Placement optimization of Positioning Nodes:

Maximizing the distinction of Indoor Zones

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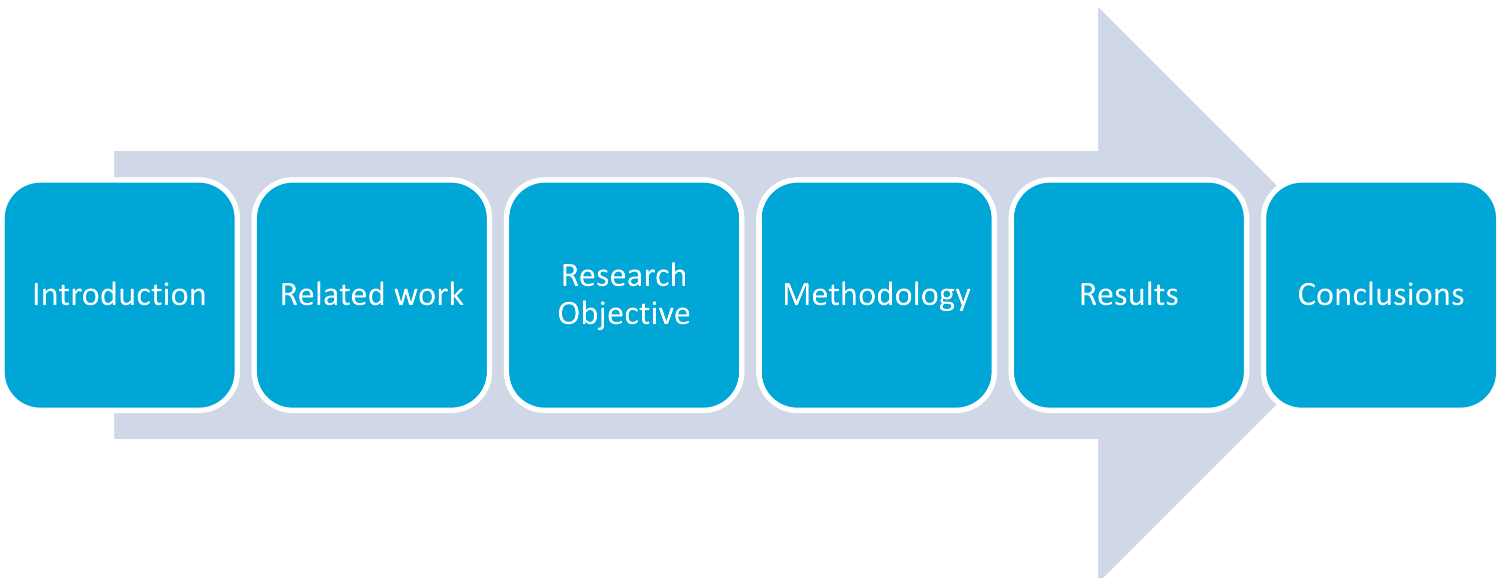
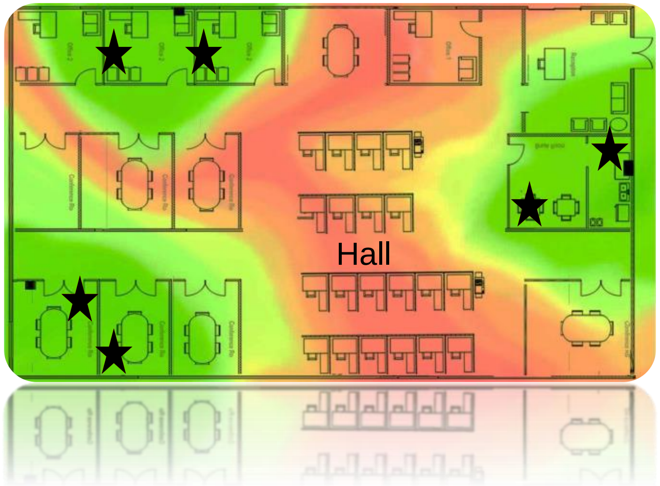
Presentation's Structure



Motivation

- **Task:** Install 6 Wi-Fi Access Points

But where is the ideal?



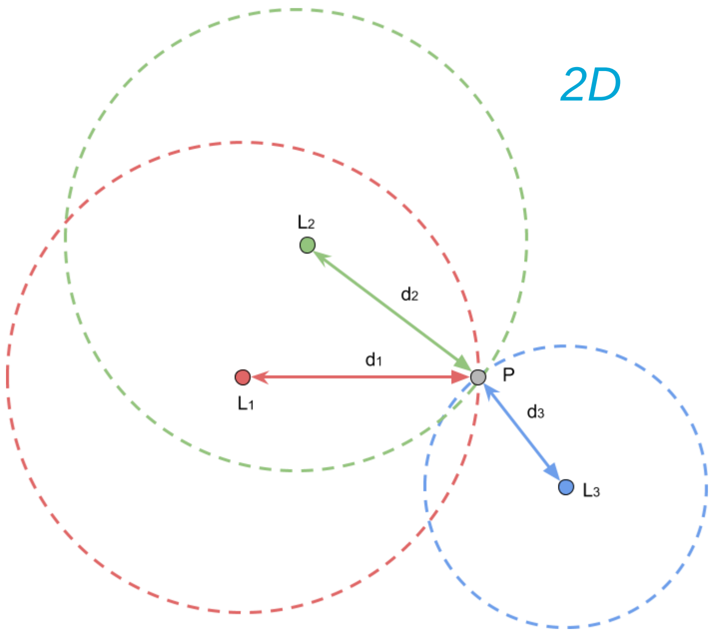
Optimizing a node Setup for better Wi-Fi

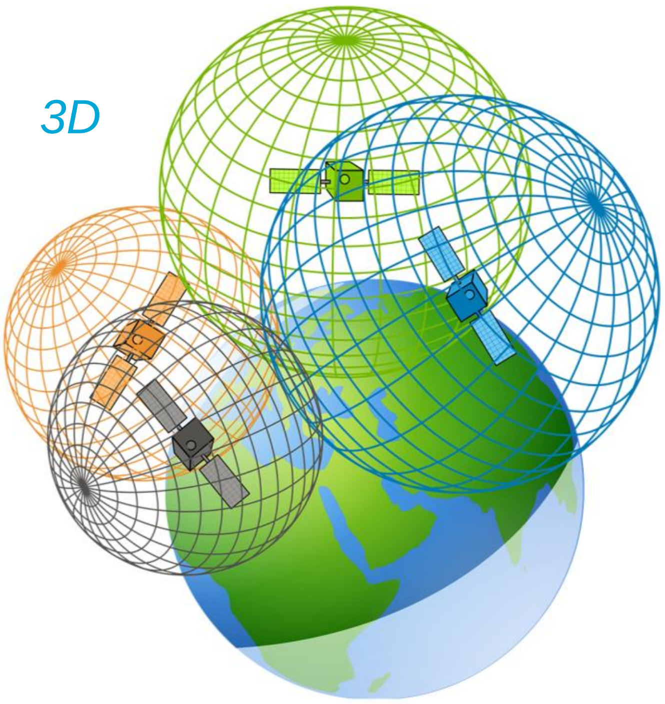
What is a positioning node?

- *Hardware installed at a known position, exchanging with a module Uni/Bi-directional signals, that can be used to deduce the module's position.*

Deducing module's position..

- Different positioning techniques..
  - Triangulation
  - Multilateration
  - Trilateration
  - Fingerprinting

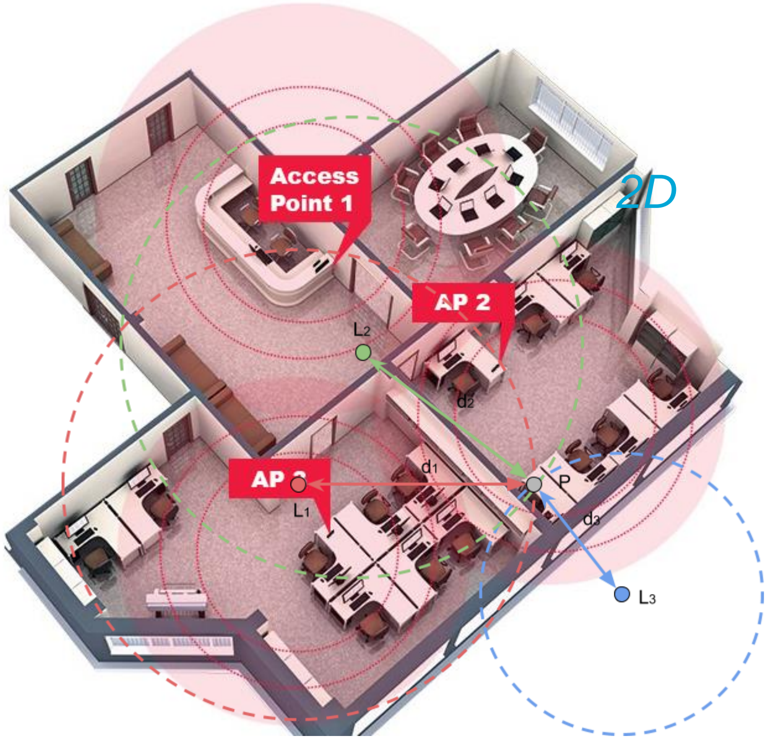




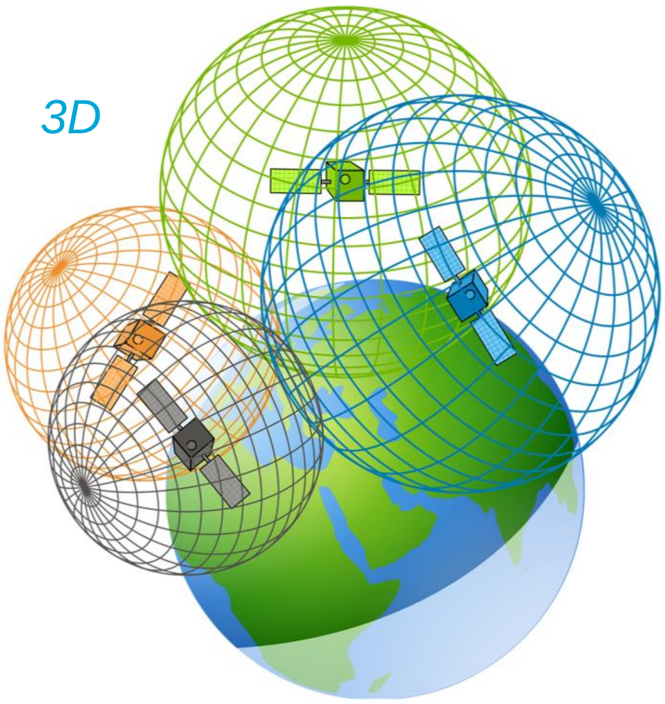
Deducing module's position..

- Different positioning techniques..
  - Triangulation
  - Multilateration
  - Trilateration
  - Fingerprinting

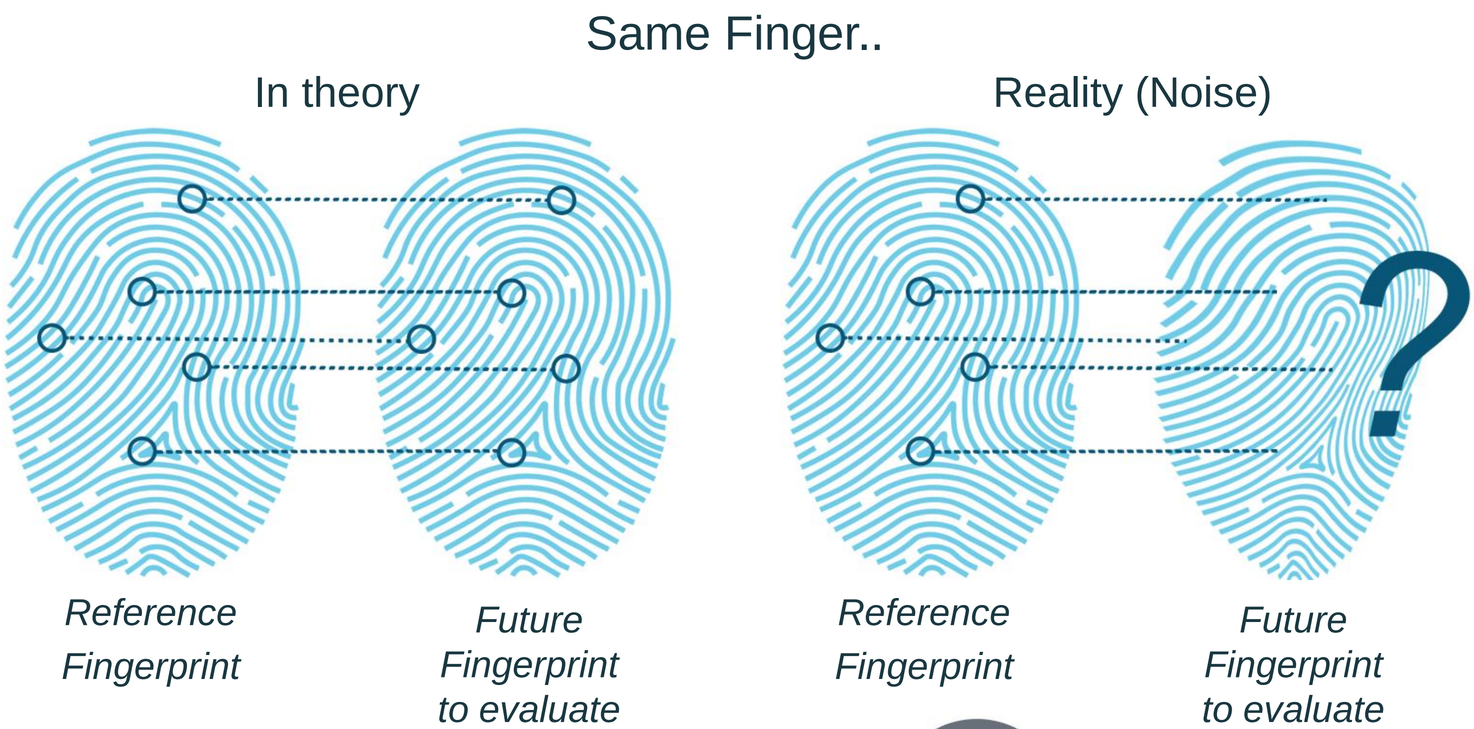
2D



3D



Why to optimize their placement?



- Placement optimization can help making our predictions less prone to such **inevitable** noise

Related Work

Aiming to optimize the placement of nodes used for fingerprint-based indoor positioning

3 essential steps:

- Select a performance metric (e.g. RSS at some specific positions)
- Model how the signal propagates
- Choose an optimization function to search where the metric becomes optimal

Most used

Performance Metrics

(Sometimes, more than one metrics were considered)

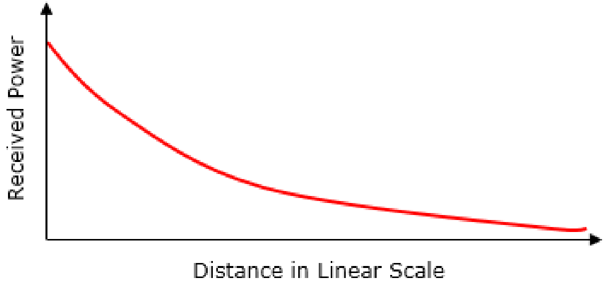
- The total signal strength or coverage
  - (Most favored in the cases where Wi-Fi APs had been utilized)
- The error of the position's estimation
- The vector distance of RSS fingerprints
  - (Most used in the latest papers)

Sometimes, the objective was to also minimize the number of required nodes *and thus the installation cost*

Most used
Radio Propagation Models

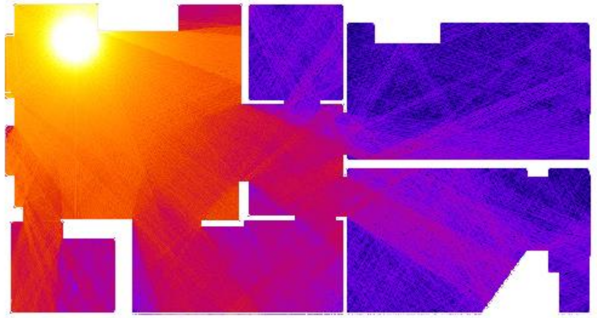
- **Simplified**
  - Exact signal interactions with the environment are highly neglected
  - *Very fast* but *less accurate*

(e.g. Free Space Path Loss)



- **Deterministic models**
  - These respect Reflections and Refractions that occur during the radio propagation
  - *Accurate* but *very slow*

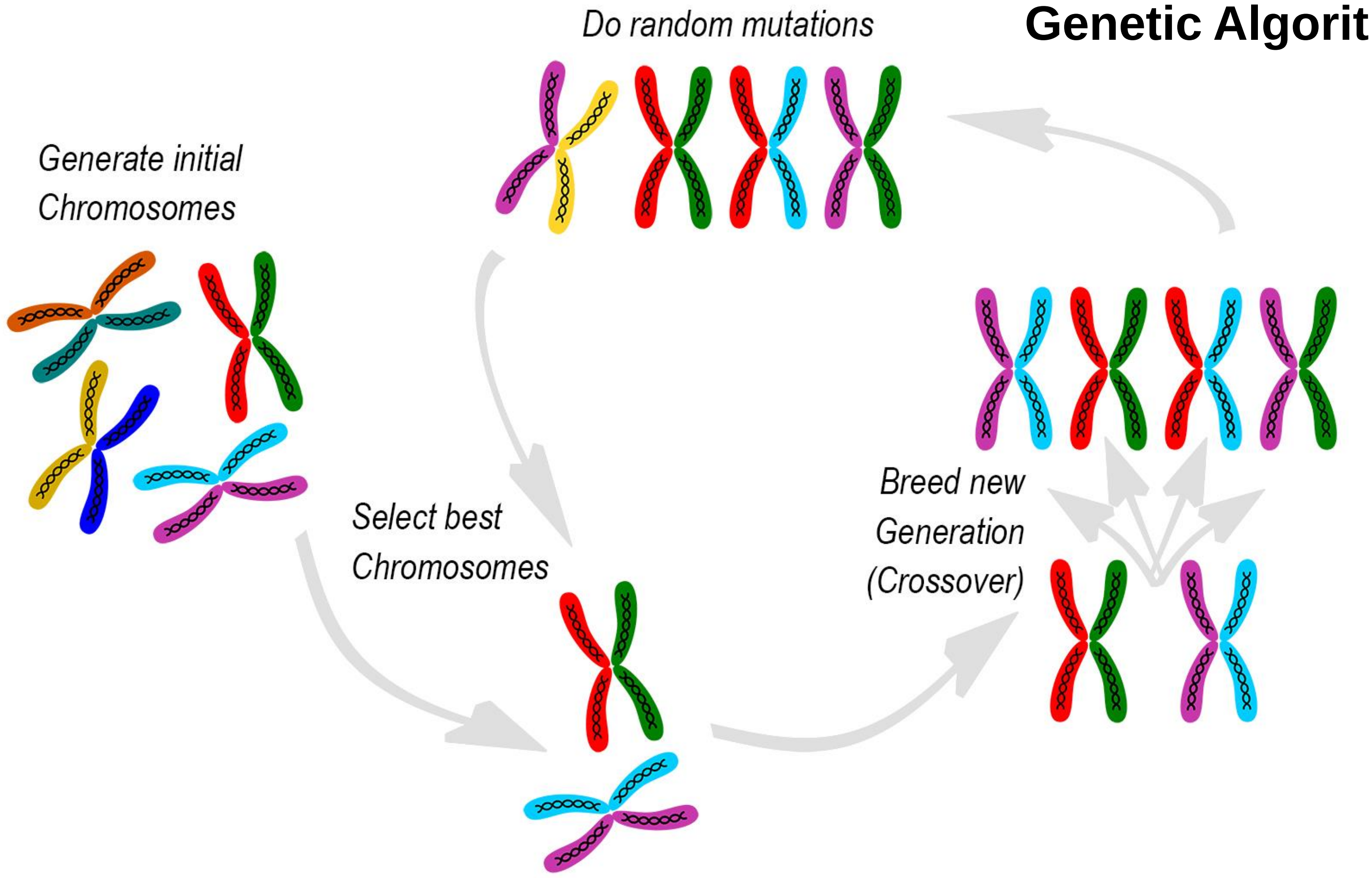
(Ray Tracing based)



Source: Jason Mark

Most used
Optimization Functions

Genetic Algorithms



Research Objective

Position vs Location

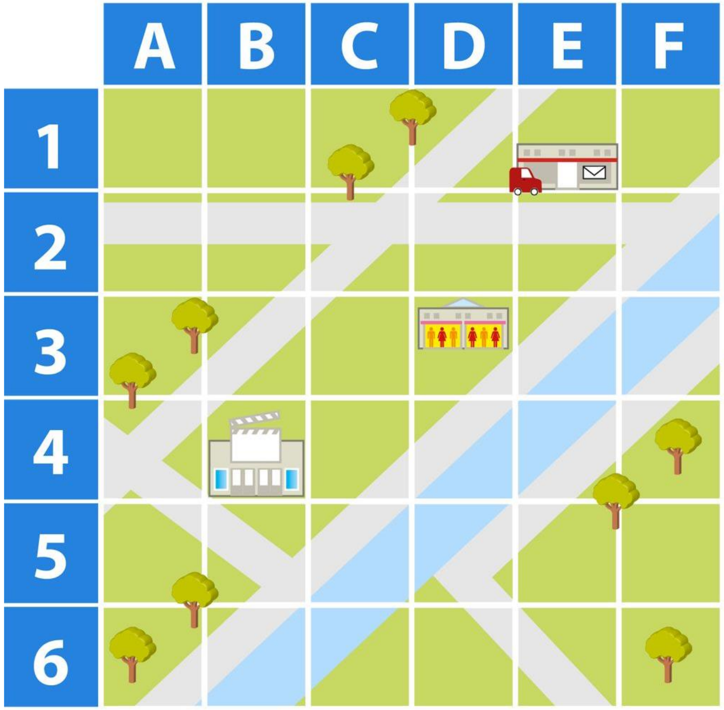
- So far, the interest of the related research has essentially been the coordinates of a physical position in some coordinate system.

  Buildings are at [1E, 3D, 4B]

but…

- In the field of Geomatics, the physical position may need symbolic enrichment before it becomes valuable.

  Buildings are at the
  left side of the river



Research Objective

To what extent can the placement of BLE nodes
that are used for fingerprint-based positioning,
be optimized to increase the location distinctiveness in an indoor environment?

- How can the location distinctiveness be defined for an indoor positioning system?
- Which metric is most suitable for measuring the radio distinctiveness among different zones?
- Which radio propagation model would offer good accuracy-complexity ratio?
- Which optimization algorithm should be utilized, to support even large-scale optimizations?
- How can the optimization results be evaluated?

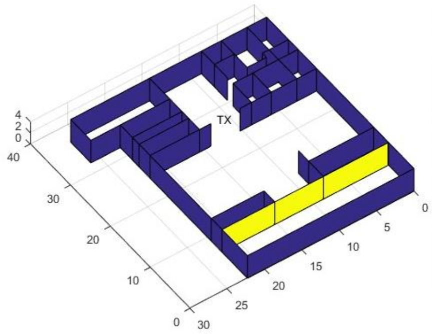
How to do it?

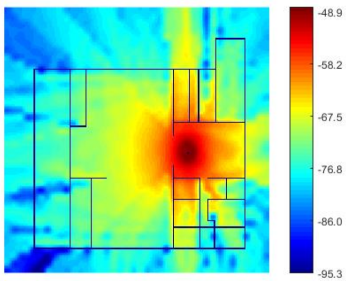
Check 2:
Is that better?

1. **We have to try different scenarios**

   - Up to some millions more checks..

2. **Find a fast way for the evaluation**





Radio Simulator

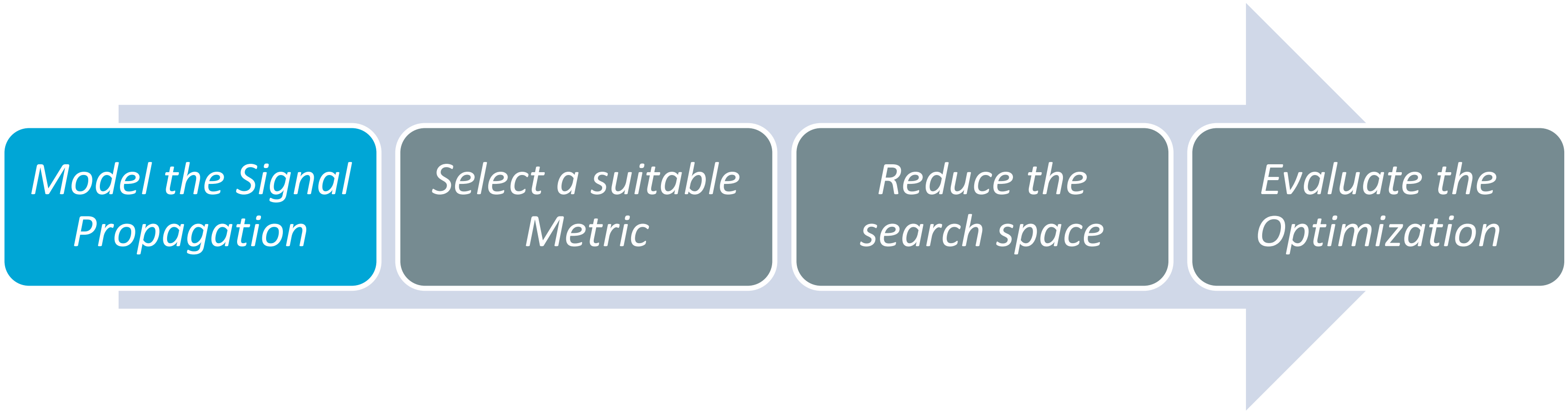
Check 1:
Is that better?

3. **Define a performance metric for the evaluation**

   i.e. Teach the Radio Simulator how does a good performance look like

4. **Reduce the search space** *(because the possible scenarios are infinite)*

Methodology



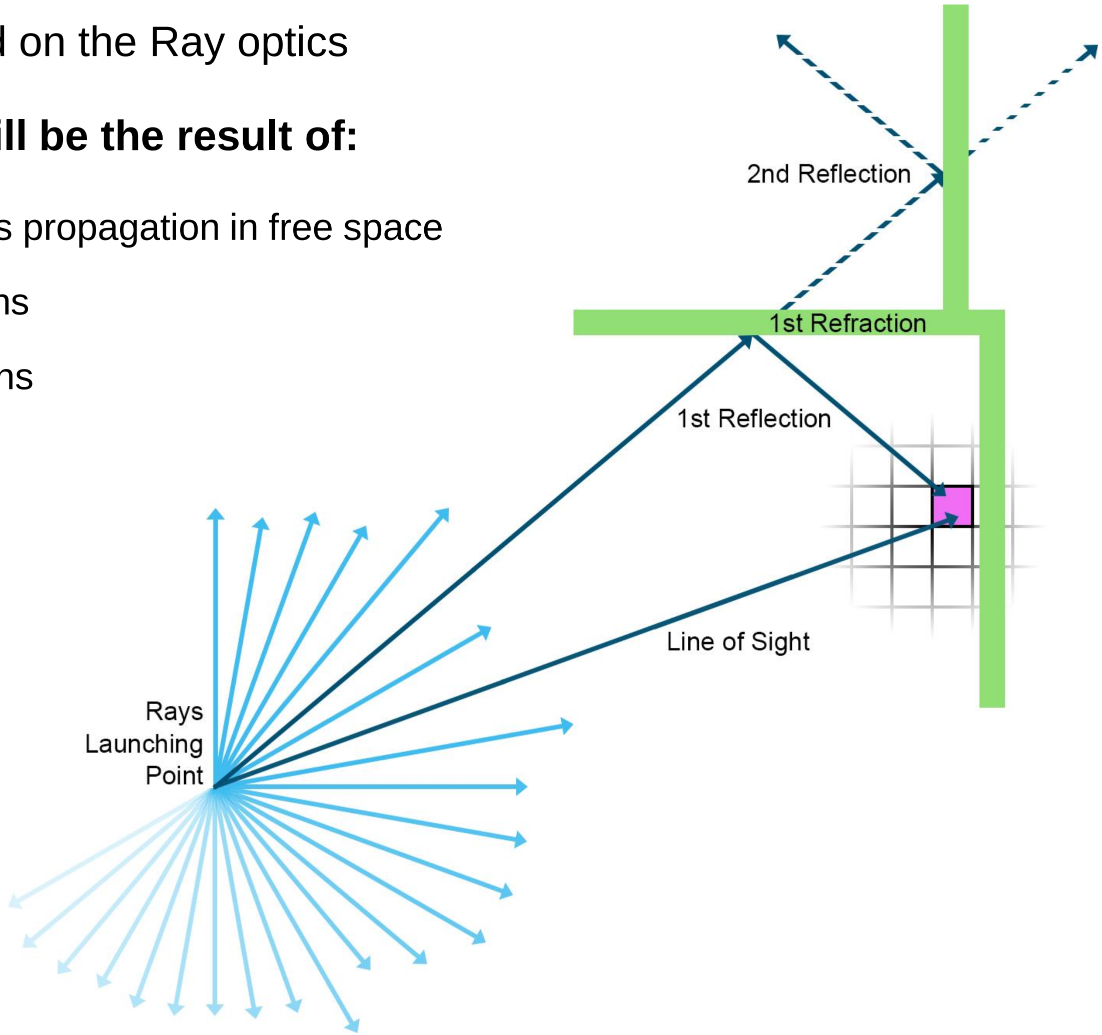
Our choice

- **Ray launching** technique based on the Ray optics
- **The attenuation of each ray will be the result of:**

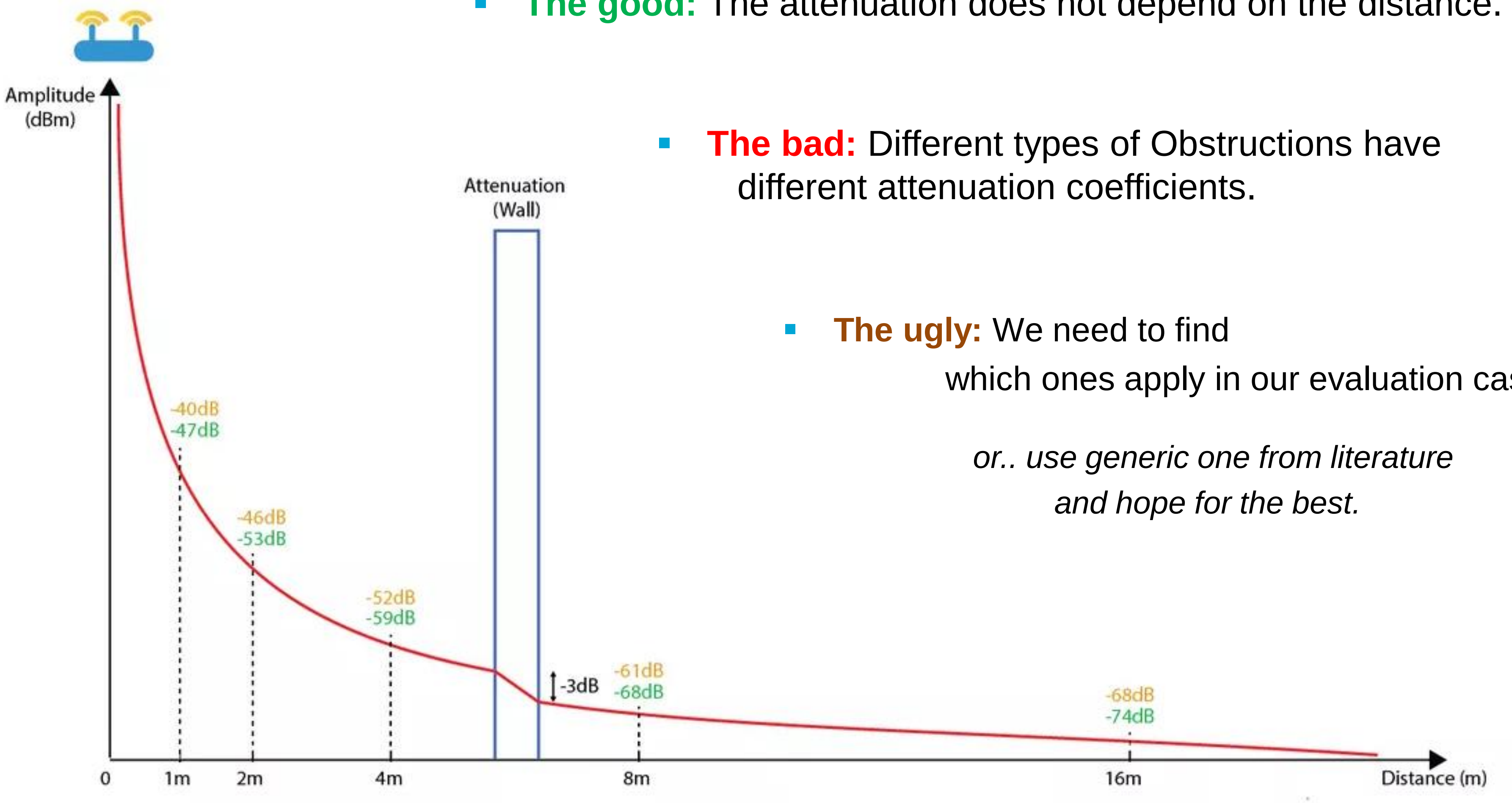
  1) The distance path-loss during its propagation in free space

  2) The attenuation due to reflections

  3) The attenuation due to refractions



Modelling the Signal Propagation



- **The good:** The attenuation does not depend on the distance.
- **The bad:** Different types of Obstructions have different attenuation coefficients.
- **The ugly:** We need to find which ones apply in our evaluation case

or.. use generic one from literature and hope for the best.

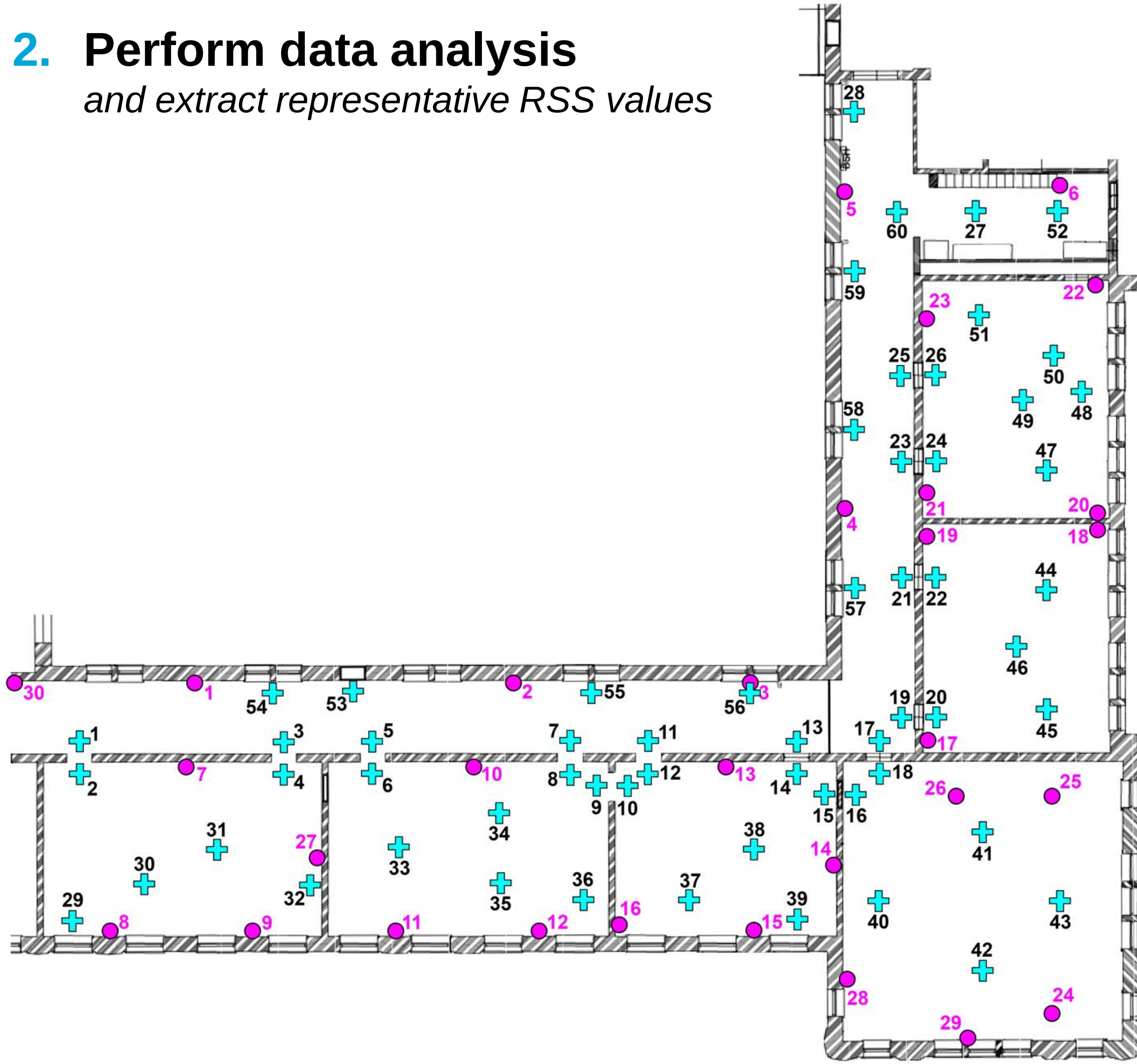
Building the Radio Simulator

1. **Collect real RSS data**
   to train the propagation model

2. **Perform data analysis**
   and extract representative RSS values

BLE beacons

360° rotatable mount

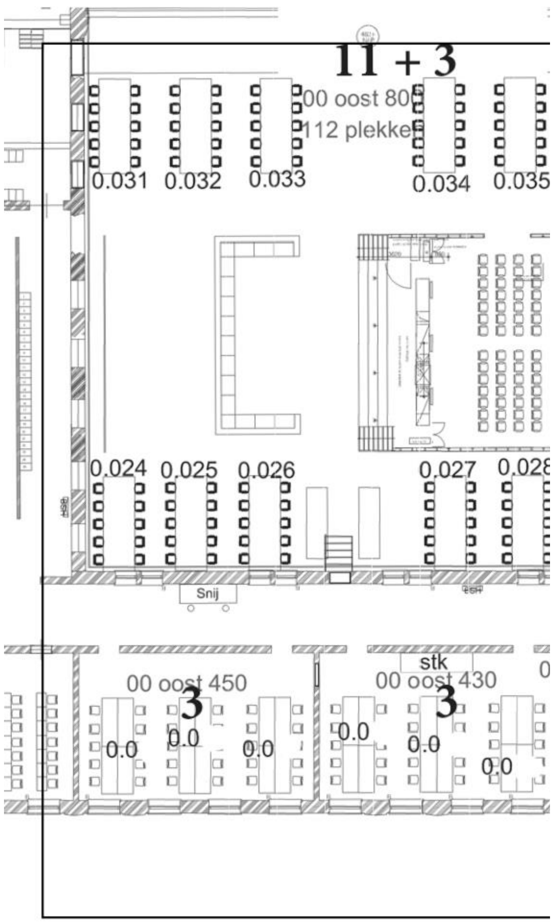


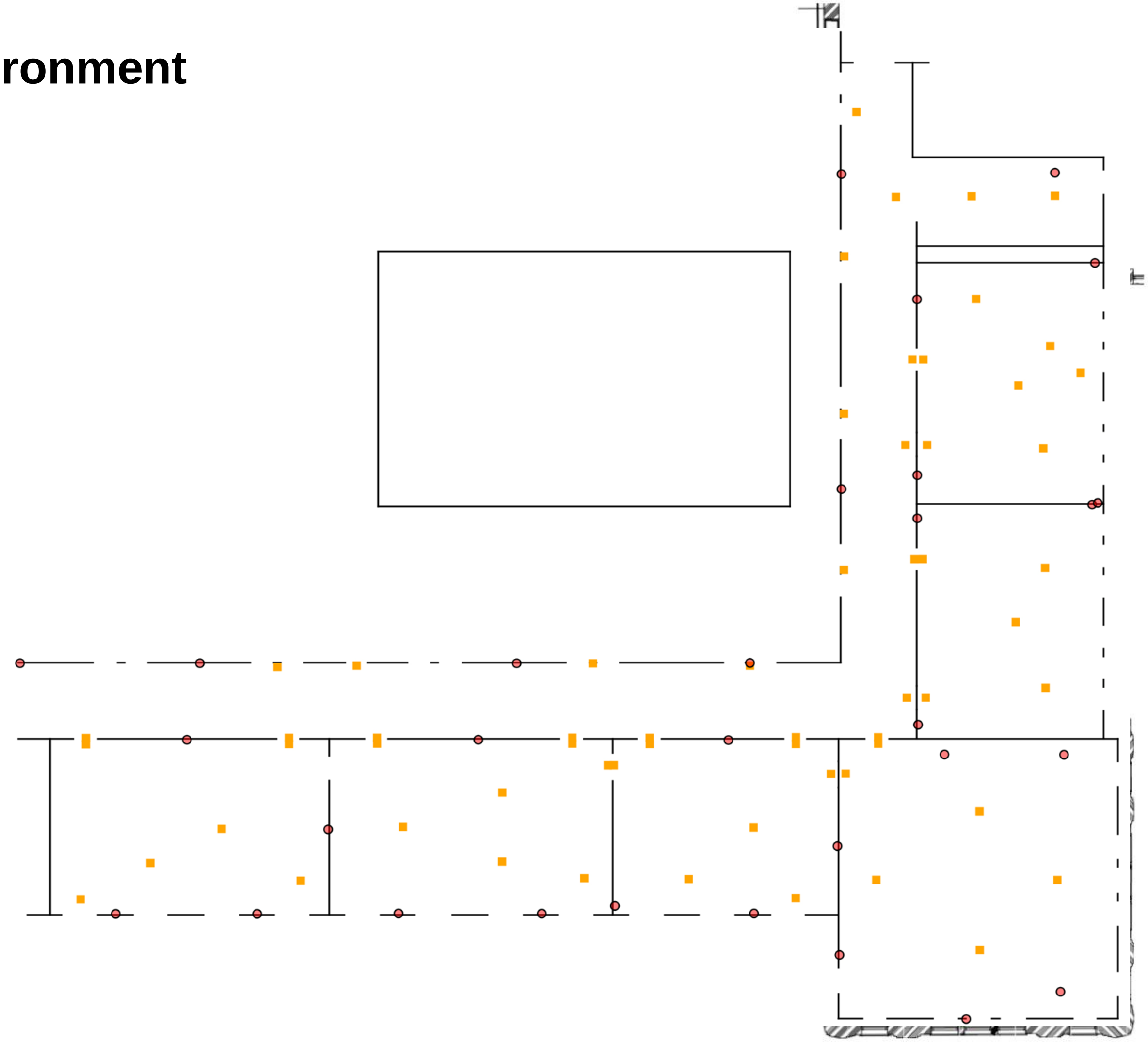
Node Position

Sample Position

Building the Radio Simulator

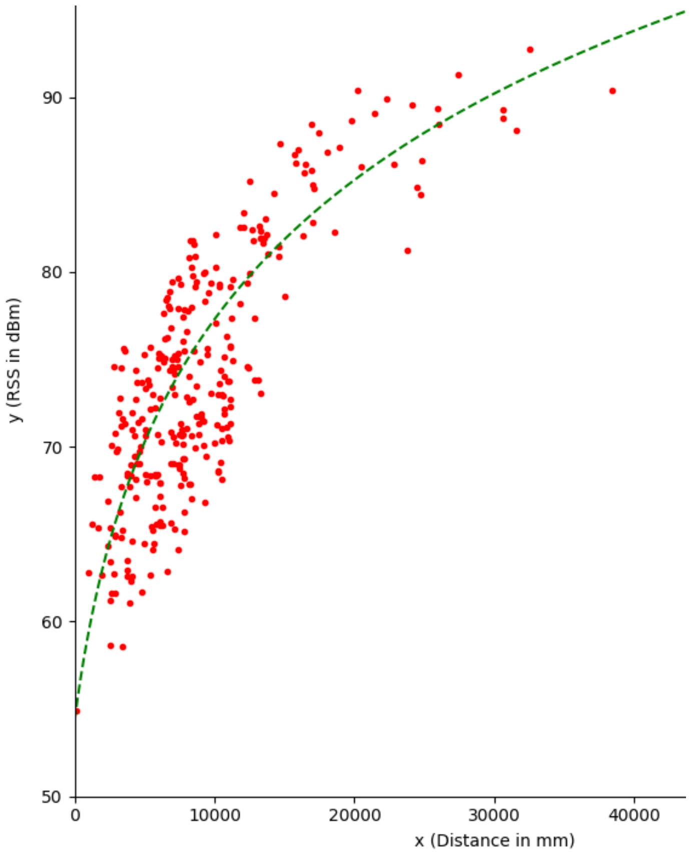
3. **Model the indoor environment**

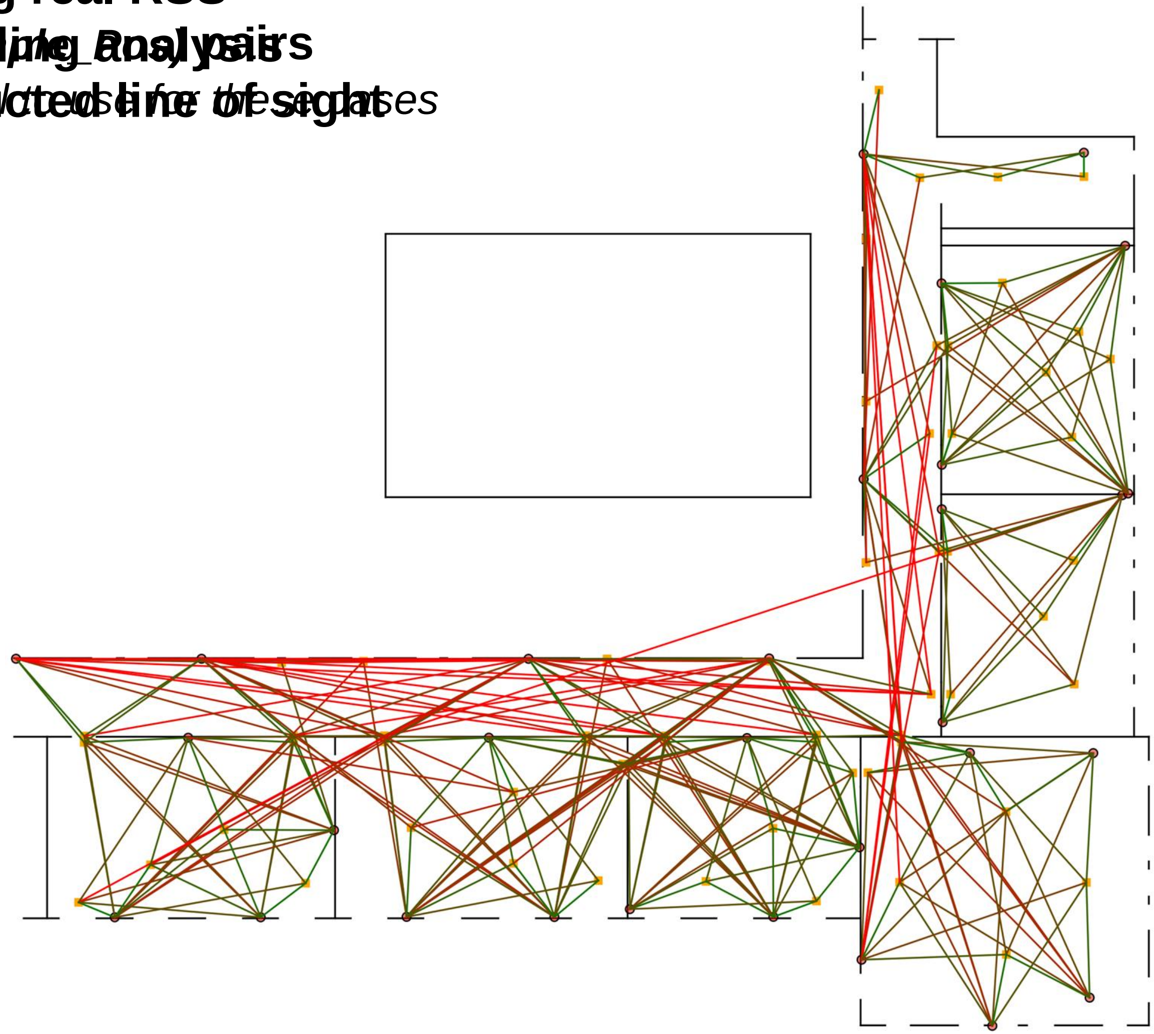




Building the Radio Simulator

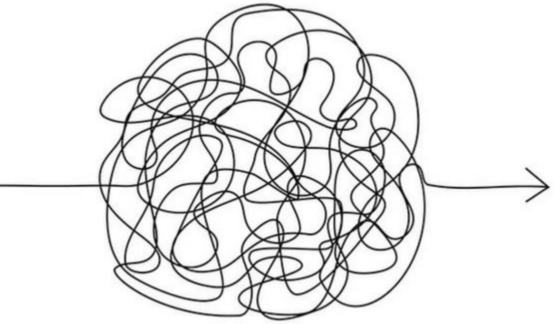
5. **Get the corresponding real RSS values from the sampling analysis**
   and create an FSPL model to use for these cases
4. **Find all *(Node, Sampling Pos)* pairs that have an unobstructed line of sight**



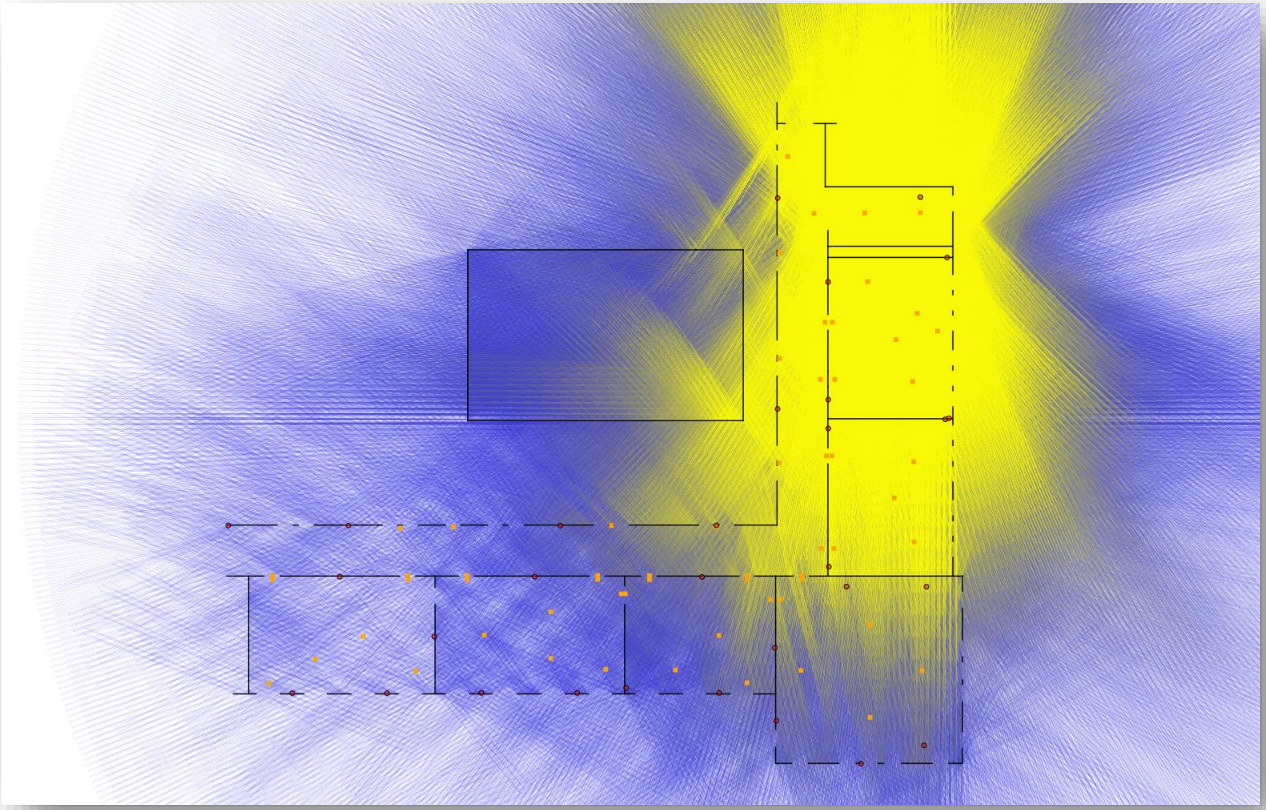


Building the Radio Simulator

6. **Build a (trainable) Ray Tracing Engine**



Could talk for hours..



Building the Radio Simulator

7. **Train the Radio Simulator**

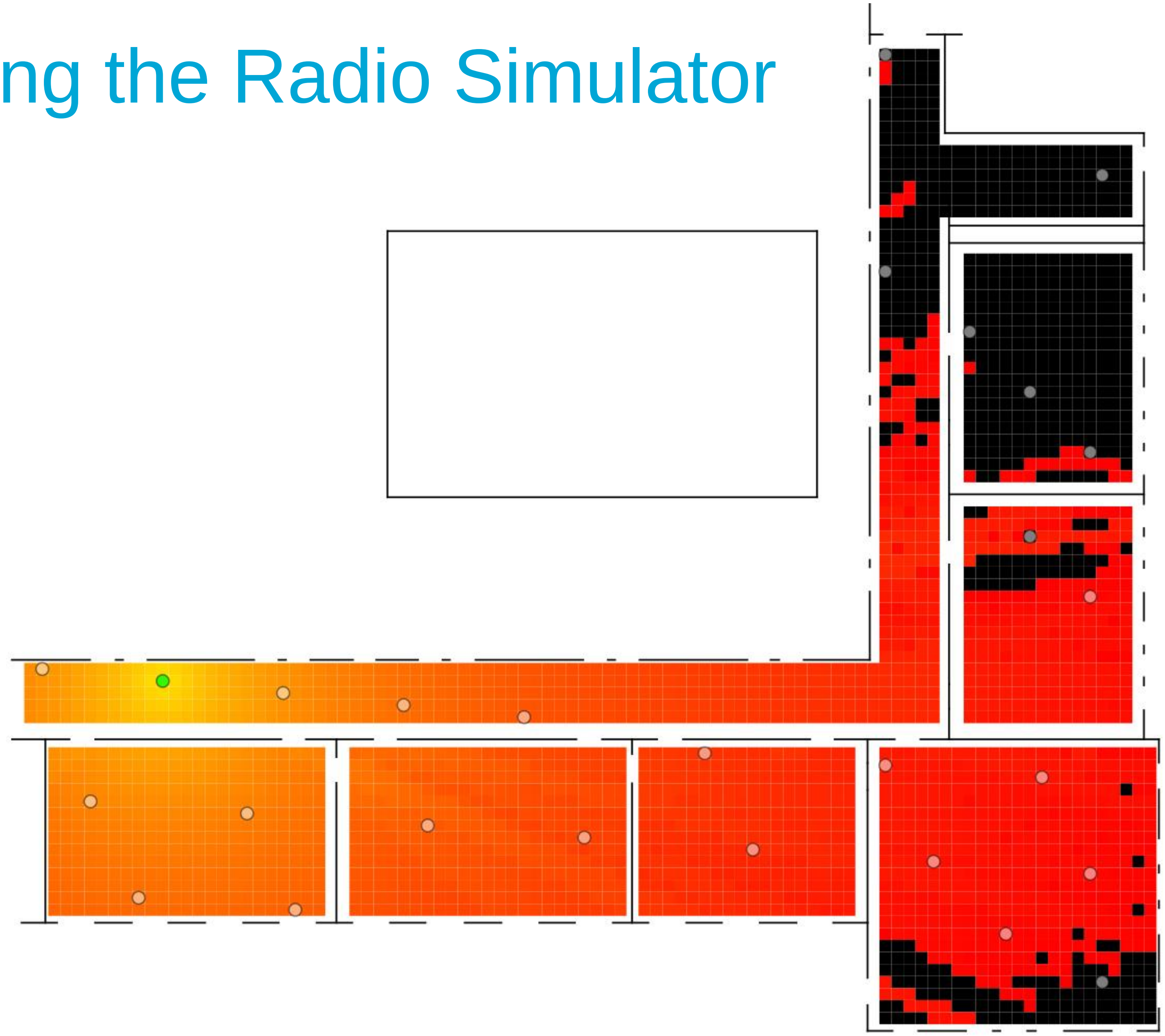
- Calculate the maximum distance that an unobstructed signal can travel until it becomes undetectable

- Recursively trace and save all possible trajectories of Rays and sub-Rays until the above distance has been reached

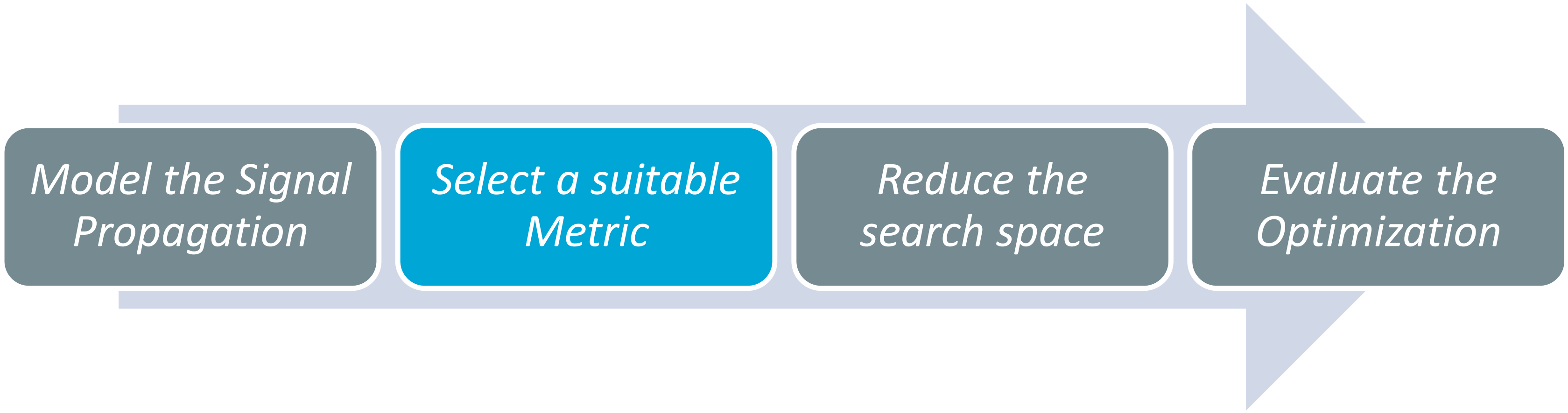
- Utilize the following optimization function:
  1. Select some logical attenuation coefficients for the obstructions
  2. Apply these coefficients to the saved Ray Set and generate a Radiomap
  3. Compare this Radiomap with the sampled "ground truth"
  4. Repeat until the Radiomaps difference becomes minimum

Average RSS error of our model: **3.39 dBm**

Building the Radio Simulator



Methodology



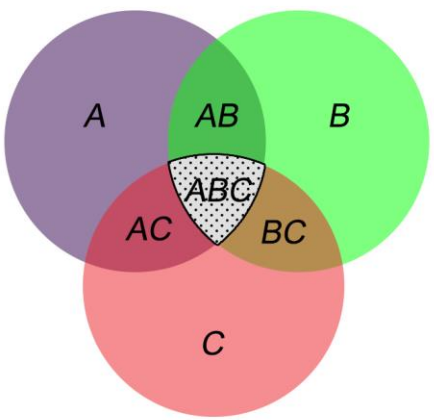
Defining the Location Distinctiveness

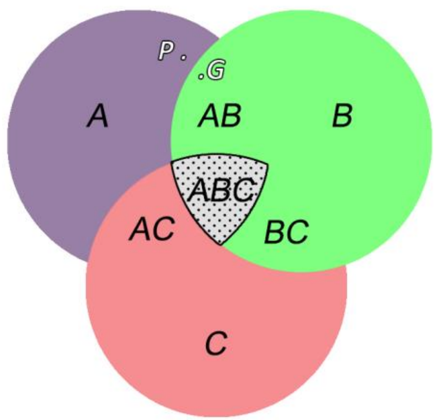
Every Location:

- Is a superset of positions which are all attributed with the same thematic identifier.

Every Position:

- Should belong to only 1 location
- Is in a bidirectional binding with a unique, yet continuously varying Radio Signature





Position G < > **Radio Signature** G_{rs}

Position P < > **Radio Signature** P_{rs}

I sense the **Radio Signature** G_{rs}

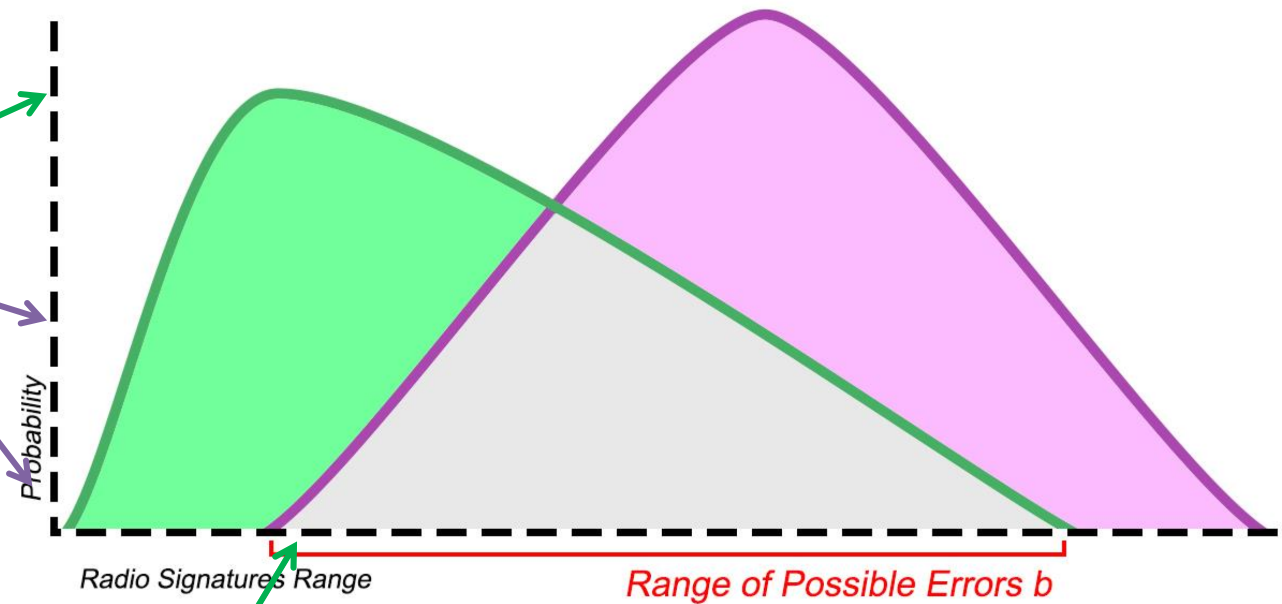
In which location am I?

Defining the Location Distinctiveness

Every Radio Signature:

- Varies according to some noise

Where am I probably?

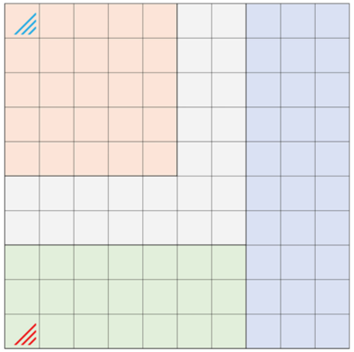


I sense **Radio Signature** G_{rs}

Selecting a Suitable Metric

Maximizing the Location Distinctiveness

Physical 2-D Space

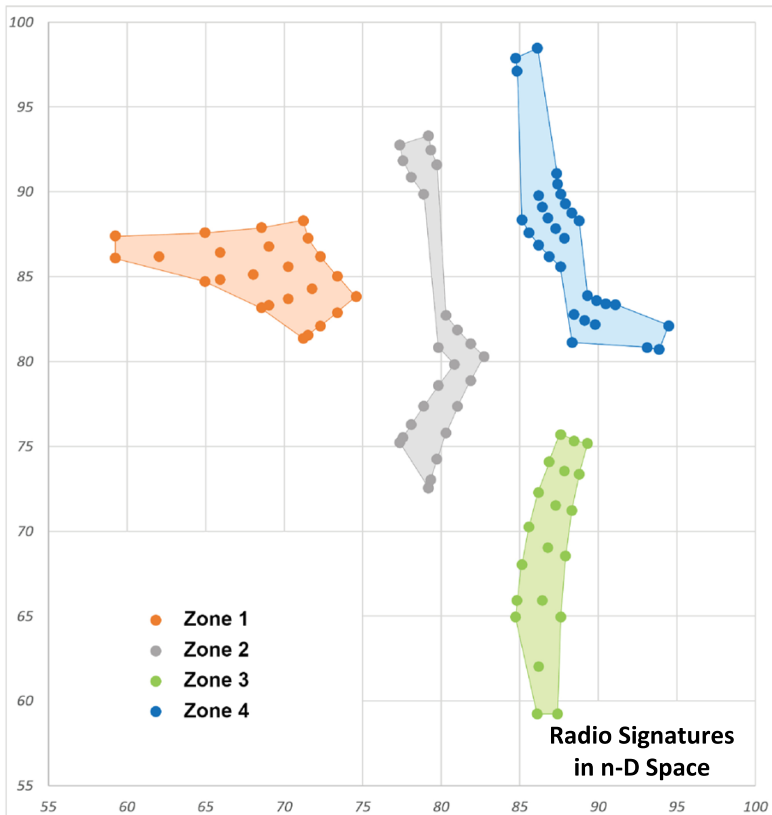


	59	65	69	71	77	79	85	86	87
59	62	66	69	72	78	79	85	86	87
65	66	68	70	72	78	80	85	86	88
69	69	70	72	73	79	80	86	87	88
71	72	72	73	75	80	81	86	87	88
77	78	78	79	80	81	82	87	88	89
79	79	80	80	81	82	83	88	88	89
85	85	85	86	86	87	88	88	89	90
86	86	86	87	87	88	88	93	90	90
87	87	88	88	88	89	89	94	94	91

RSSI from Beacon 1 *(dBm)*

87	87	88	88	88	93	93	98	98	91
86	86	86	87	87	92	92	97	90	90
85	85	85	86	86	91	92	88	89	90
83	83	84	84	85	90	83	88	88	89
81	82	82	83	84	81	82	87	88	89
75	76	76	77	79	80	81	86	87	88
73	73	74	76	77	79	80	86	83	84
65	66	68	70	72	74	76	81	82	84
59	62	66	69	72	74	75	81	82	83
	59	65	69	71	73	75	81	82	83

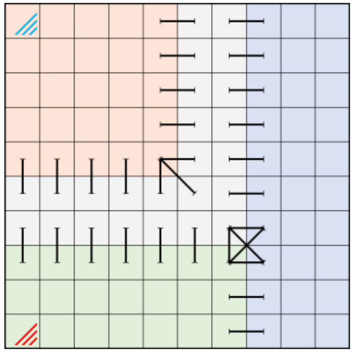
RSSI from Beacon 2 *(dBm)*



Selecting a Suitable Metric

Maximizing the Location Distinctiveness

Physical 2-D Space

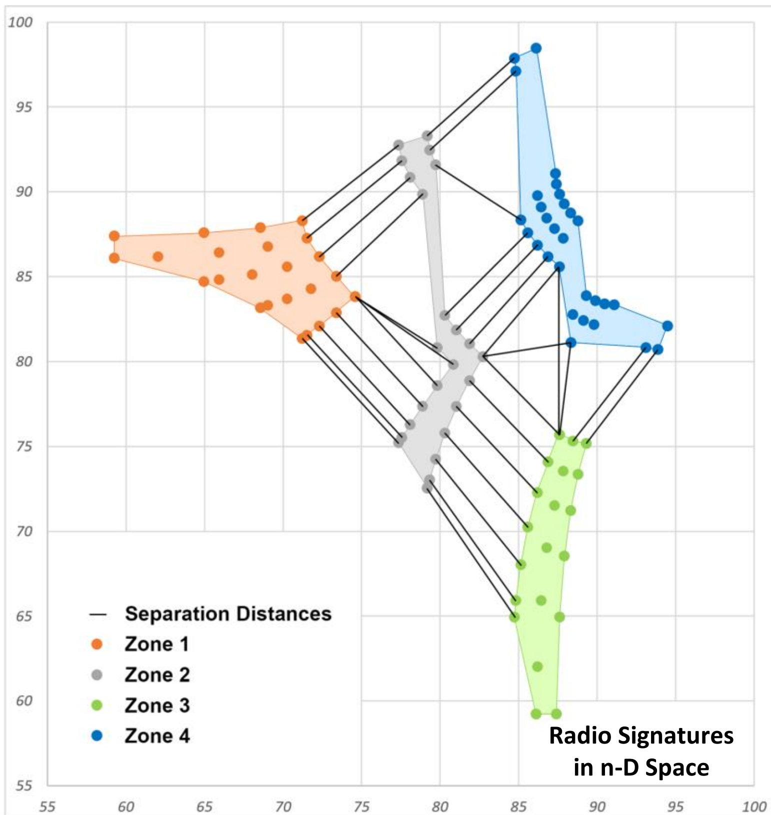


	59	65	69	71	77	79	85	86	87
59	62	66	69	72	78	79	85	86	87
65	66	68	70	72	78	80	85	86	88
69	69	70	72	73	79	80	86	87	88
71	72	72	73	75	80	81	86	87	88
77	78	78	79	80	81	82	87	88	89
79	79	80	80	81	82	83	88	88	89
85	85	85	86	86	87	88	88	89	90
86	86	86	87	87	88	88	93	90	90
87	87	88	88	88	89	89	94	94	91

RSSI from Beacon 1 *(dBm)*

87	87	88	88	88	93	93	98	98	91
86	86	86	87	87	92	92	97	90	90
85	85	85	86	86	91	92	88	89	90
83	83	84	84	85	90	83	88	88	89
81	82	82	83	84	81	82	87	88	89
75	76	76	77	79	80	81	86	87	88
73	73	74	76	77	79	80	86	83	84
65	66	68	70	72	74	76	81	82	84
59	62	66	69	72	74	75	81	82	83
	59	65	69	71	73	75	81	82	83

RSSI from Beacon 2 *(dBm)*



Objective reminder:

- *Spread the **different** Radio Signatures*
- The Separation Area is defined by an alpha shape
- To maximize the Location Distinctiveness, we need to stretch this hyperplane
- Computing the surface of the hyperplane is not easy

How to use the Separation Distances

- Maximize the Minimum Separation Distance (MMD):
  - Generate different deployments
  - Retrieve the Minimum Separation Distance in each deployment
  - Compare all retrieved features and choose the maximum distance
  - The optimal solution is the deployment from which this distance was retrieved.

But..

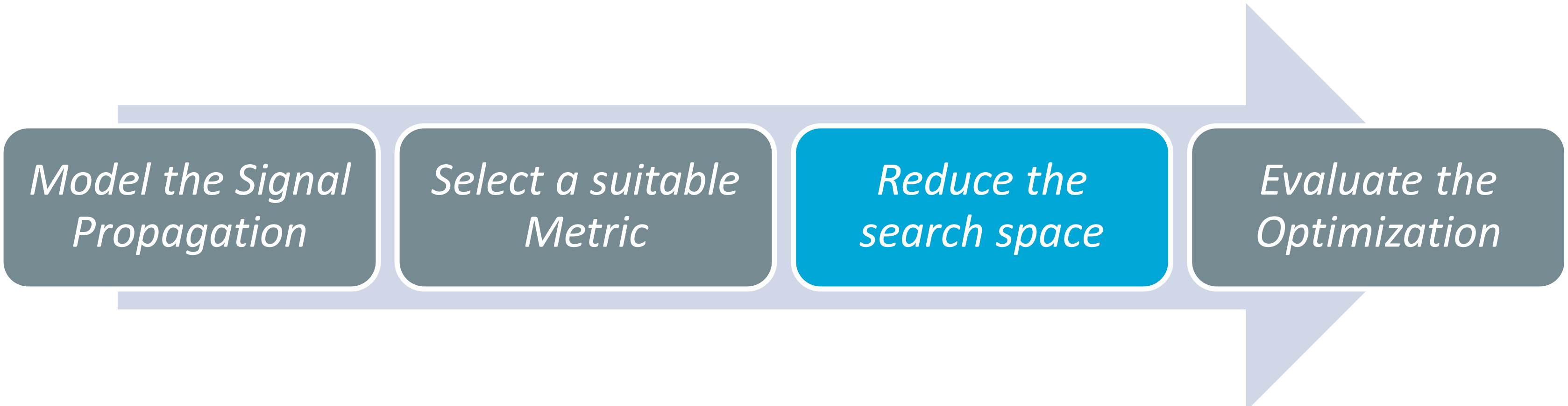
-This approach maximizes the most problematic separation area

- Not the overall area

Alternatively:

Maximize the Product of the n Shortest Separation Distances

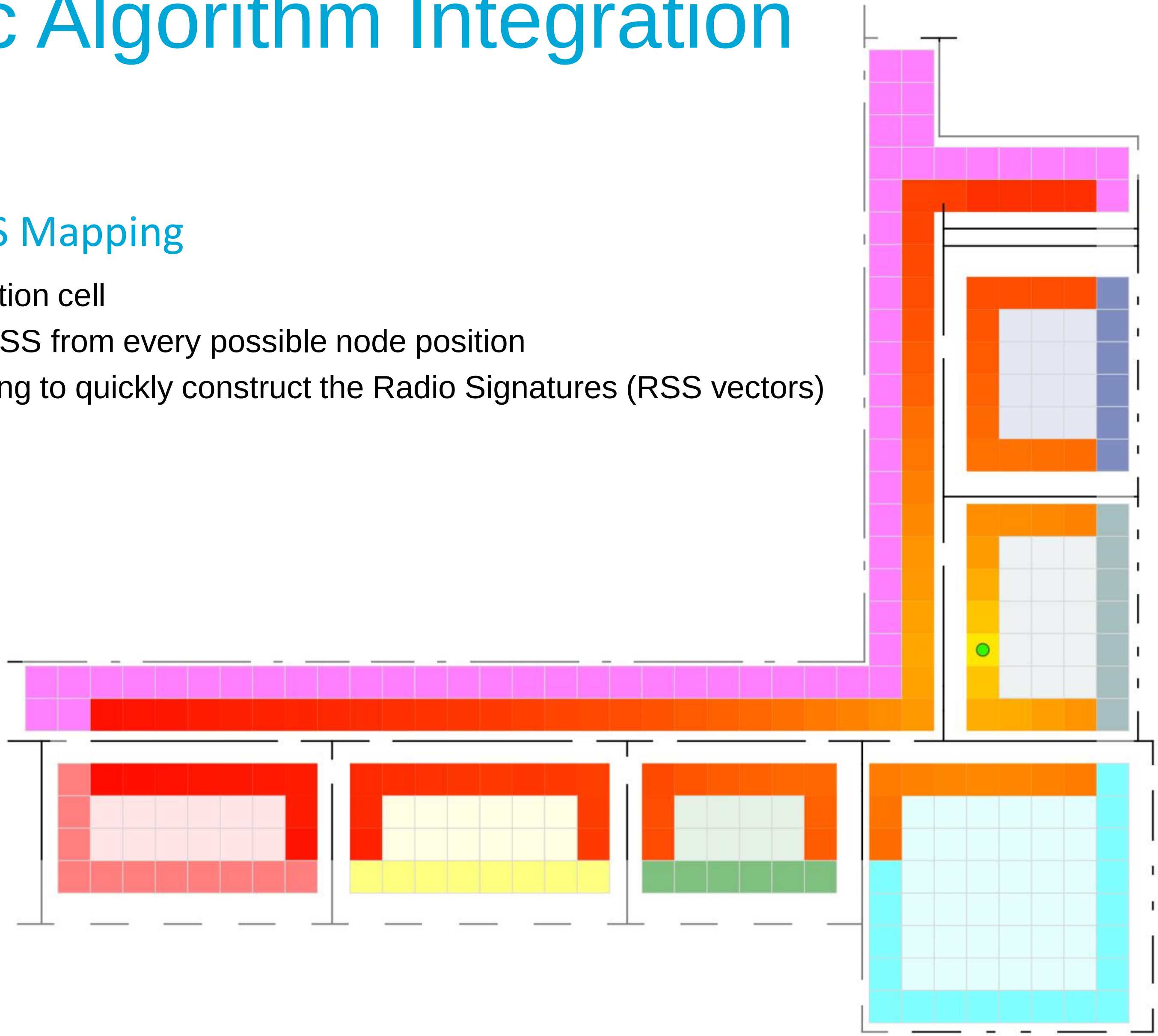
Methodology



Genetic Algorithm Integration

1) Build an RSS Mapping

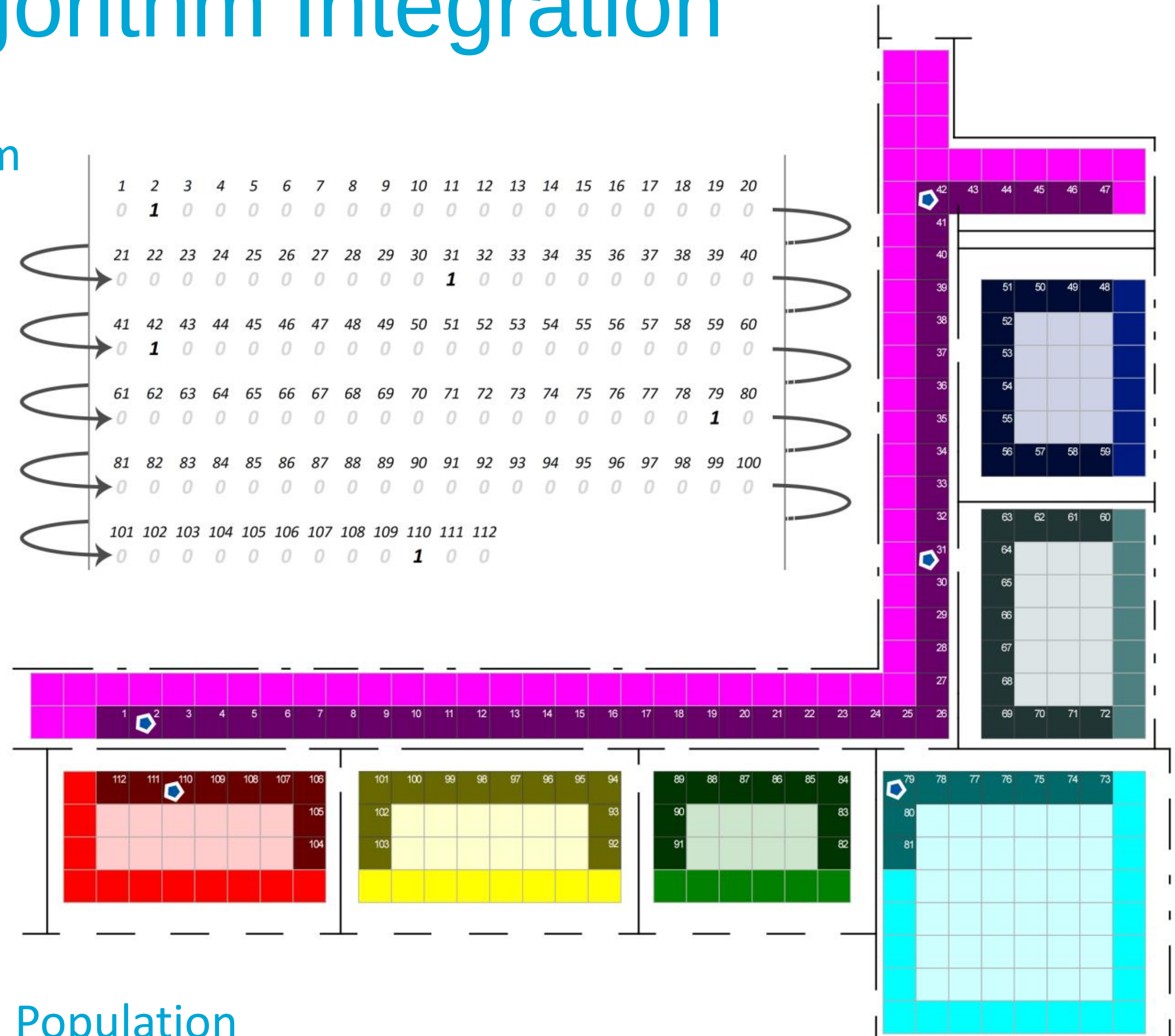
- At each separation cell
- Compute the RSS from every possible node position
- Use this mapping to quickly construct the Radio Signatures (RSS vectors)



Genetic Algorithm Integration

2) Encode the Problem

A chromosome
and its Genes:



3) Generate the initial Population

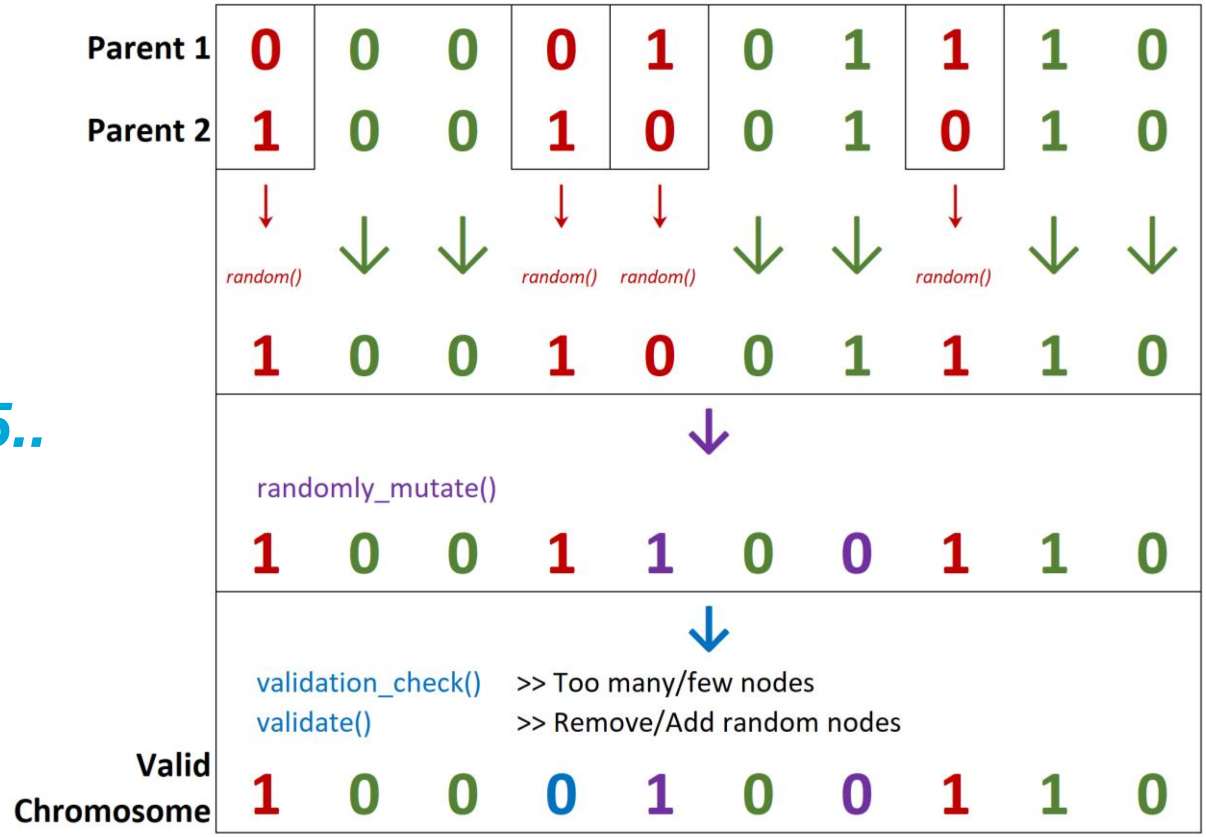
(e.g. 100 Chromosomes)

Integrating the Genetic Algorithm

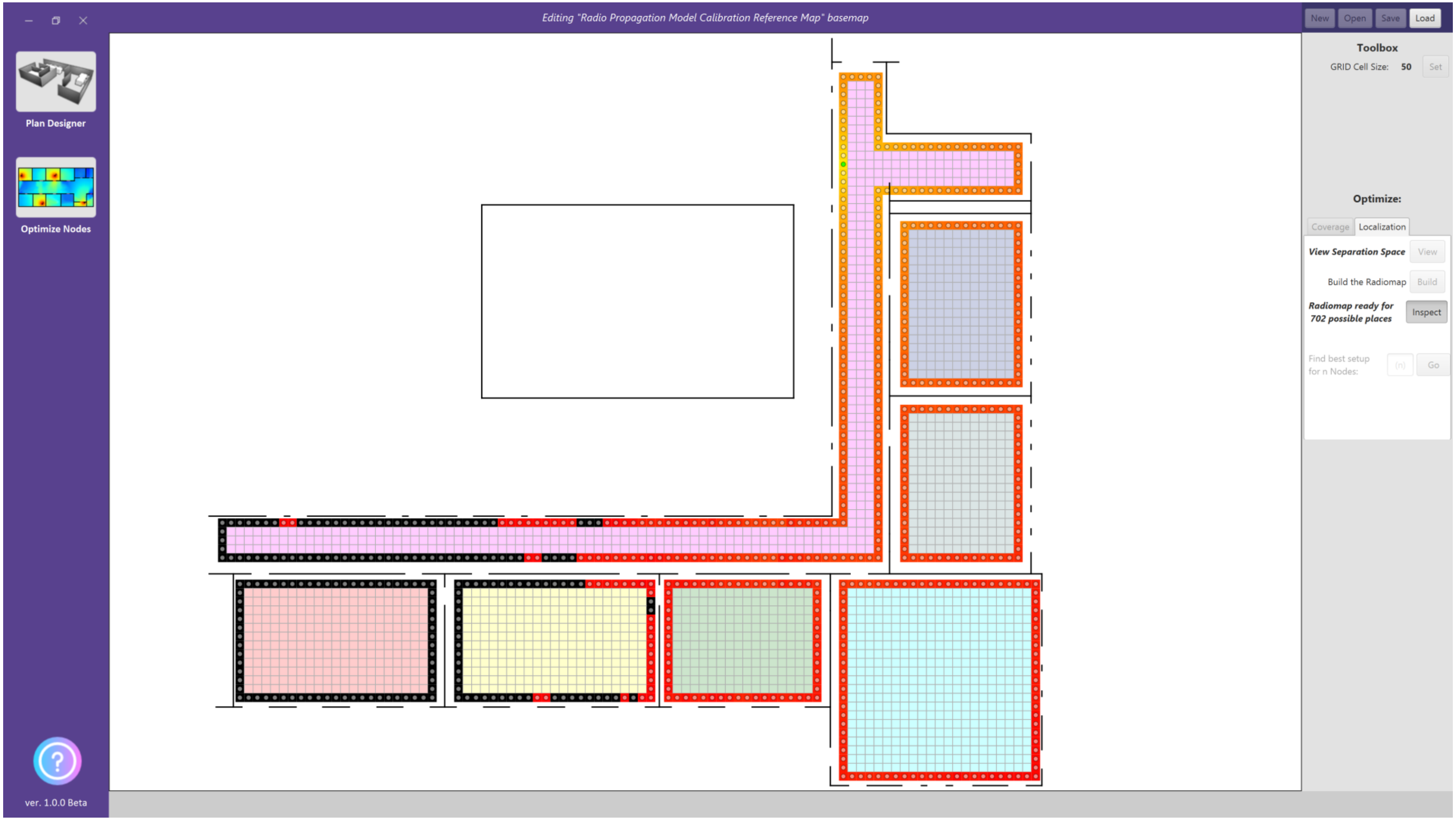
4) Keep only the fittest Chromosomes *(e.g. deployments with the best separations)*

5) Use the fittest parent Chromosomes to produce new Childs:

Repeat 4,5..

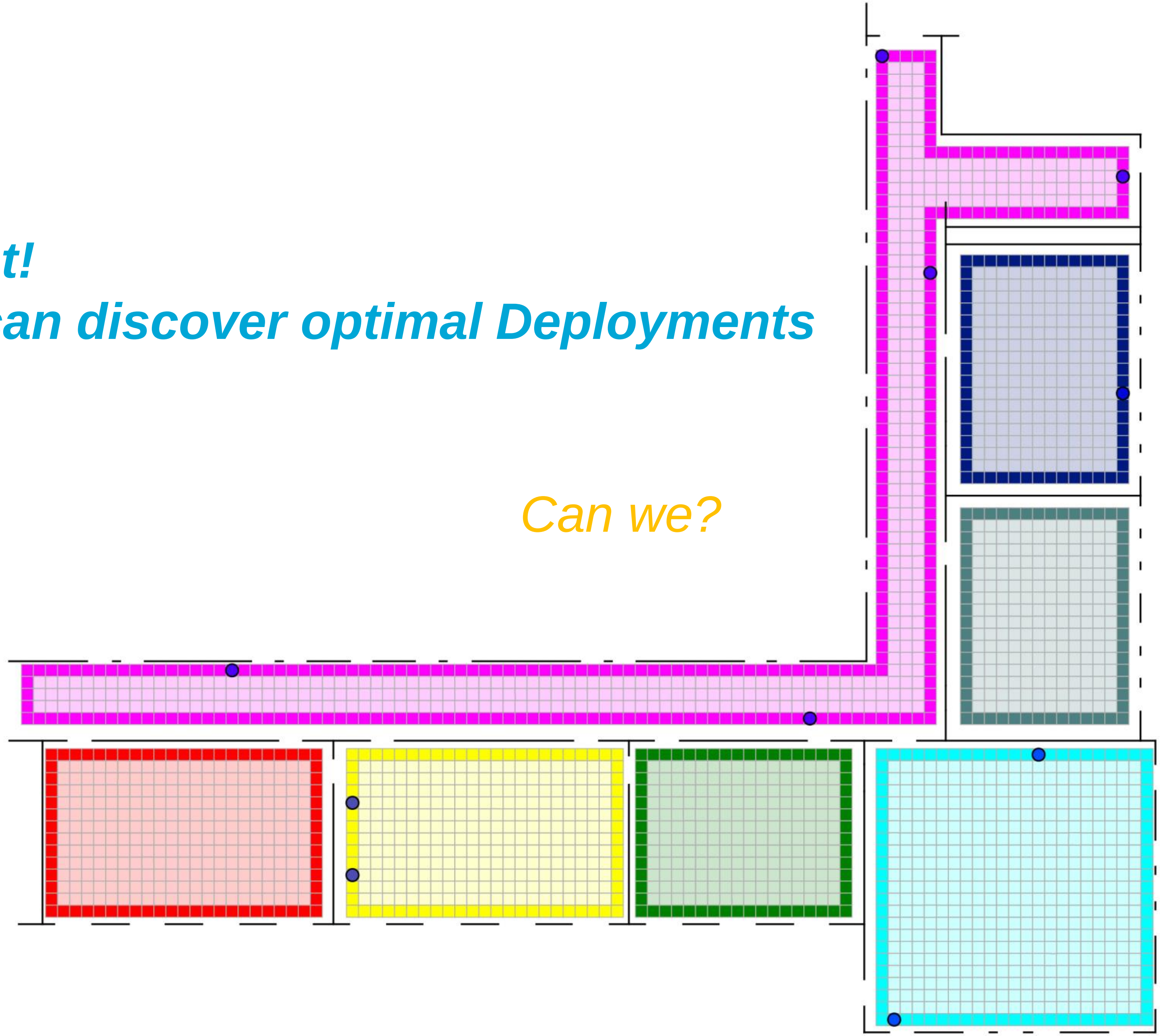


Mesh Optimizer



Great!
We can discover optimal Deployments

Can we?



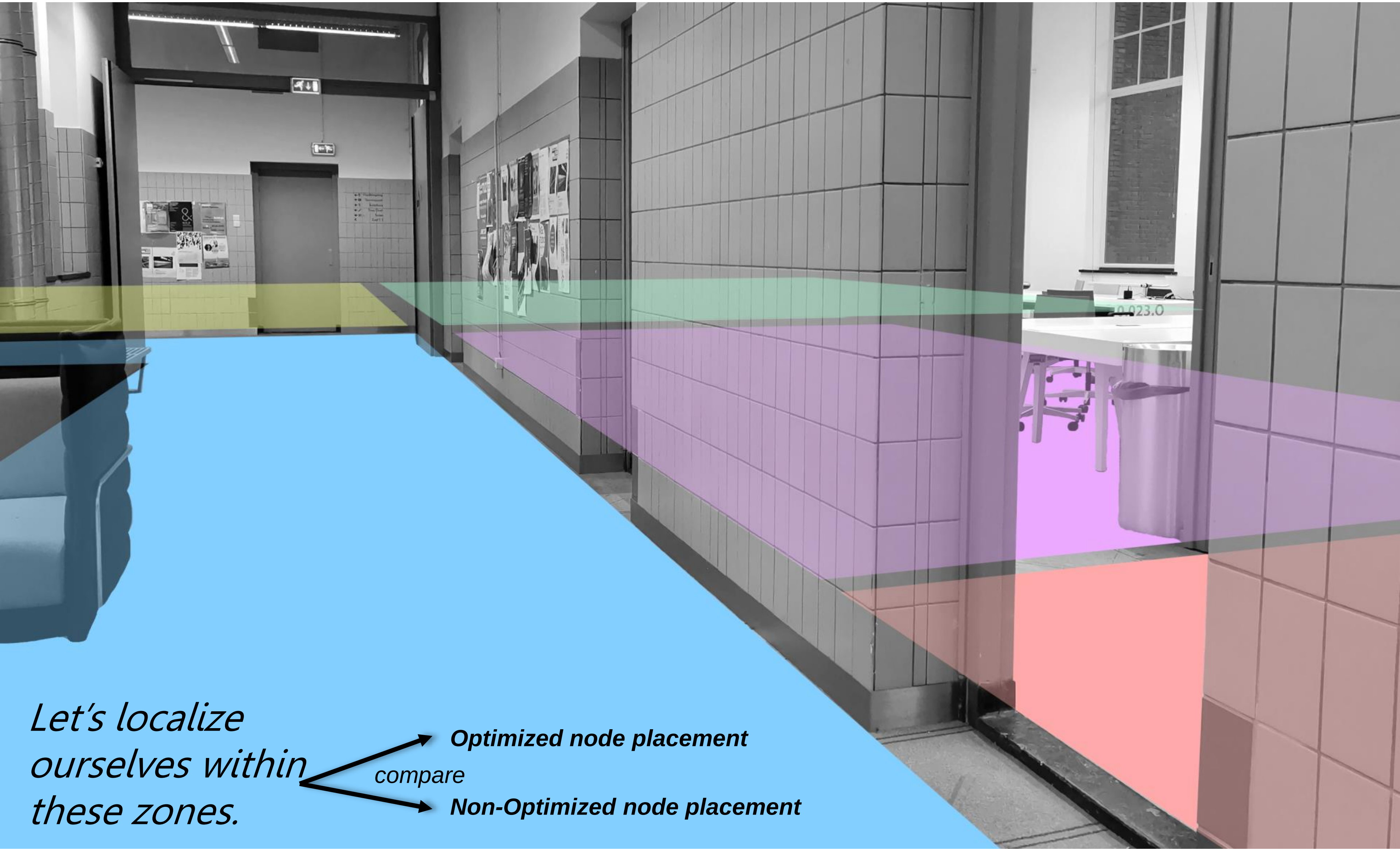
Methodology

Model the Signal Propagation

Select a suitable Metric

Reduce the search space

Evaluate the Optimization



Let's localize ourselves within these zones.

compare

Optimized node placement

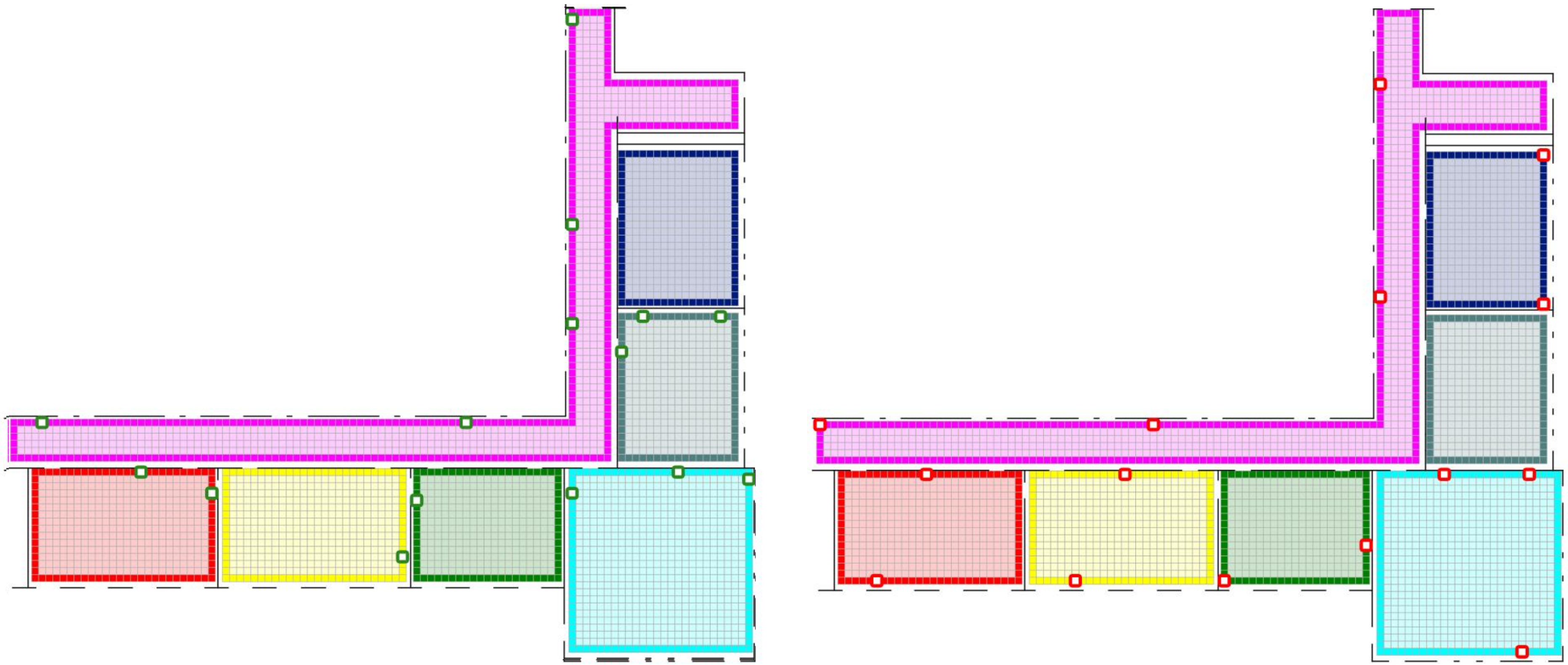
Non-Optimized node placement

Evaluation Process

Test Case 3: 15-Nodes Setup

Optimized node placement

Non-optimized node placement



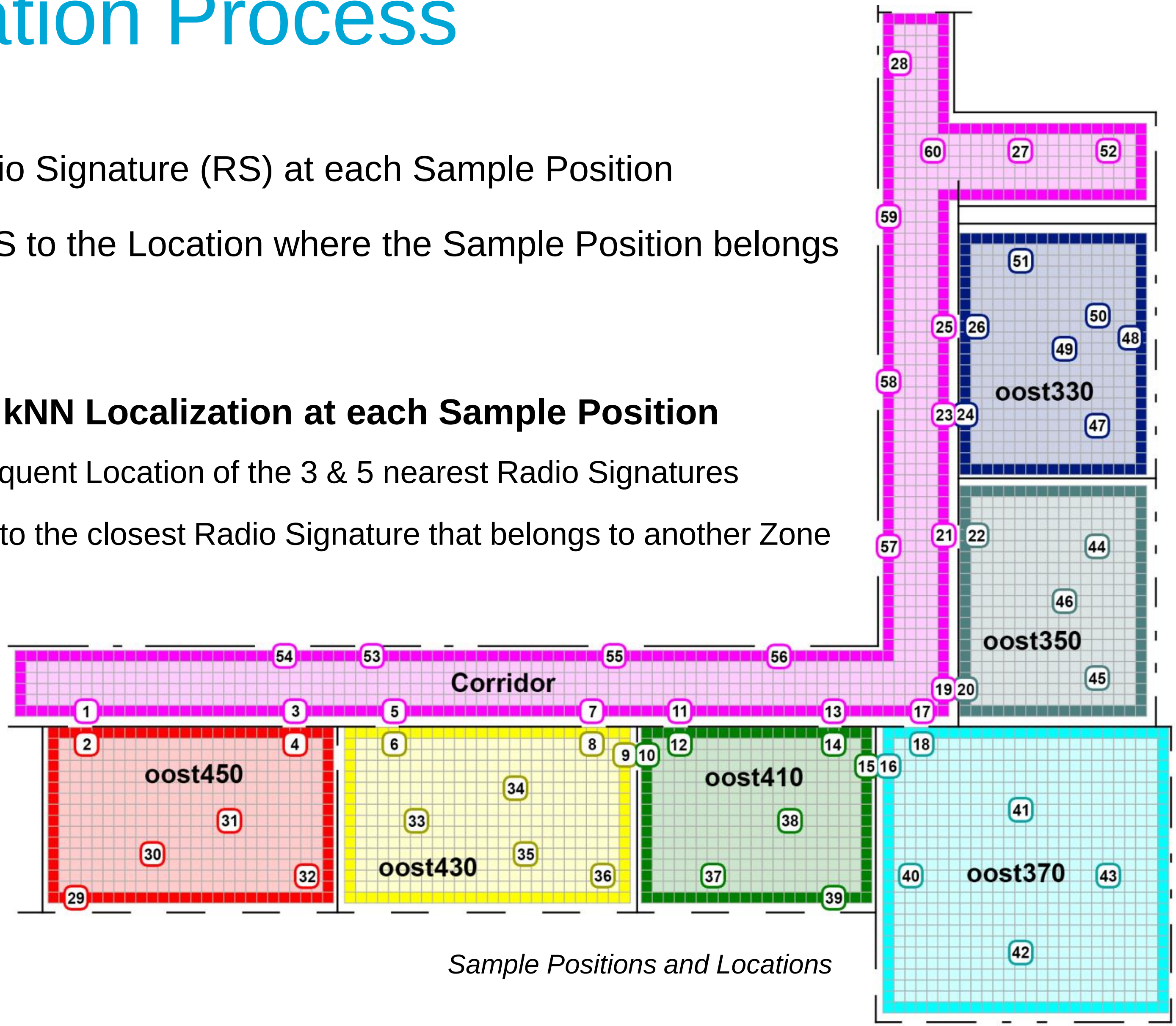
Evaluation Process

1) Get the Radio Signature (RS) at each Sample Position

2) Link each RS to the Location where the Sample Position belongs

3) Assess the kNN Localization at each Sample Position

- Find the most frequent Location of the 3 & 5 nearest Radio Signatures
- Get the distance to the closest Radio Signature that belongs to another Zone *(instead of k=1)*



Sample Positions and Locations

Results

30 Nodes				
Sample Pos	Zone	Non Opt	Opt	% Gain
25	*corridor*	6,8	12,0	75
26	*oost330*	6,8	12,0	75
13	*corridor*	7,4	8,2	11
14	*oost410*	7,4	8,2	11
5	*corridor*	8,5	9,8	16
6	*oost430*	8,5	9,8	16
9	*oost430*	8,5	11,0	29
10	*oost410*	8,5	11,0	29
1	*corridor*	8,6	9,8	14
2	*oost450*	8,6	9,8	14
11	*corridor*	9,2	11,1	21
12	*oost410*	9,2	11,1	21
3	*corridor*	9,4	10,9	16
4	*oost450*	9,4	10,9	16
17	*corridor*	9,4	11,7	24
18	*oost370*	9,4	11,7	24
7	*corridor*	9,8	7,8	-21
8	*oost430*	9,8	7,8	-21
19	*corridor*	10,6	11,5	8
20	*oost350*	10,6	11,5	8
21	*corridor*	10,8	12,2	12
22	*oost350*	10,8	12,2	12
23	*corridor*	11,8	10,6	-10
24	*oost330*	11,8	10,6	-10
15	*oost410*	11,9	12,0	1
16	*oost370*	11,9	12,0	1
53	*corridor*	13,8	17,1	24
51	*oost330*	16,3	20,1	23
54	*corridor*	16,4	19,5	19
49	*oost330*	17,8	20,3	14

15 Nodes				
Sample Pos	Zone	Non Opt	Opt	% Gain
9	*oost430*	4,0	6,7	70
10	*oost410*	4,0	6,7	70
25	*corridor*	4,7	6,2	32
26	*oost330*	4,7	6,2	32
13	*corridor*	5,1	5,0	-1
14	*oost410*	5,1	5,0	-1
1	*corridor*	5,3	7,3	37
2	*oost450*	5,3	7,3	37
7	*corridor*	5,4	6,7	23
8	*oost430*	5,4	6,7	23
11	*corridor*	6,5	7,7	19
12	*oost410*	6,5	7,7	19
5	*corridor*	6,7	8,6	29
6	*oost430*	6,7	8,6	29
3	*corridor*	6,9	7,1	3
4	*oost450*	6,9	7,1	3
17	*corridor*	7,4	7,2	-2
18	*oost370*	7,4	7,2	-2
23	*corridor*	7,9	8,3	5
24	*oost330*	7,9	8,3	5
19	*corridor*	8,1	8,0	-1
20	*oost350*	8,1	8,0	-1
16	*oost370*	8,4	10,2	22
15	*oost410*	8,6	10,2	18
53	*corridor*	9,1	10,9	21
21	*corridor*	9,4	9,0	-4
22	*oost350*	9,4	9,0	-4
40	*oost370*	10,0	13,4	35
54	*corridor*	10,3	13,9	35
58	*corridor*	11,0	14,8	34

5 Nodes				
Sample Pos	Zone	Non Opt	Opt	% Gain
9	*oost430*	1,8	5,9	237
10	*oost410*	1,8	5,5	214
13	*corridor*	2,2	4,5	102
14	*oost410*	2,2	4,5	102
25	*corridor*	2,9	3,5	21
26	*oost330*	2,9	3,5	21
5	*corridor*	3,0	3,2	5
6	*oost430*	3,0	3,2	5
1	*corridor*	3,2	4,1	28
2	*oost450*	3,2	4,1	28
55	*corridor*	3,3	7,3	122
7	*corridor*	3,4	5,1	53
8	*oost430*	3,4	5,1	53
18	*oost370*	3,5	4,7	36
20	*oost350*	3,5	5,2	51
21	*corridor*	3,7	3,0	-21
22	*oost350*	3,7	3,0	-21
19	*corridor*	4,4	5,2	19
16	*oost370*	4,6	3,9	-15
17	*corridor*	4,6	4,7	2
23	*corridor*	4,6	3,5	-24
24	*oost330*	4,6	3,5	-24
11	*corridor*	4,7	4,3	-9
12	*oost410*	4,7	4,3	-9
3	*corridor*	4,9	3,3	-32
4	*oost450*	4,9	3,3	-32
31	*oost450*	4,9	5,7	17
35	*oost430*	5,0	8,8	76
56	*corridor*	5,7	8,6	52
53	*corridor*	5,9	5,3	-10

Distances to the closest Radio Signature that belongs to another Zone

33	*oost430*	18,2	18,5	1
55	*corridor*	18,7	20,6	10
58	*corridor*	18,8	15,5	-18
31	*oost450*	19,0	20,7	9
50	*oost330*	19,8	26,2	32
40	*oost370*	20,2	18,3	-9
57	*corridor*	20,4	26,8	31
30	*oost450*	21,0	17,9	-15
34	*oost430*	21,2	20,3	-4
59	*corridor*	21,4	21,1	-2
46	*oost350*	21,6	29,6	37
48	*oost330*	21,9	29,3	34
44	*oost350*	22,4	26,1	16
47	*oost330*	22,4	26,1	16
37	*oost410*	22,6	20,8	-8
56	*corridor*	22,7	18,8	-17
38	*oost410*	22,7	19,9	-12
35	*oost430*	23,6	25,3	7
41	*oost370*	23,8	20,5	-14
39	*oost410*	24,2	18,3	-24
32	*oost450*	24,4	23,6	-3
29	*oost450*	25,0	20,9	-17
45	*oost350*	25,5	20,5	-20
36	*oost430*	25,8	23,9	-7
60	*corridor*	26,4	22,1	-16
27	*corridor*	26,7	25,7	-4
43	*oost370*	29,5	27,4	-7
52	*corridor*	32,2	29,8	-7
28	*corridor*	32,9	34,1	4
42	*oost370*	40,1	29,0	-28
				7,28
				avg

51	*oost330*	11,1	11,8	6
56	*corridor*	12,0	15,7	30
55	*corridor*	12,2	16,2	32
31	*oost450*	12,3	13,9	13
39	*oost410*	12,5	13,4	7
38	*oost410*	12,6	14,3	13
34	*oost430*	12,7	14,2	11
49	*oost330*	12,8	15,1	18
57	*corridor*	13,6	18,8	39
33	*oost430*	13,7	14,5	5
41	*oost370*	13,8	15,6	13
32	*oost450*	14,3	14,4	1
36	*oost430*	14,5	18,3	27
37	*oost410*	15,1	14,7	-3
35	*oost430*	15,5	16,9	9
44	*oost350*	15,7	14,5	-8
47	*oost330*	15,7	14,5	-8
52	*corridor*	15,8	21,8	38
50	*oost330*	16,2	15,8	-3
30	*oost450*	16,2	16,7	3
46	*oost350*	16,4	21,9	34
59	*corridor*	16,5	11,8	-28
27	*corridor*	17,0	18,2	7
45	*oost350*	17,3	15,6	-10
48	*oost330*	17,8	19,1	7
43	*oost370*	20,3	19,5	-4
29	*oost450*	21,2	17,4	-18
60	*corridor*	21,5	16,2	-25
28	*corridor*	24,5	26,9	10
42	*oost370*	24,8	20,3	-18
				13,01
				avg

36	*oost430*	6,0	10,6	77
15	*oost410*	6,0	3,9	-36
40	*oost370*	6,0	6,0	0
32	*oost450*	6,3	9,3	47
38	*oost410*	6,4	9,4	47
57	*corridor*	6,4	8,4	31
33	*oost430*	6,4	6,3	-2
58	*corridor*	6,4	4,9	-24
54	*corridor*	6,6	8,2	25
37	*oost410*	6,9	9,1	31
34	*oost430*	7,1	7,1	0
47	*oost330*	7,3	8,2	13
59	*corridor*	7,3	12,3	68
39	*oost410*	7,4	6,0	-19
42	*oost370*	7,8	6,4	-18
41	*oost370*	8,1	7,4	-9
45	*oost350*	8,3	6,4	-23
43	*oost370*	8,4	6,7	-21
30	*oost450*	8,6	5,4	-37
49	*oost330*	8,9	8,8	0
51	*oost330*	8,9	5,0	-44
60	*corridor*	9,5	5,0	-48
48	*oost330*	9,7	10,2	5
52	*corridor*	9,7	9,2	-5
50	*oost330*	10,3	7,8	-24
46	*oost350*	10,4	9,0	-13
44	*oost350*	10,5	8,1	-23
27	*corridor*	10,9	8,2	-25
29	*oost450*	11,8	8,2	-30
28	*corridor*	14,0	7,8	-44
				15,77
				avg

Results

Localization using the kNN algorithm
(for k= 3, 5)

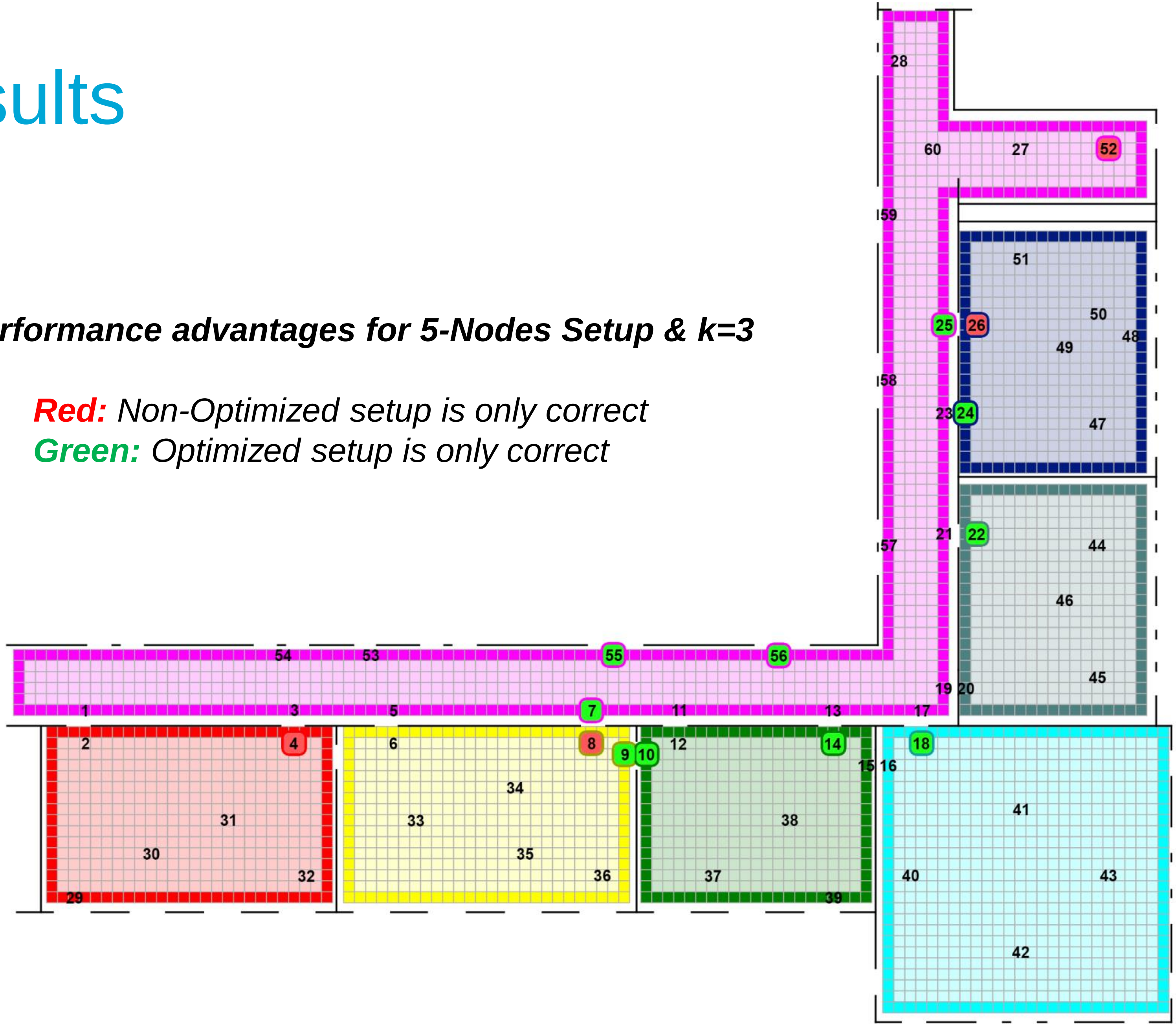
	30 Nodes						15 Nodes						5 Nodes					
	k:3			k:5			k:3			k:5			k:3			k:5		
	N	O1	O2	N	O1	O2	N	O1	O2	N	O1	O2	N	O1	O2	N	O1	O2
Correct Estimations:	53	53	53	46	44	41	52	54	53	48	46	42	48	54	52	47	45	42

N *(Non-Optimized) Sparse Deployment*
O1 *Maximization of the Minimum Separation Distance*
O2 *Maximization of the Product of the n Shortest Separation Distances*

Results

Performance advantages for 5-Nodes Setup & k=3

Red: *Non-Optimized setup is only correct*
Green: *Optimized setup is only correct*



Conclusions

- **How can the location distinctiveness be defined for an indoor positioning system?**

  - The RS span among all positions where localization errors are less probable

- **Which metric is most suitable for measuring the radio distinctiveness among different zones?**

  - Two metrics have been proposed.
  - The maximization of the Minimum Separation Distance led to the best results.

- **Which radio propagation model would offer good accuracy-complexity ratio?**

  - Only the very slow finite-difference time-domain method can outperform the RL technique.
  - Hence, the best option is the RL.

Conclusions

- **Which optimization algorithm should be utilized, to support even large-scale optimizations?**

  - The use of a Genetic Algorithm for the optimization exceeded our expectations.
  - Moreover, is easily scalable.

- **How can the optimization results be evaluated?**

  - If everything is accurately modeled, via a Monte Carlo procedure.
  - Yet, we compared to 3 non-optimized deployments that can be typically found in a real scenario.
  - Ideally, the optimized scenario should be evaluated in practice.

Conclusions

To what extent can the placement of BLE nodes (that are used for fingerprint-based positioning), be optimized to increase the location distinctiveness in an indoor environment?

- The simulated evaluation showed that every optimized deployment introduced better localization performance and location distinctiveness, when the Nearest Neighbor was considered.
- A performance gain is also expected when other localization techniques are used along with the fingerprinting. (e.g. Bayesian Estimations)
- This optimization is expected to also have effect in the non-simulated case. Otherwise, our radio propagation modelling was not accurate enough.

Thank you!