall.

The thesis project shows improvement in the performance of a mobile network when it is self-optimised. The study also confirms that there is indeed a suitable time interval for self-optimisation, and the interval is 240 minutes. The results consistently observe best network performance in the case of self-optimisation using RS power.

The results also bring into question the suitability of the algorithm for the self-optimisation using antenna tilt, and the result section motivates why the tilt optimisations do not work as expected. The last part of the results section presents a contrast between the two simulation areas, and motivates why the 'No SON' case for Purmerend performs better than that for Friesland. In general, the self-optimisation throughput performance for Friesland is significantly better than that for Purmerend.

The coverage performance of the optimisation for both the simulation areas stays excellent. A recommendation has been made to consider sacrificing some of the coverage, in order to see an improvement in the throughputs, since coverage and quality have an intrinsic trade-off in a mobile network.

SCOPE FOR FUTURE WORK

The research conducted in this thesis project helped to gain insight into the existence of a suitable time interval for optimisation, and the most suitable parameters to carry out the self-optimisation of a mobile network. However, several parts of this study can be tweaked or nuanced further in order to gain a deeper understanding of the topic. As an extension of this project, the study of the self-optimisation time interval can be conducted by using an adaptive algorithm instead of an incremental one, such that changes in the optimisation parameters need not be done one step at a time, but the amount of change to be introduced can be ascertained by the algorithm. In addition, instead of having a common algorithm for all the three optimisation methods, separate algorithms more suited to functioning of each method, can be implemented. The algorithm could also factor in the coverage performance of the network, so that a realistic balance can be maintained between coverage and quality.

The study can be extended to include more simulation areas, for example, an urban area scenario, such as Amsterdam or Eindhoven, could be considered. Other methods of self-optimisation of a network could also be considered, such as antenna azimuth optimisation.

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