Wi-Fi network-based indoor localisation

The case of the TU Delft campus

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Introduction

- Indoor/outdoor localisation
- Location-Based Services (LBS)
- Indoor LBS:
  - Management applications

Problem statement

- Management:
  - Real-time information demand
  - Large coverage
  - Current methods inefficient
- Indoor localisation:
  - Current accuracy not sufficient

Research question

To what extent can indoor Wi-Fi monitoring be used for **indoor localisation** in order to determine **occupancy** rhythms and **movement patterns** within and between **rooms** to support campus management?

Location-based service:

Occupancy and movement

Real-time

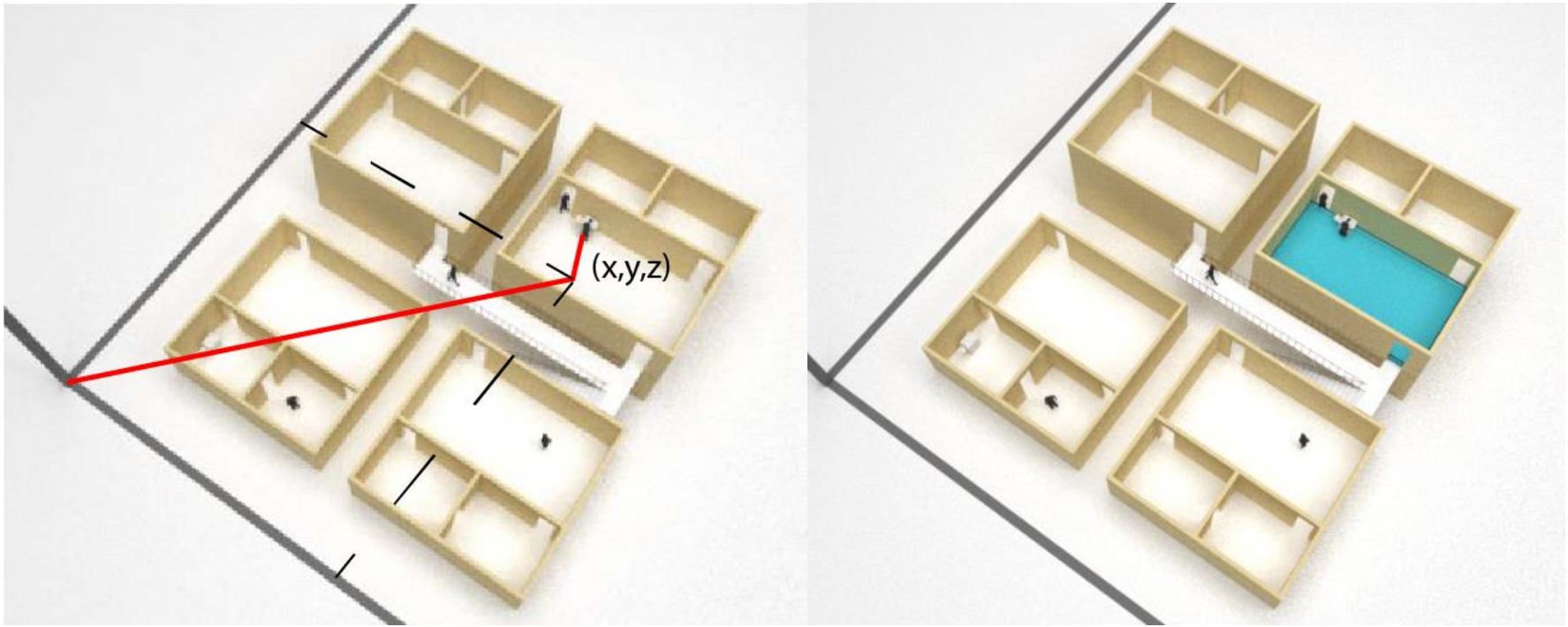
Room level accuracy

Sub-questions

- What are the requirements to occupancy information by campus management?
- How to position a user with Wi-Fi? (techniques and methods)
- How to increase the accuracy of Wi-Fi localisation? (influences, placement and limitations)
- ..

Theoretical framework

Concepts of placement: position and location



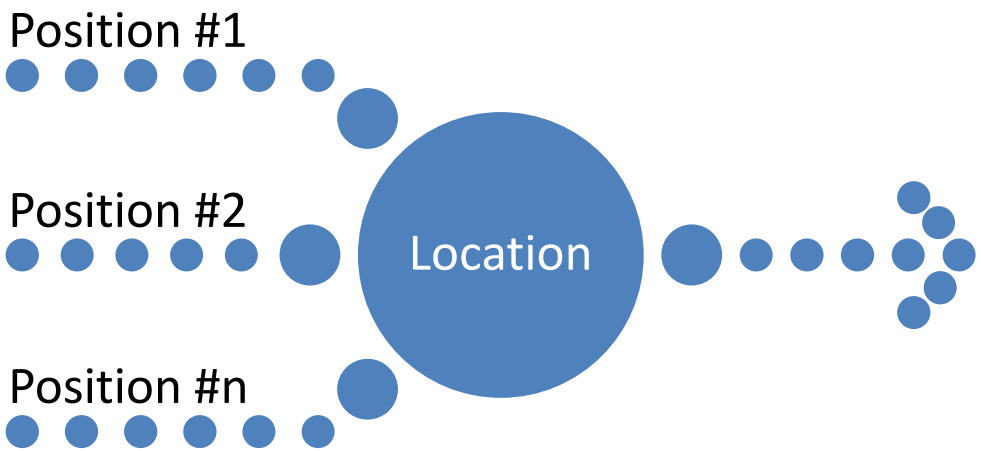
Zlatanova, 2016

Localisation through positioning

techniques

Wi-Fi,
Bluetooth

methods



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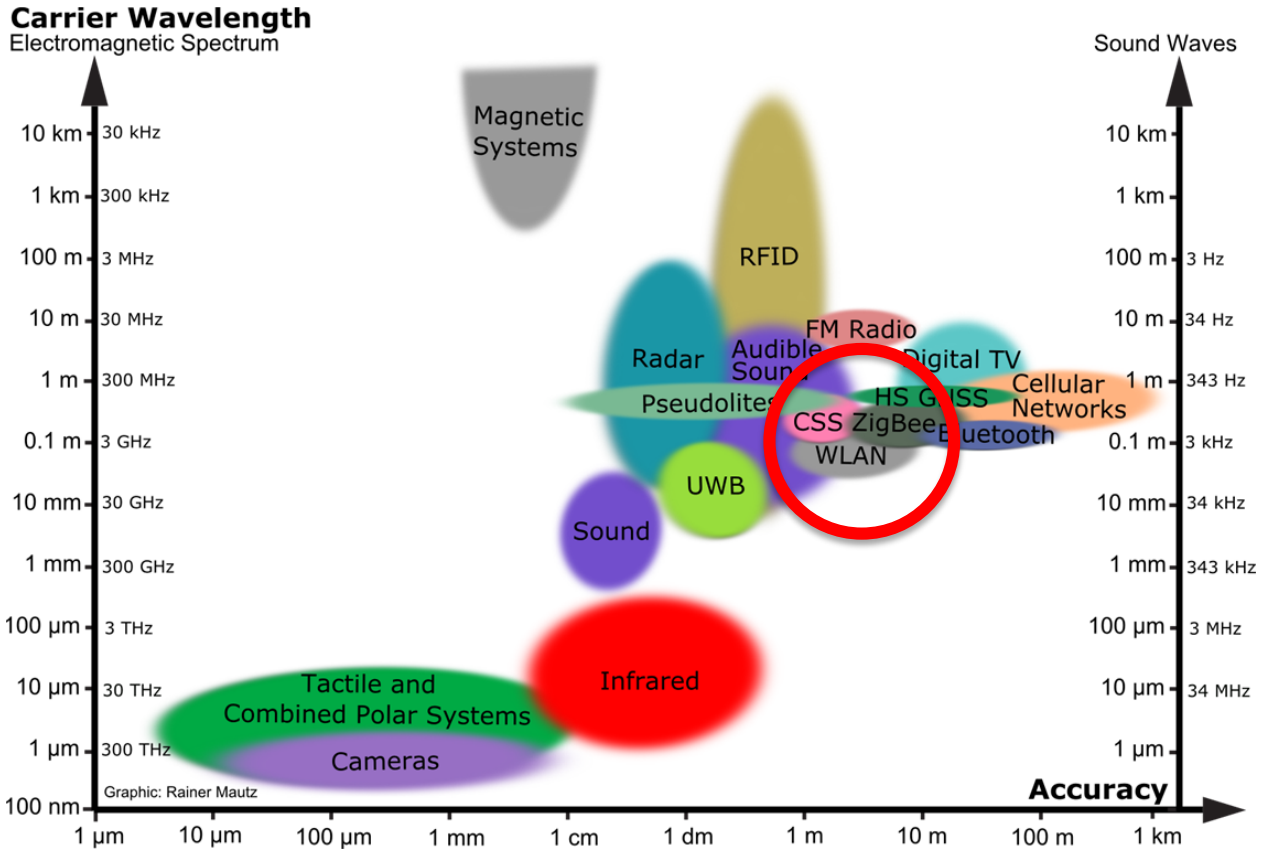
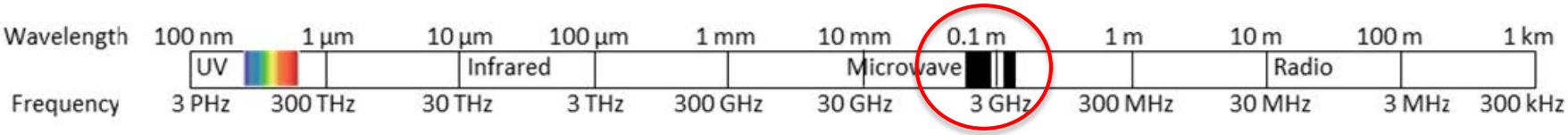
Wireless measuring techniques



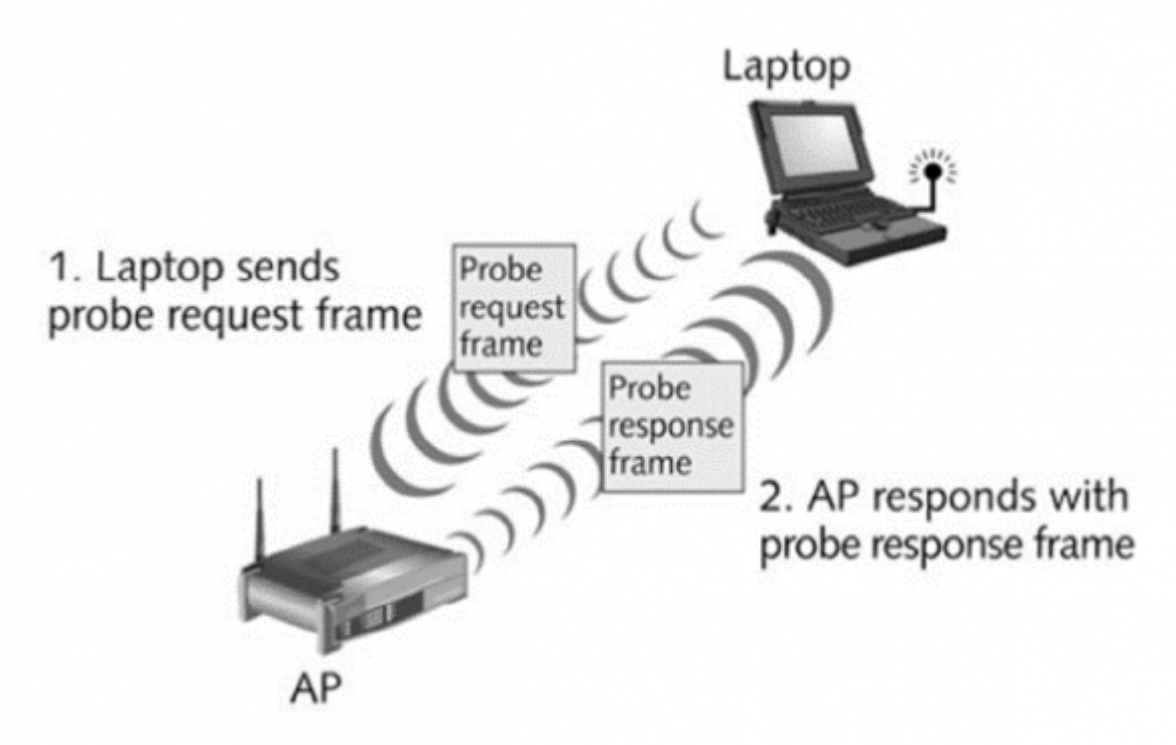
Mautz, 2012

Wi-Fi

- Communication **standard** and **trademark** owned by the Wi-Fi Alliance
- Wireless local area network (WLAN) products that are based on the Institute of Electrical and Electronics Engineers' **(IEEE) 802.11 standards**

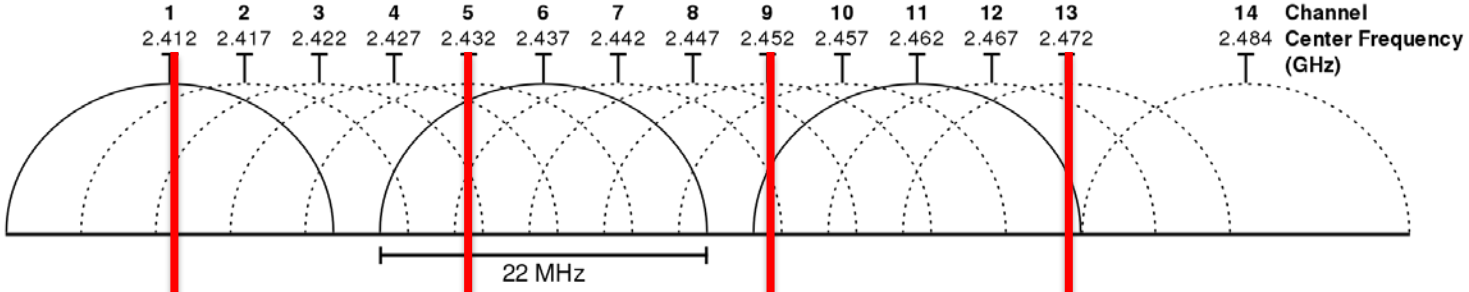


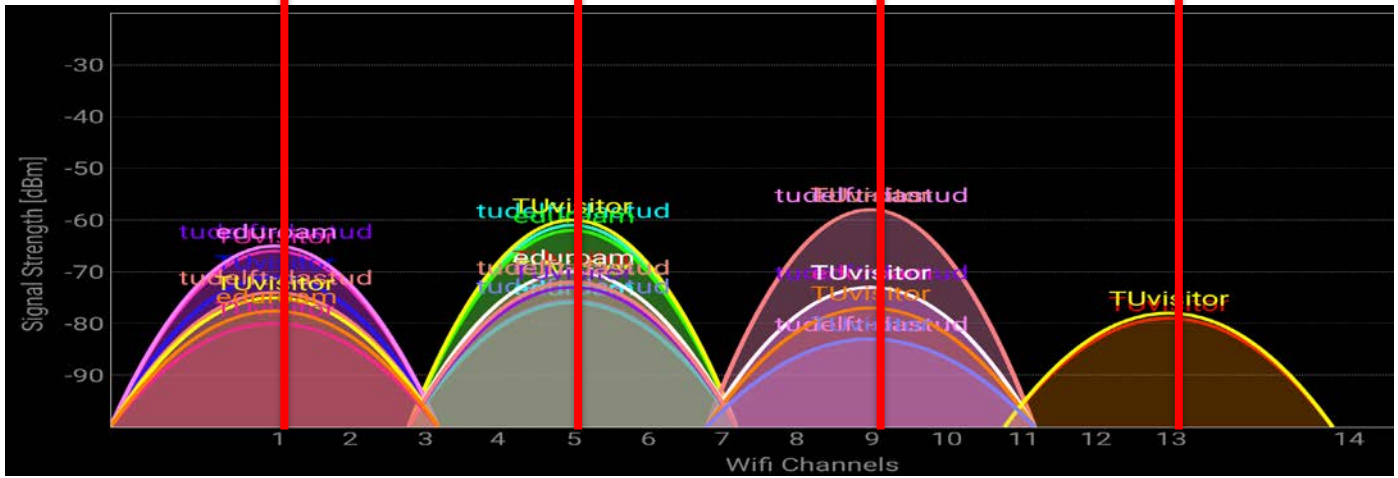
Probe requests



Beacon frames

Wi-Fi channels





Network-based Wi-Fi tracking measures

- Signal strength indication
- Time
- Scanner node
- MAC address
- Manufacturer (type of device)

- Channel, quality information, noise

Localisation principles

- Based on time
- Based on angles
- Based on signal strength

Ranging

Free-space signal propagation model

$$P_R \propto P_T \frac{G_T G_R}{4\pi d^p}$$

Indoor path-loss model

$$P_L(d_i) = P_L(d_0) + 10(n)\log_{10}\left(\frac{d_i}{d_0}\right)$$

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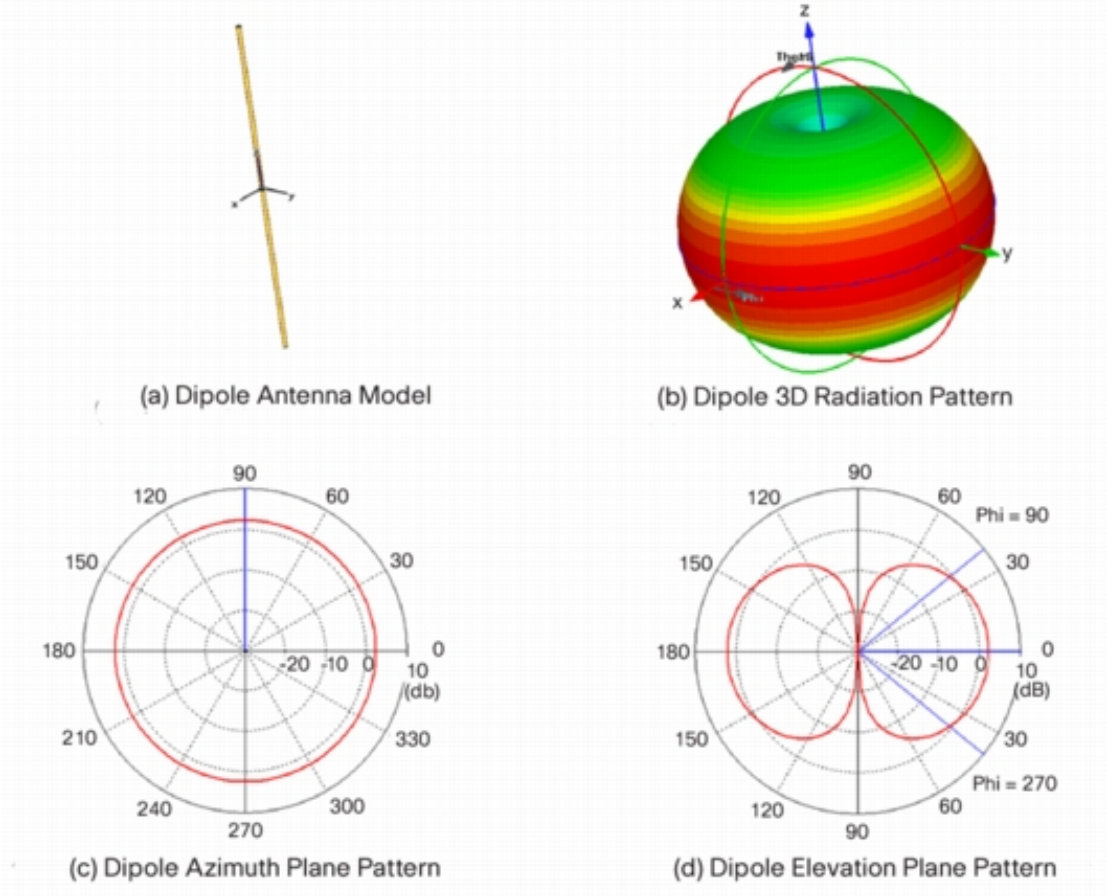
Antennas


(a) Dipole Antenna Model
(b) Dipole 3D Radiation Pattern
90
120
60
150
30
180
0
210
330
240
300
270
-20 -10 0
10
(db)
(c) Dipole Azimuth Plane Pattern
Phi = 90
Phi = 270
(dB)
(d) Dipole Elevation Plane Pattern

Indoor environment and influences

Multipath reflection

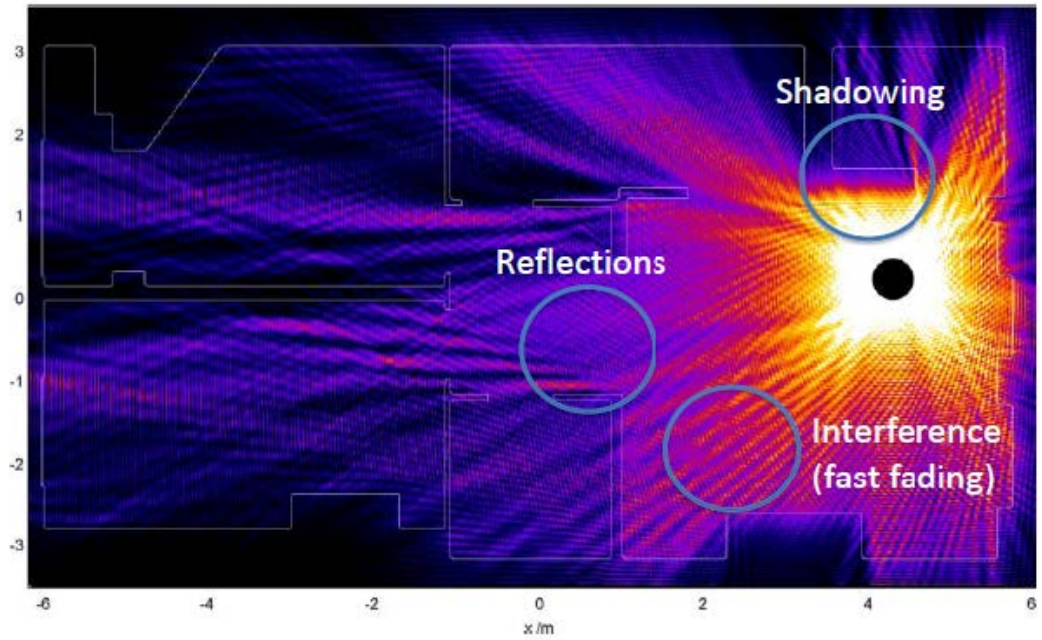
Absorption

Refraction

Scattering

Diffraction

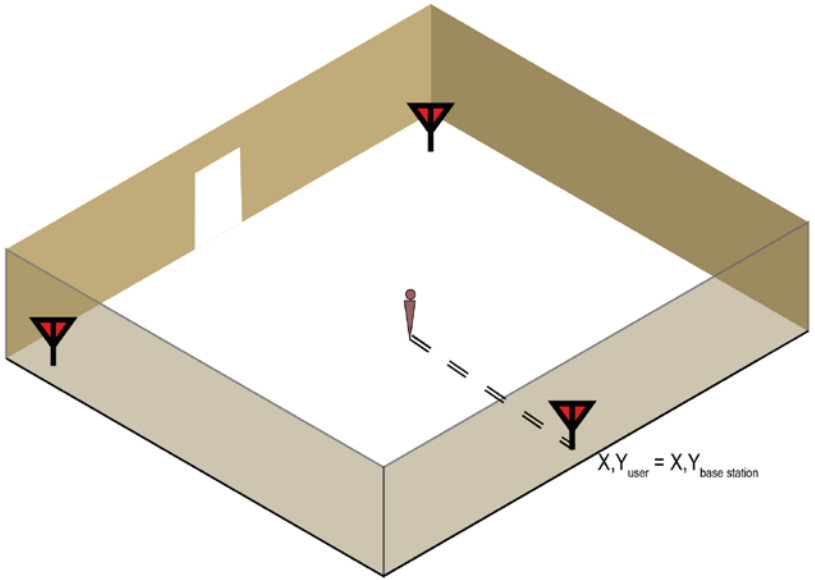
Depolarisation

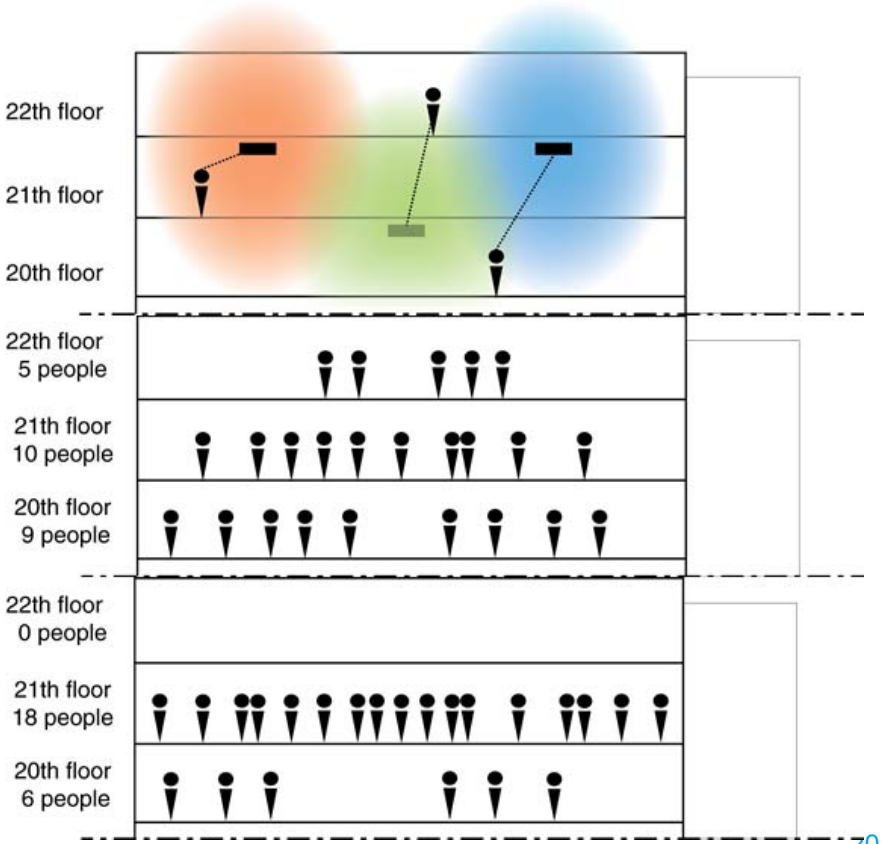


Positioning methods

- Cell/connectivity-based localisation
- RSSI fingerprinting
- RSSI (multi)lateration

Cell/connectivity-based localisation





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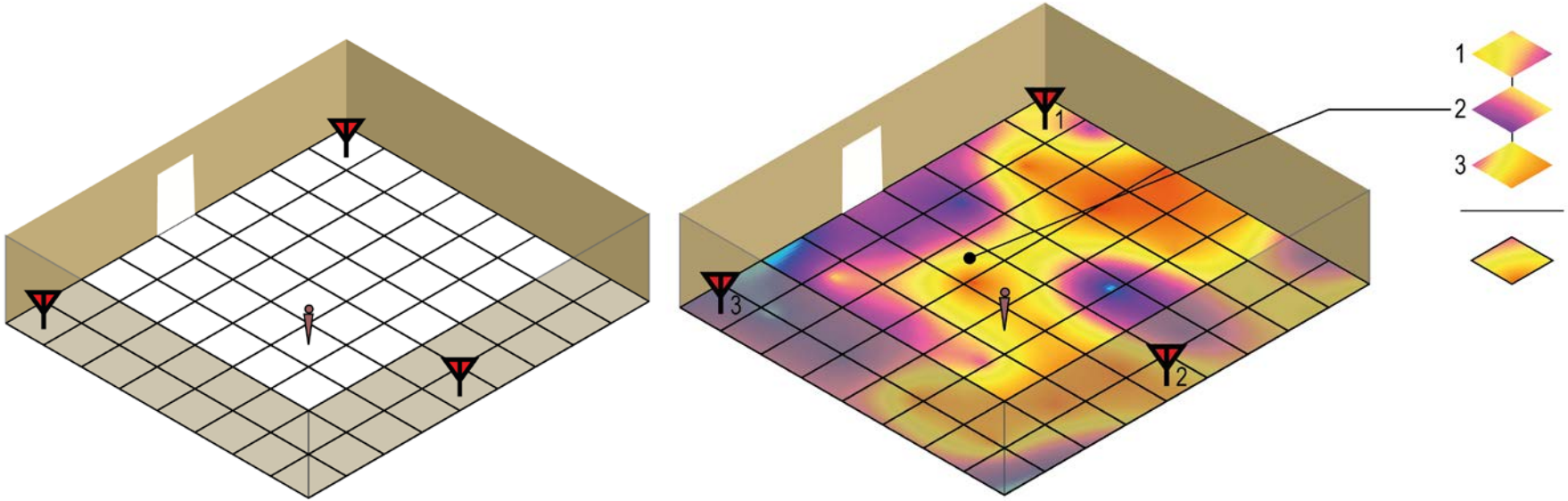
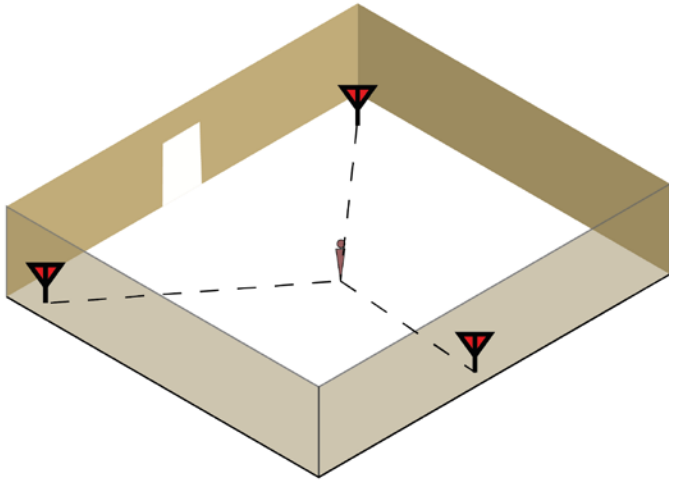
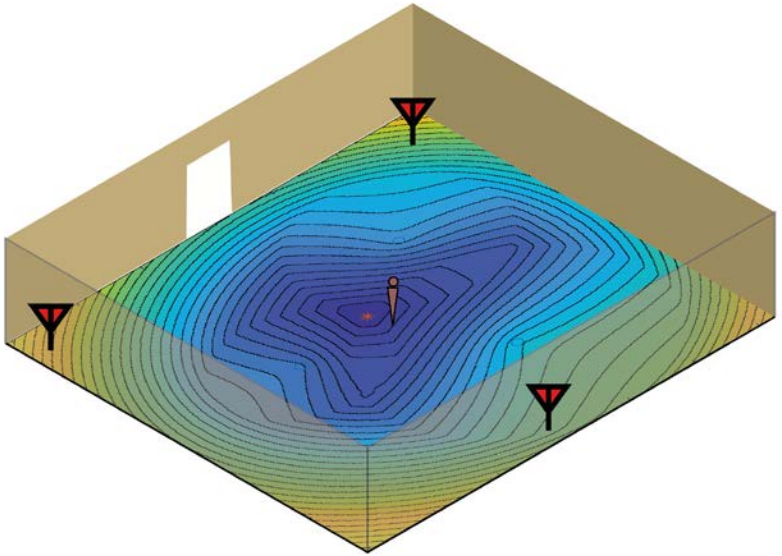
RSSI fingerprinting

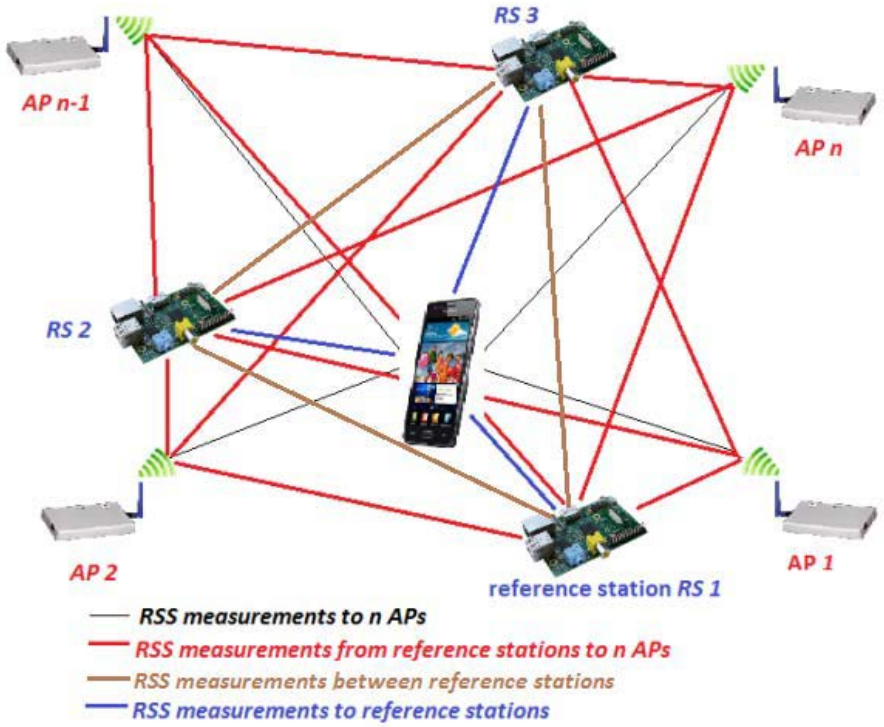


RSSI (multi)lateration





Improving Wi-Fi ranging



(Retscher & Tatschl, 2016)

Goals

- Quantitative / qualitative
- Facility sharing
- Scheduling
- Increase user satisfaction
- Reduce costs
- Reduce environmental footprint

Requirements

Table 3.1: Requirements for real-time occupancy and exploitation measurements.

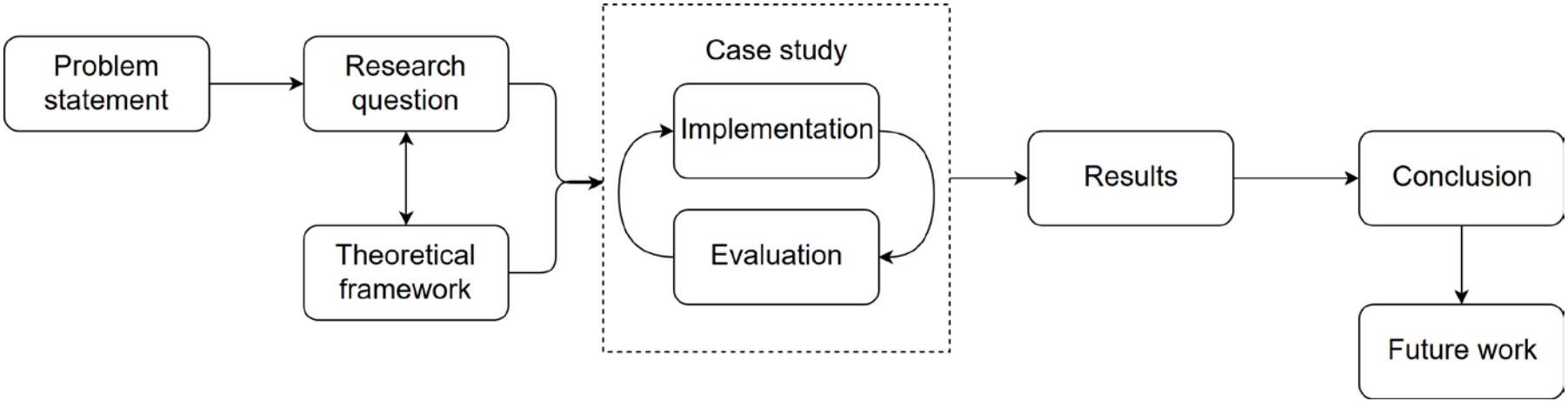
Criteria	Criteria Description	Requirement
horizontal accuracy	need for specific room determination	room detection
vertical accuracy	need for determination of a specific floor in a building	floor detection
privacy	maintenance of the user privacy	in accordance with GDPR
latency delay	delay with which position are available to the management	none
availability	the amount of time the information can be accessed	during office hours

Privacy regulations

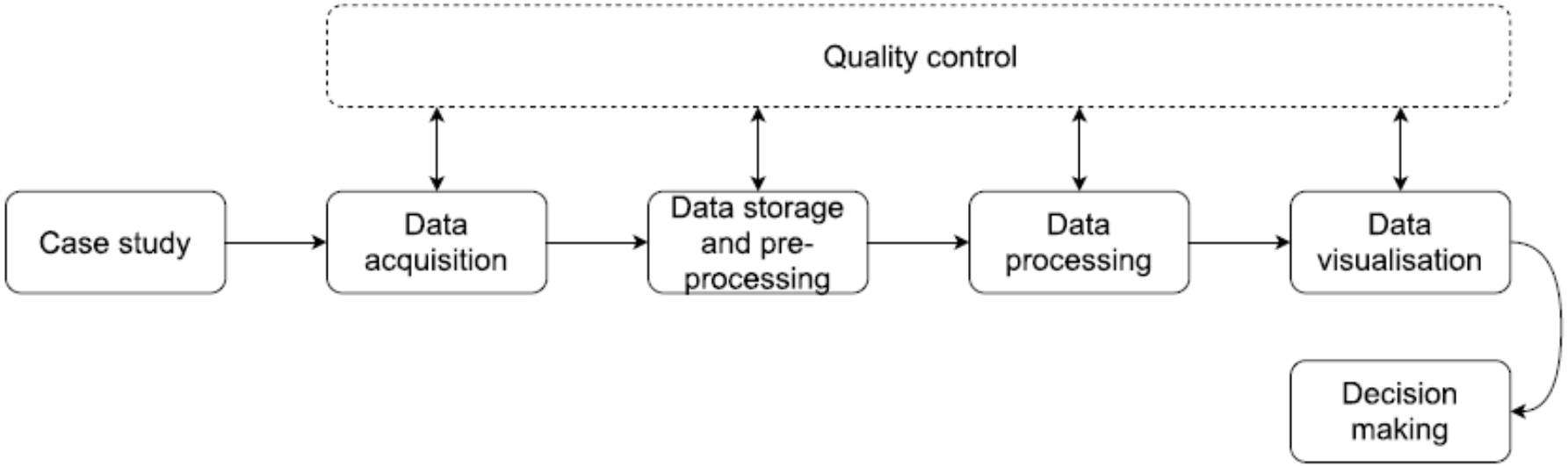
- Personal data:
  - ”any **information** relating to an identified or **identifiable** natural person (”data subject”); an identifiable person is one who can be identified, **directly or indirectly**, in particular by reference to an identification number or to one or more factors specific to his physical, physiological, mental, economic, cultural or social identity;” (Parliament, 1995, article 2 a).
- Law for the Protection of Personal Information (LPPI) & GDPR

Conceptual framework

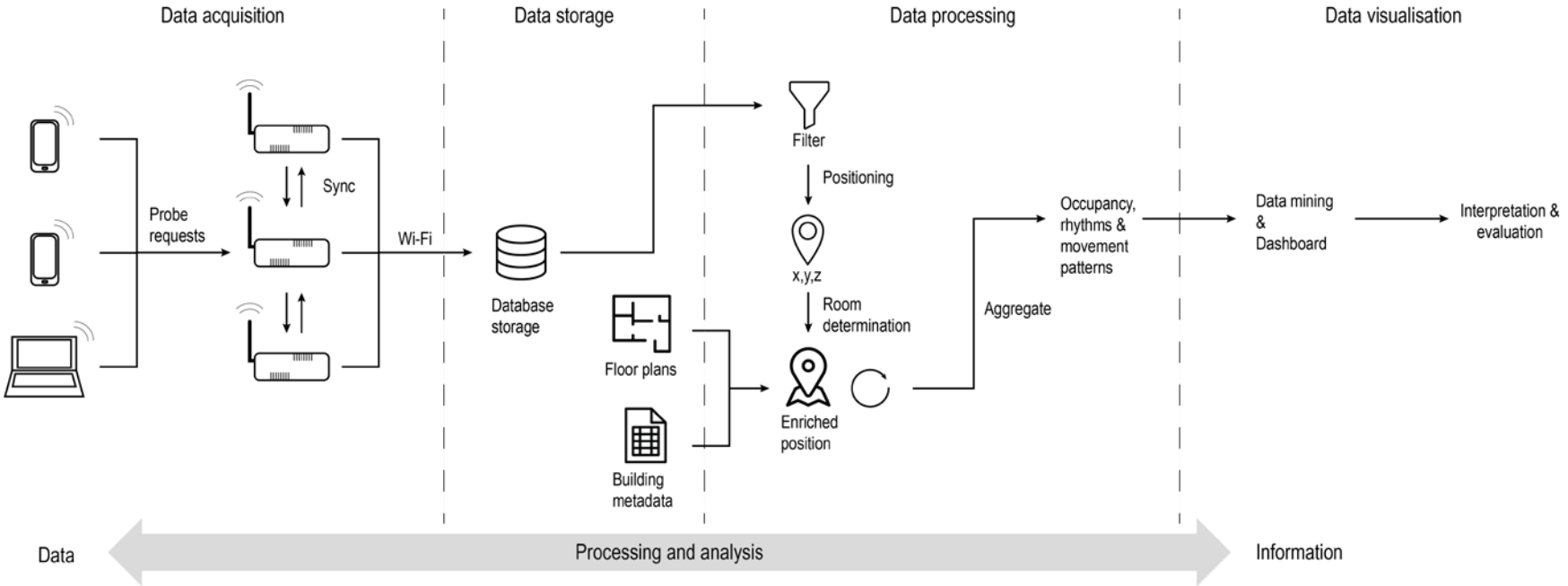
Methodology overview



Conceptual framework and implementation

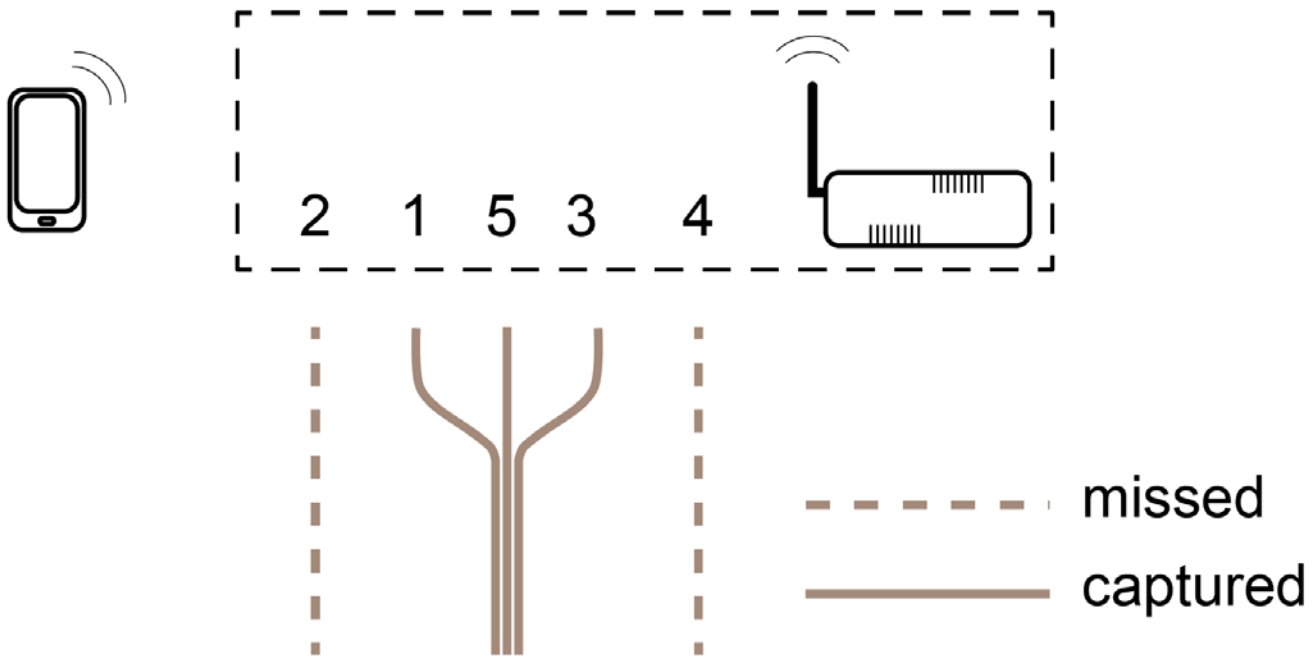


System overview

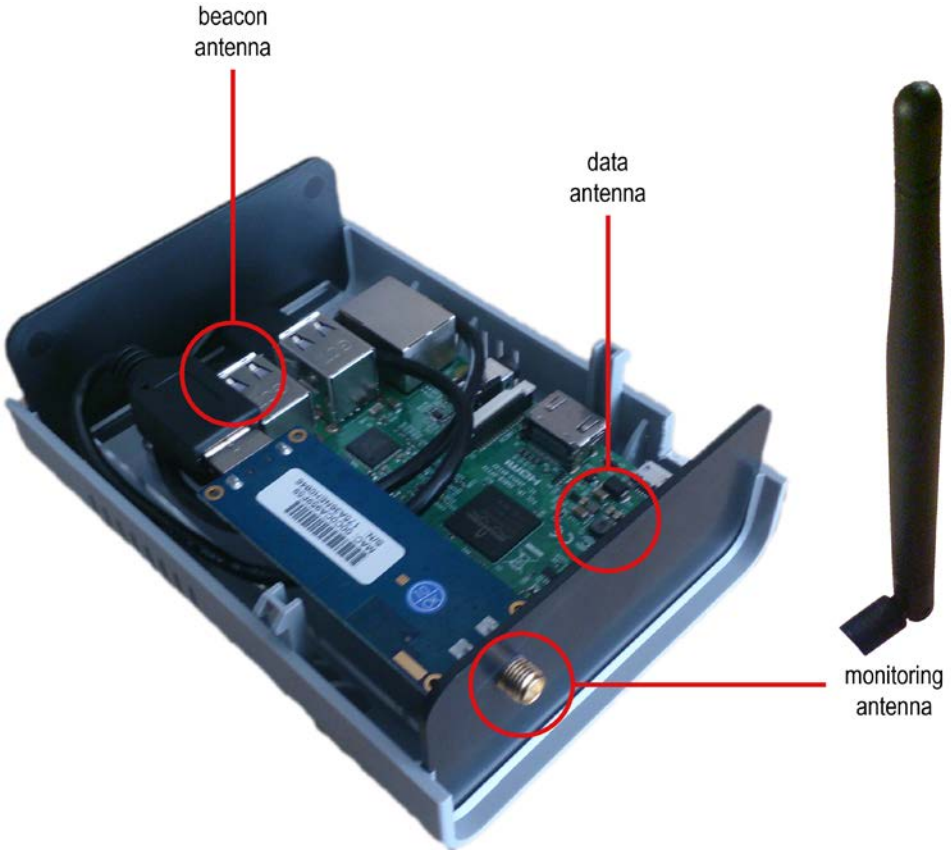


Data acquisition

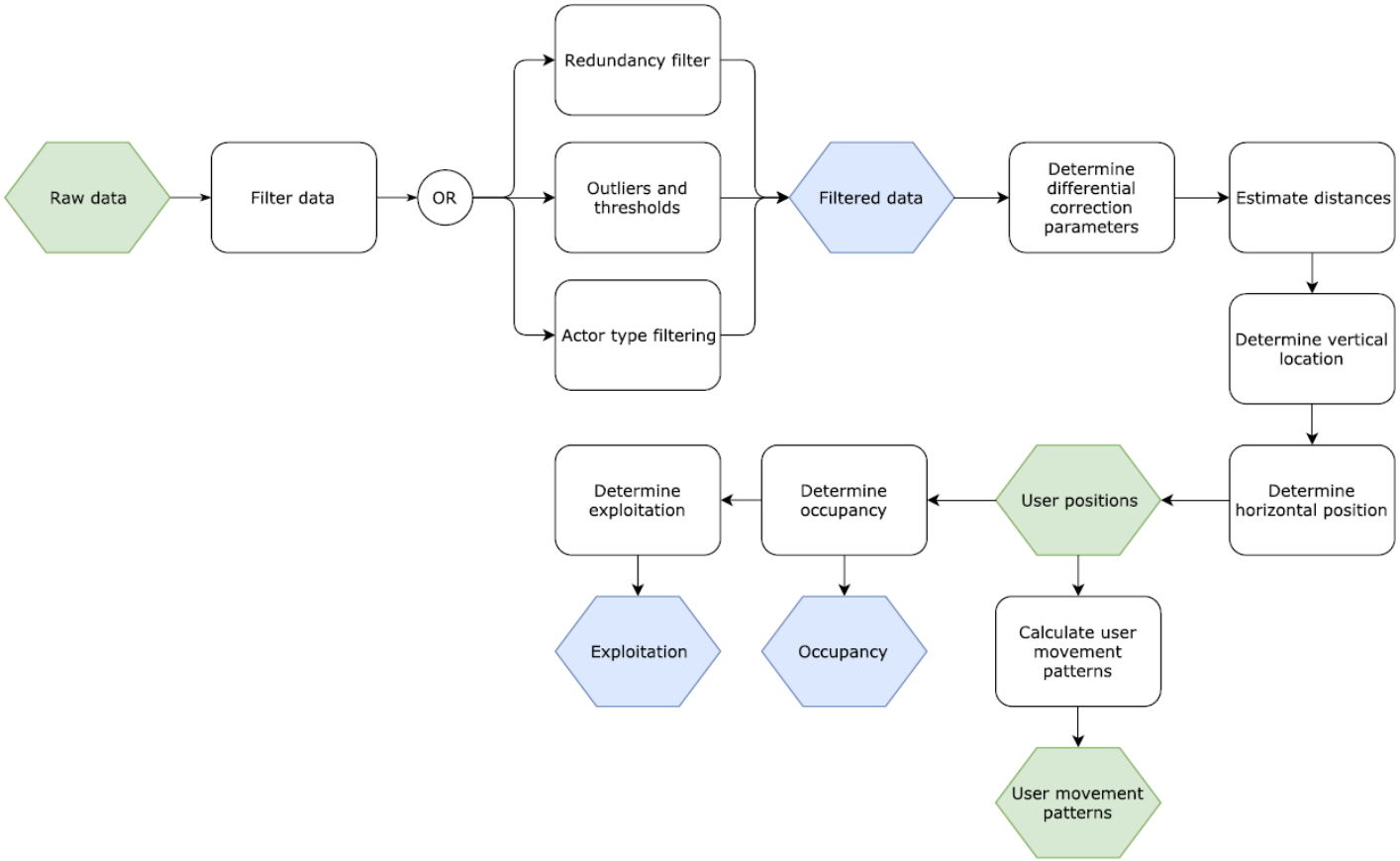
multiple scanner nodes register client device



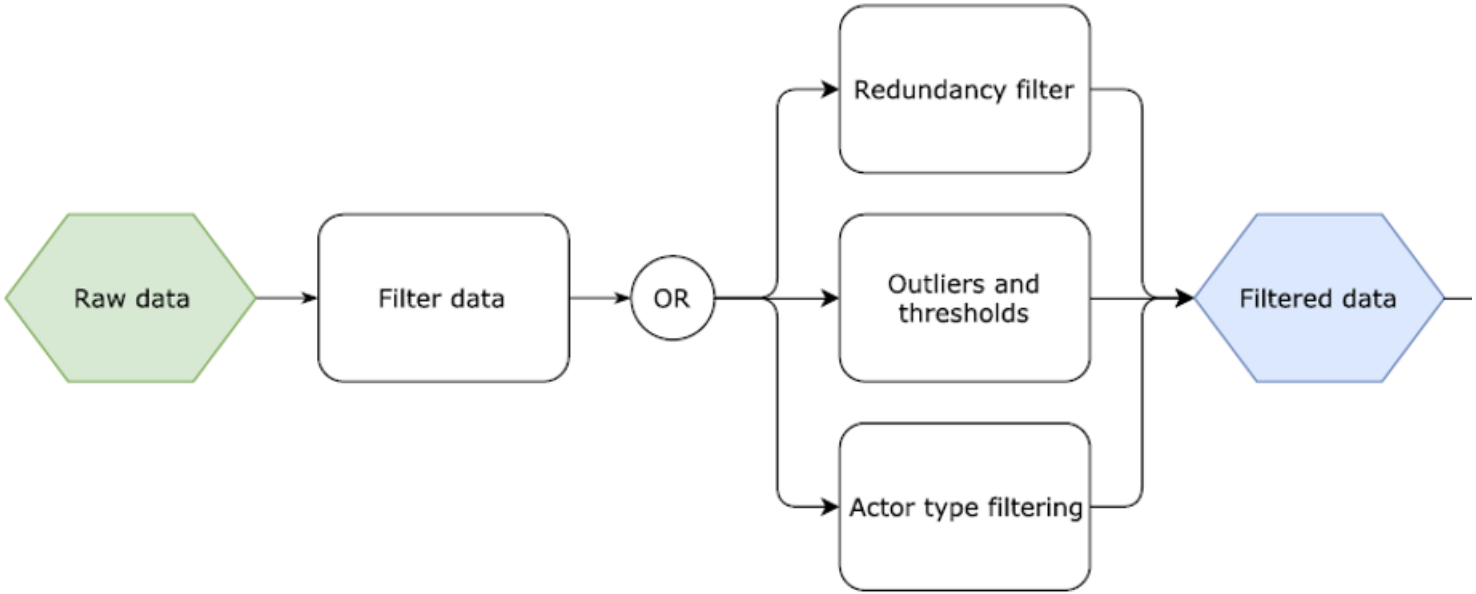
Reference station components



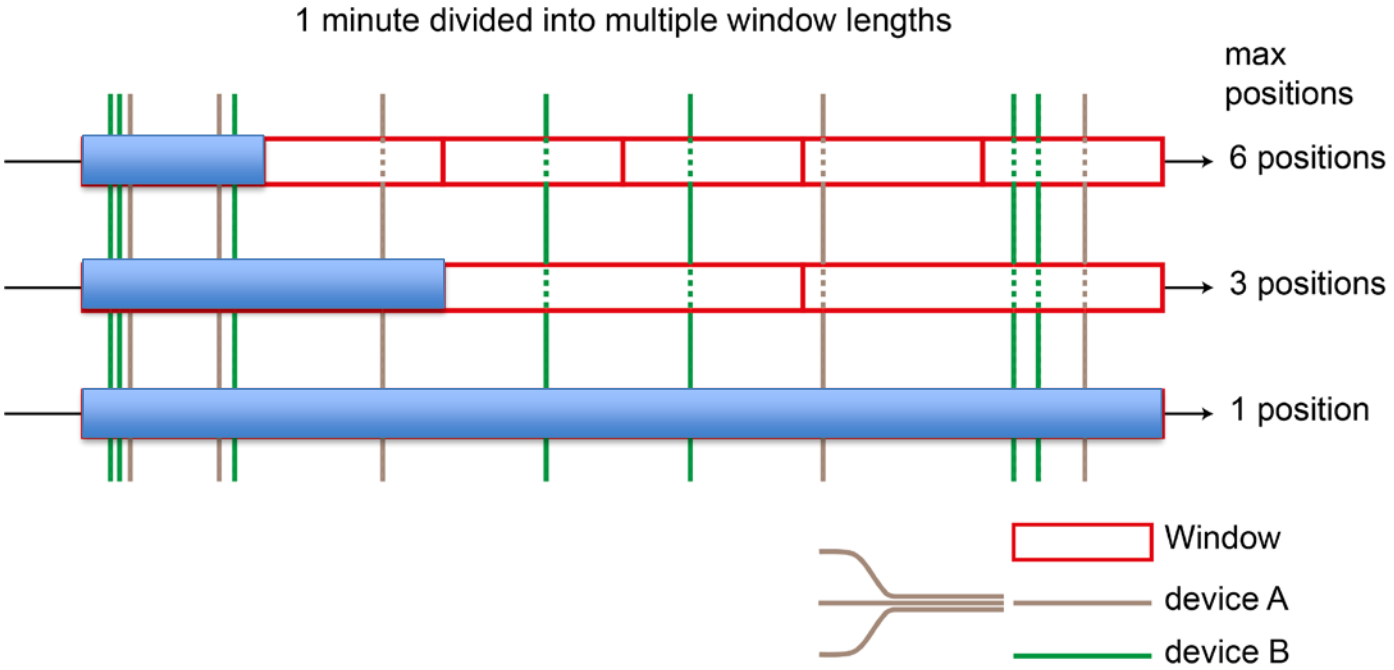
Data processing



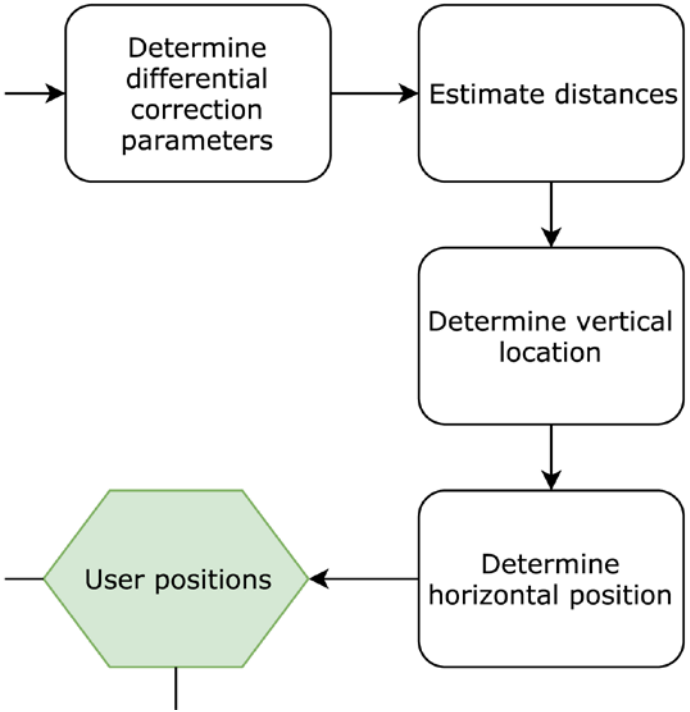
Filtering


Raw data
Filter data
OR
Redundancy filter
Outliers and thresholds
Actor type filtering
Filtered data

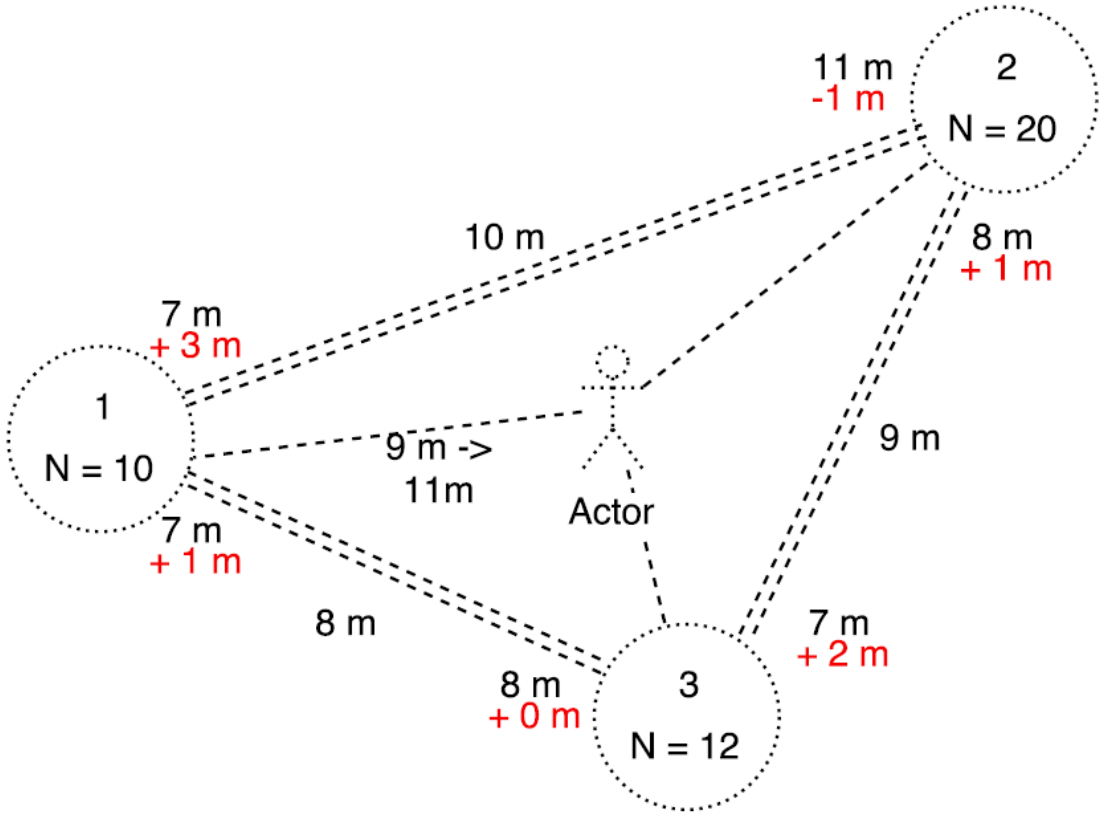
Windows


1 minute divided into multiple window lengths
max positions
6 positions
3 positions
1 position
Window
device A
device B

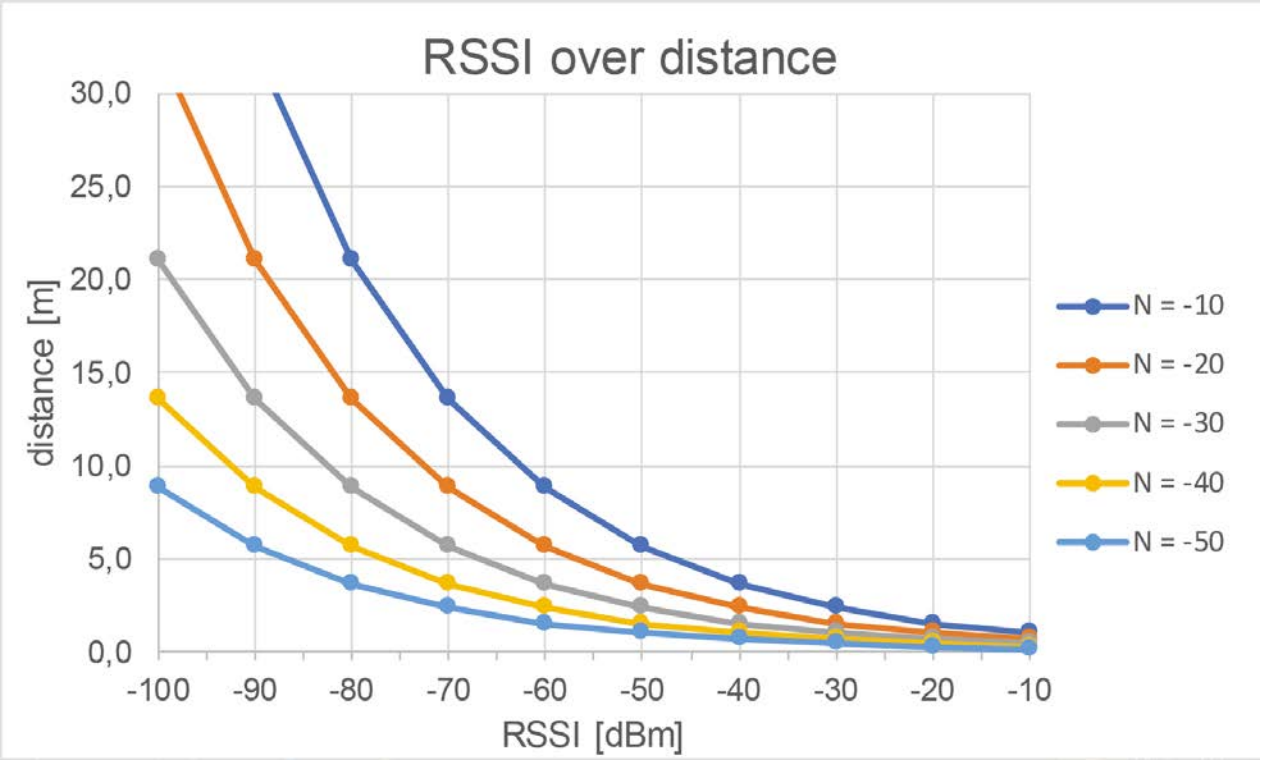
Position estimation



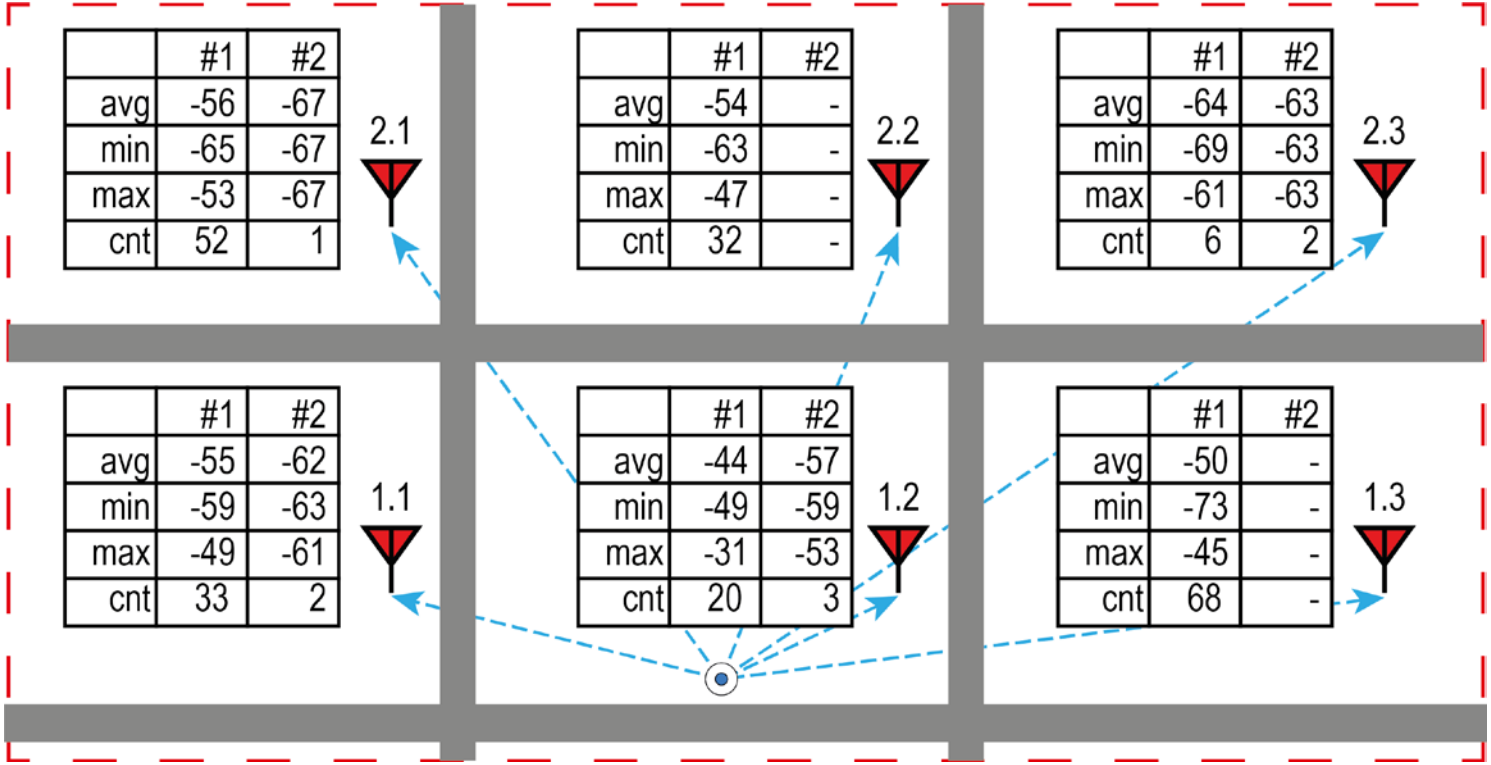
Differential correction parameters



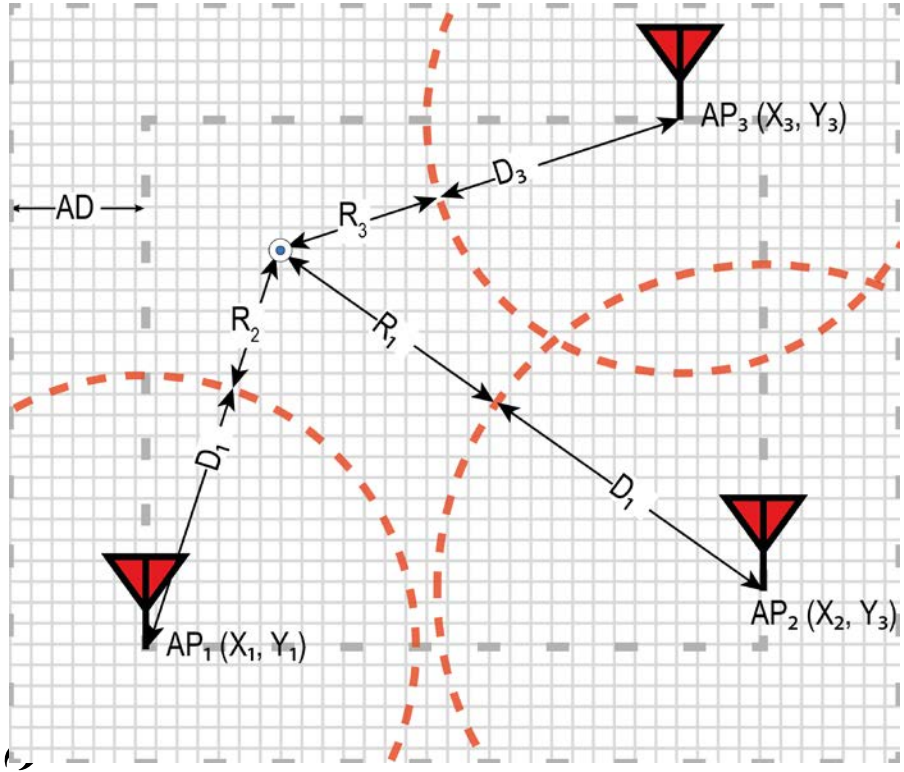
Distance estimation

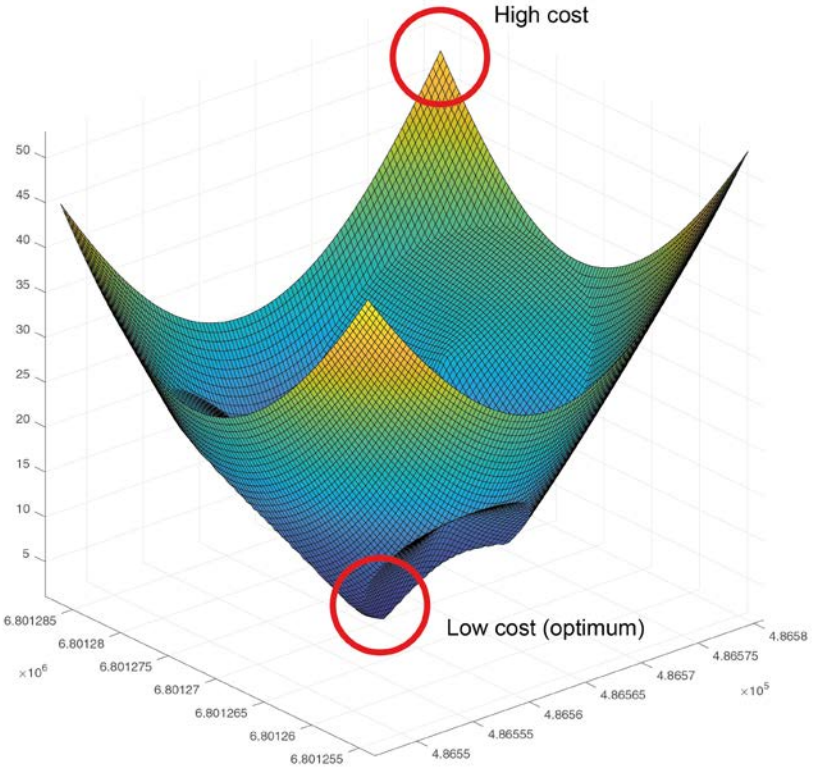


Floor level determination



Determining the horizontal position





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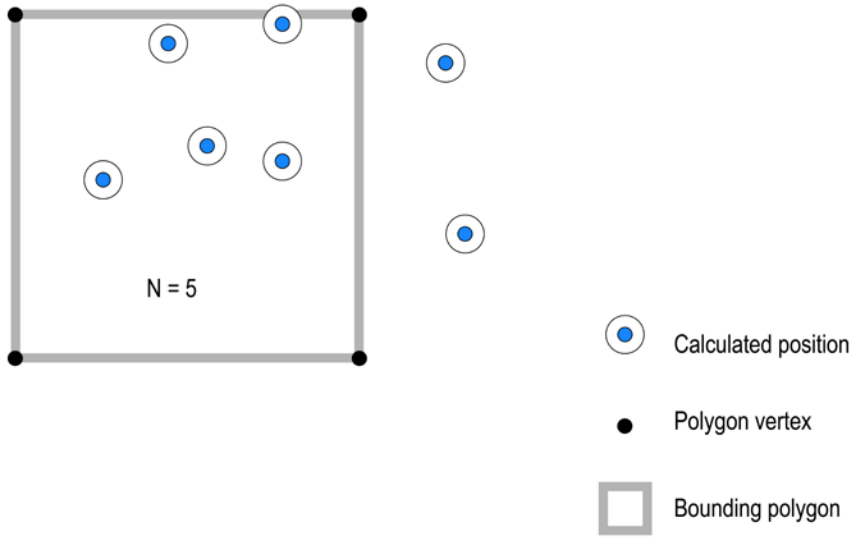
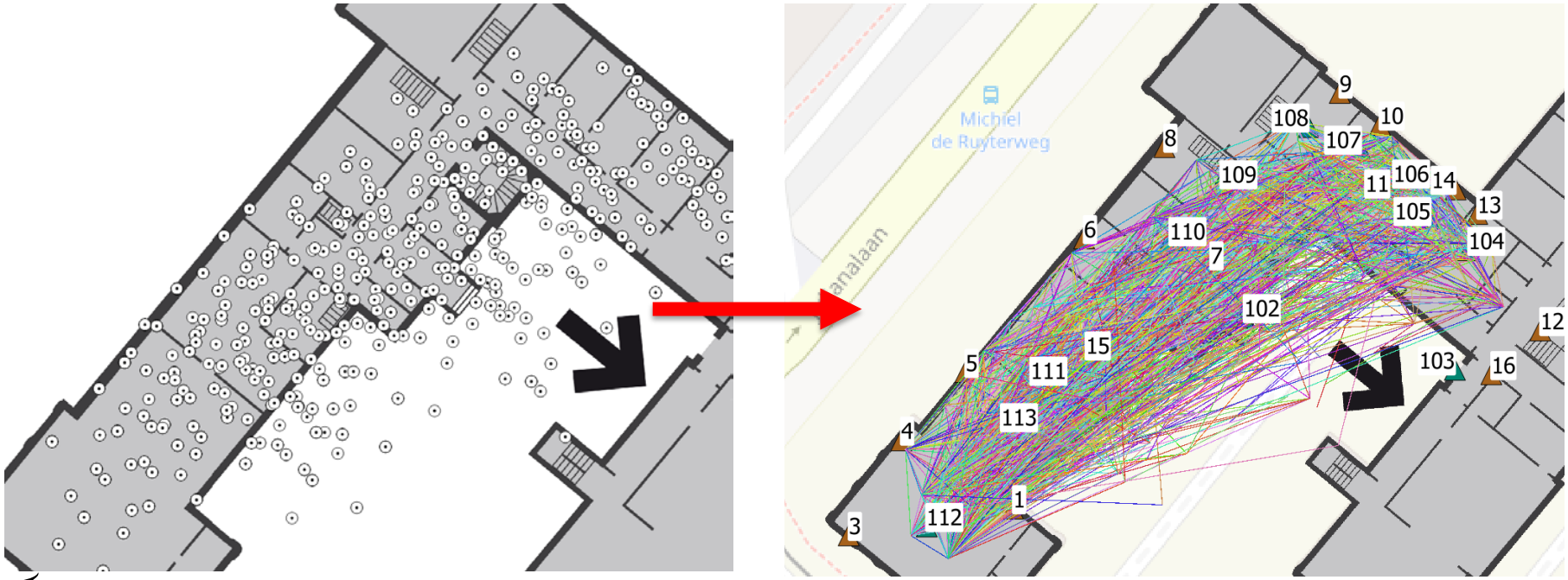
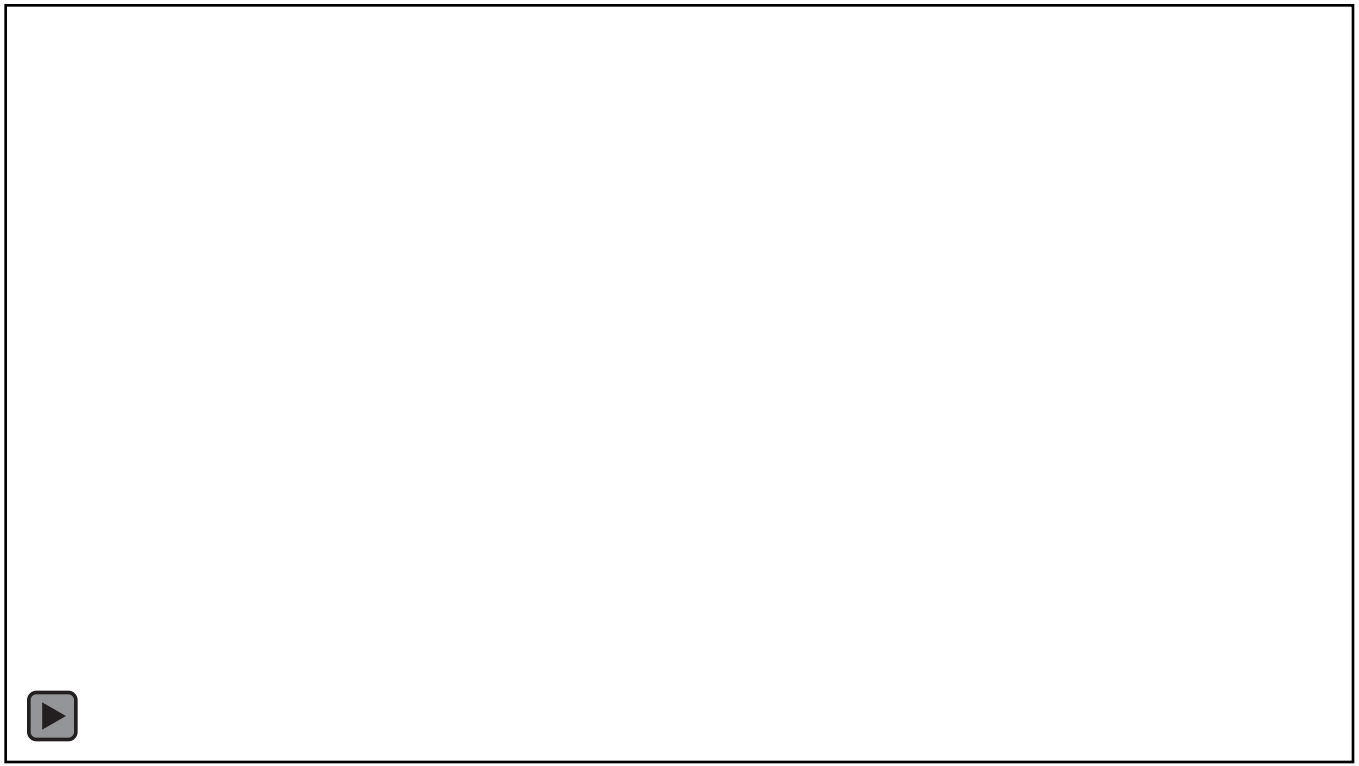
Calculating occupancy



Positions to movement patterns

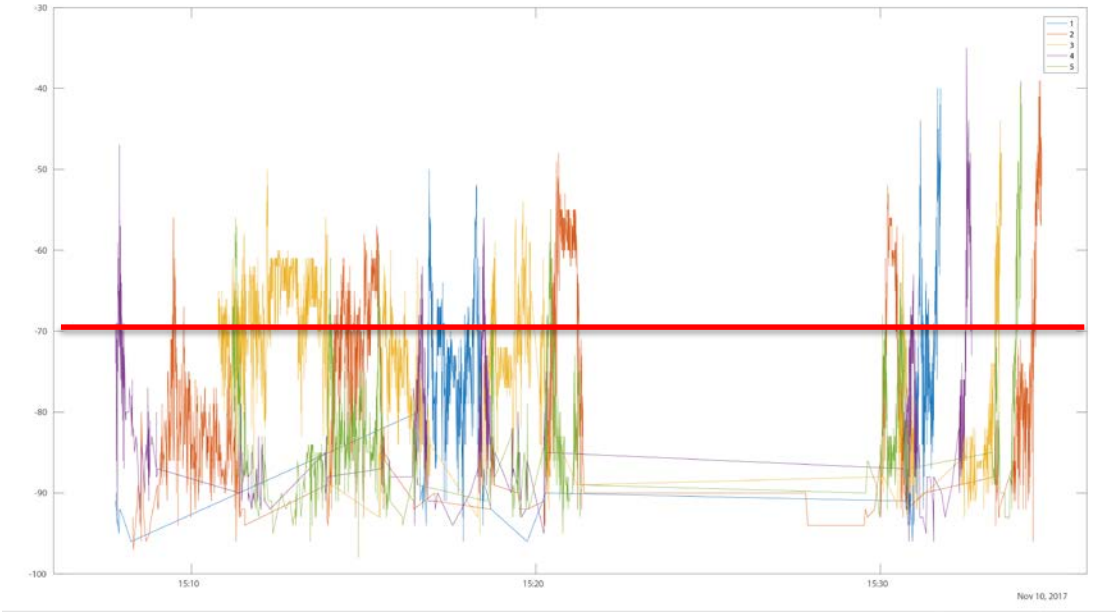


Case study: evacuation of Architecture

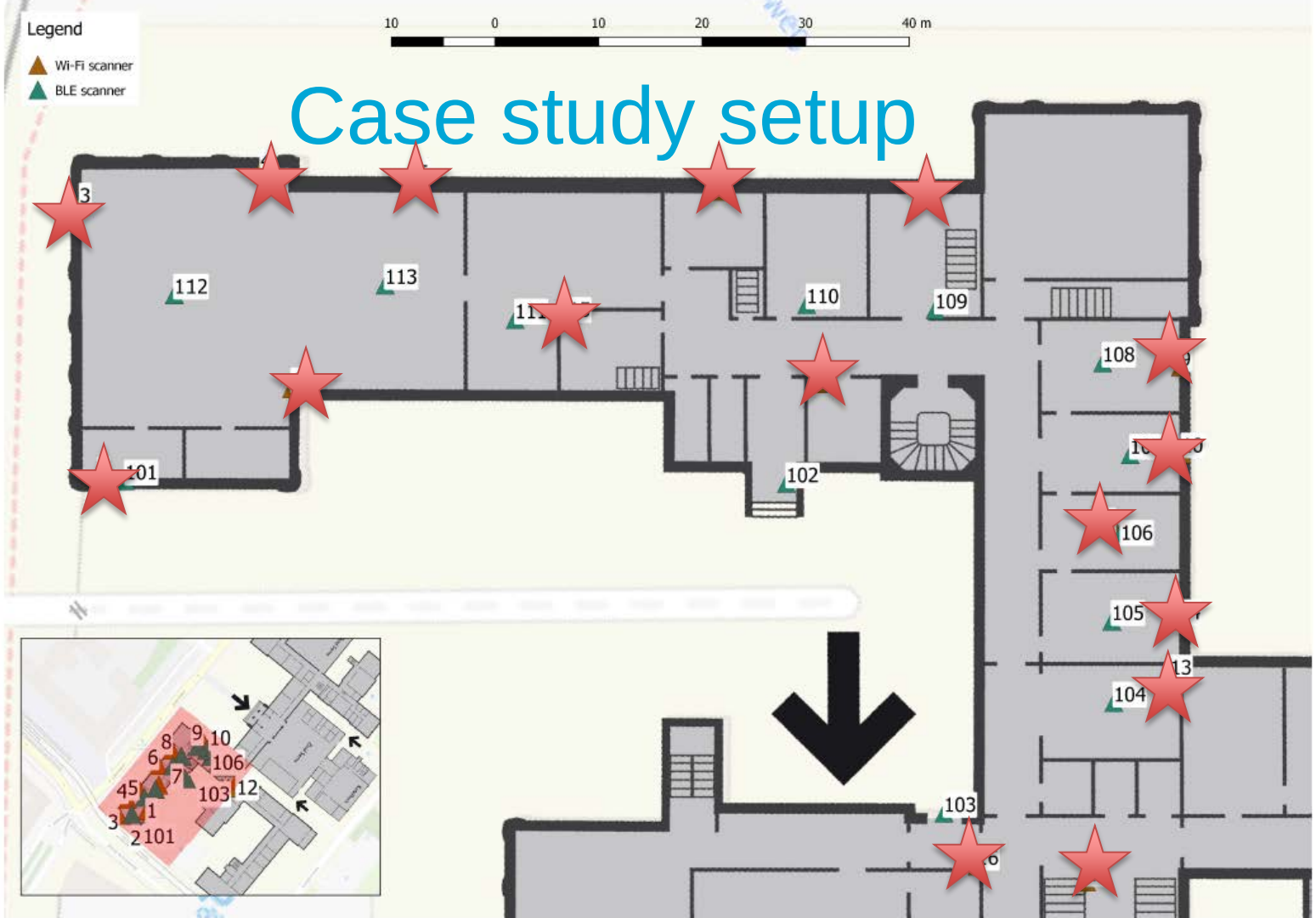


Data validation

- Bluetooth bracelets during evacuation

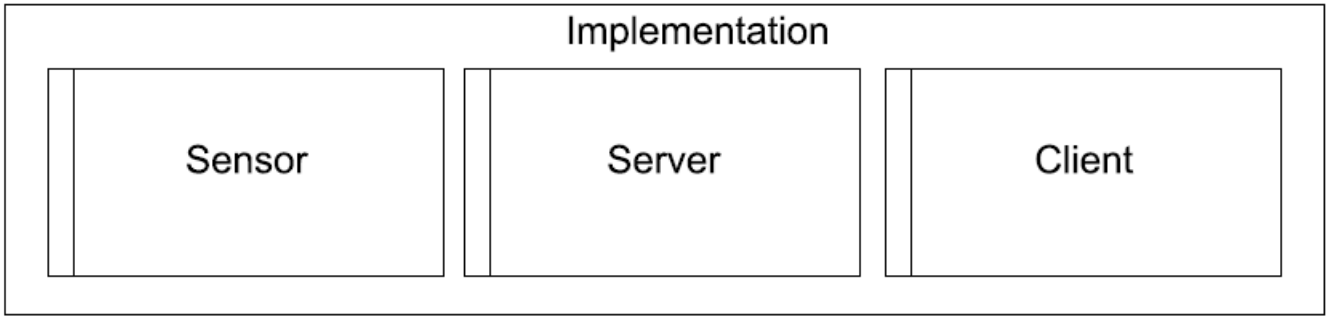


Case study setup



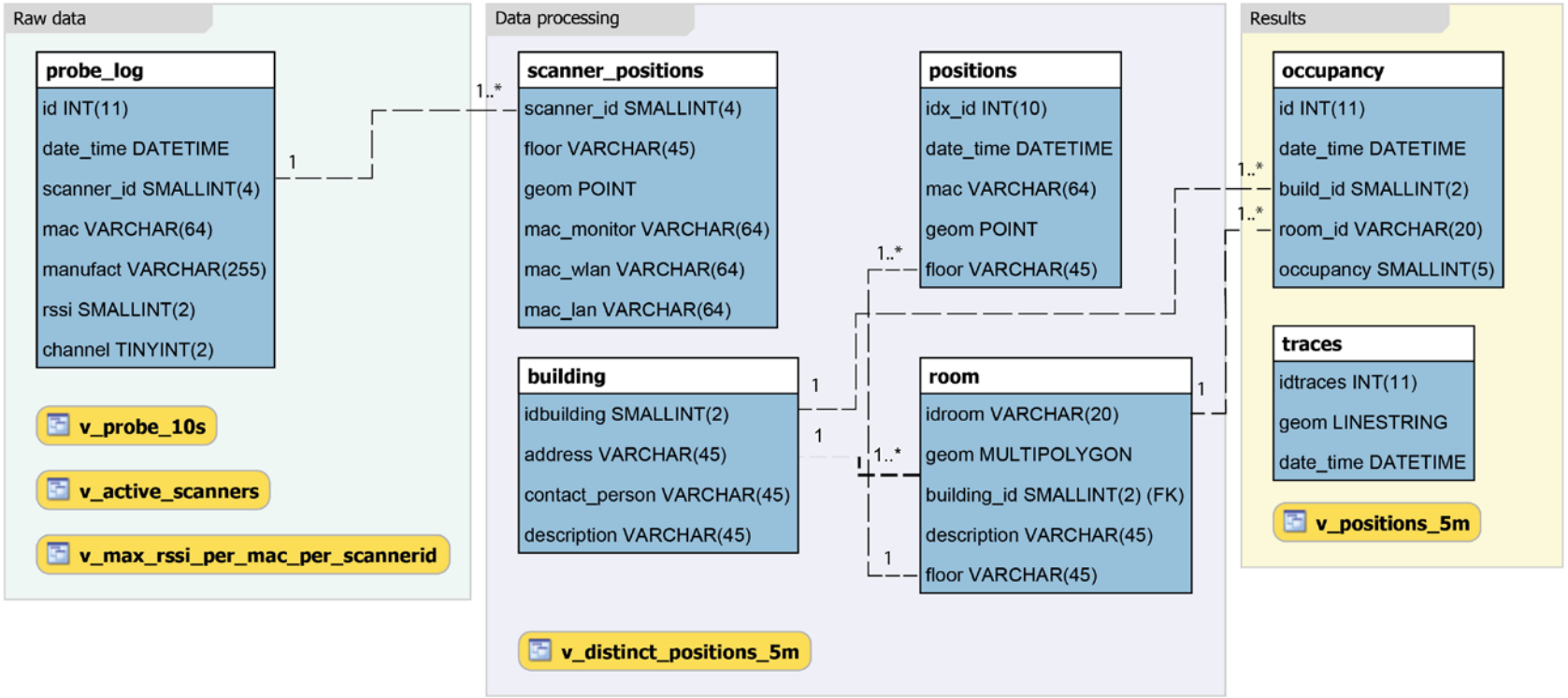
Implemtation overview

- ScaPy Biondi (2008)
- MySQL spatial
- Javascript modules
  - Trilat Dias (2016)
  - Chart.js Timberg (2017)
  - OpenLayers Schaub (2017)



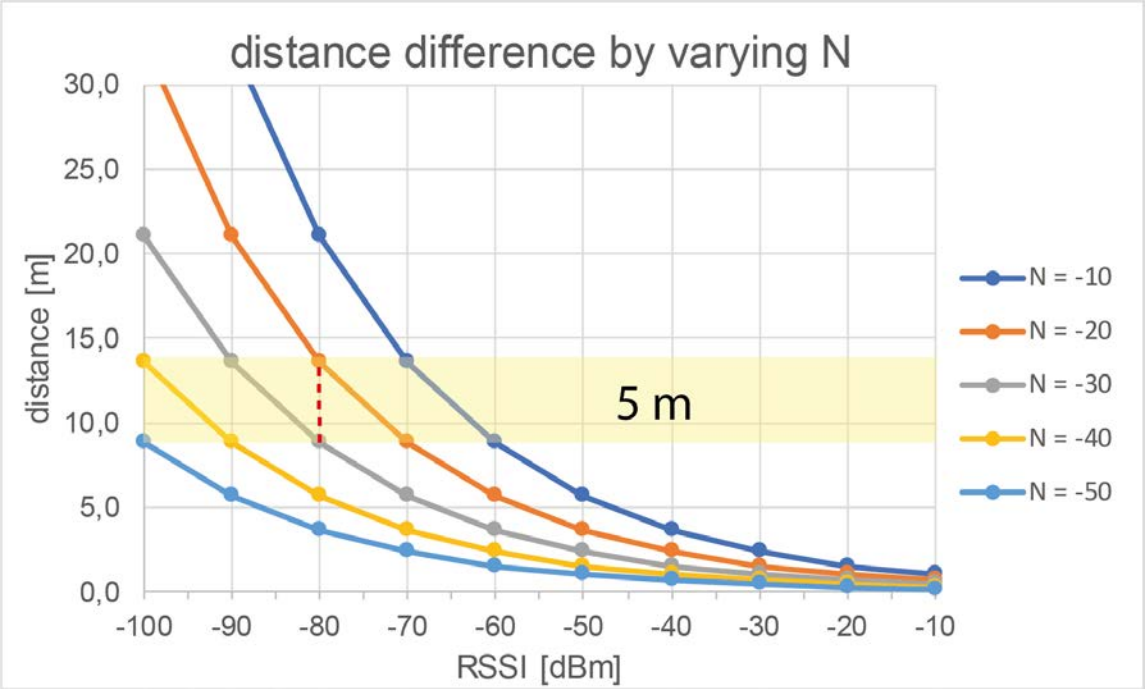
Anonimisation of personal data

Database structure

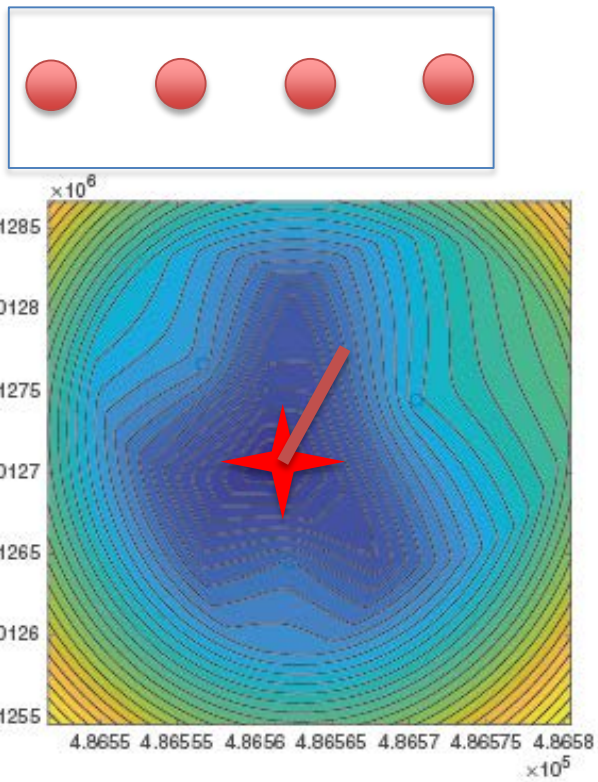


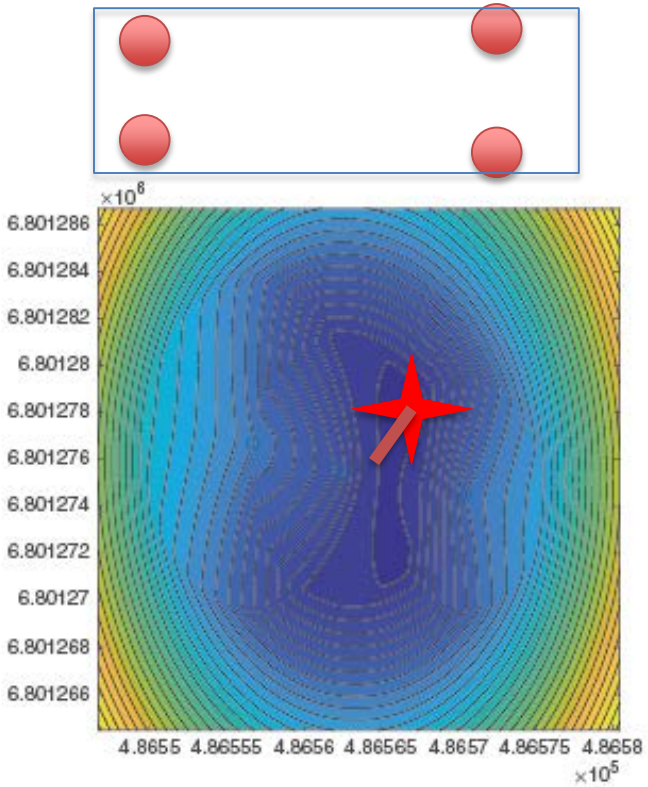
Results

Differential correction difference



Distribution of base stations





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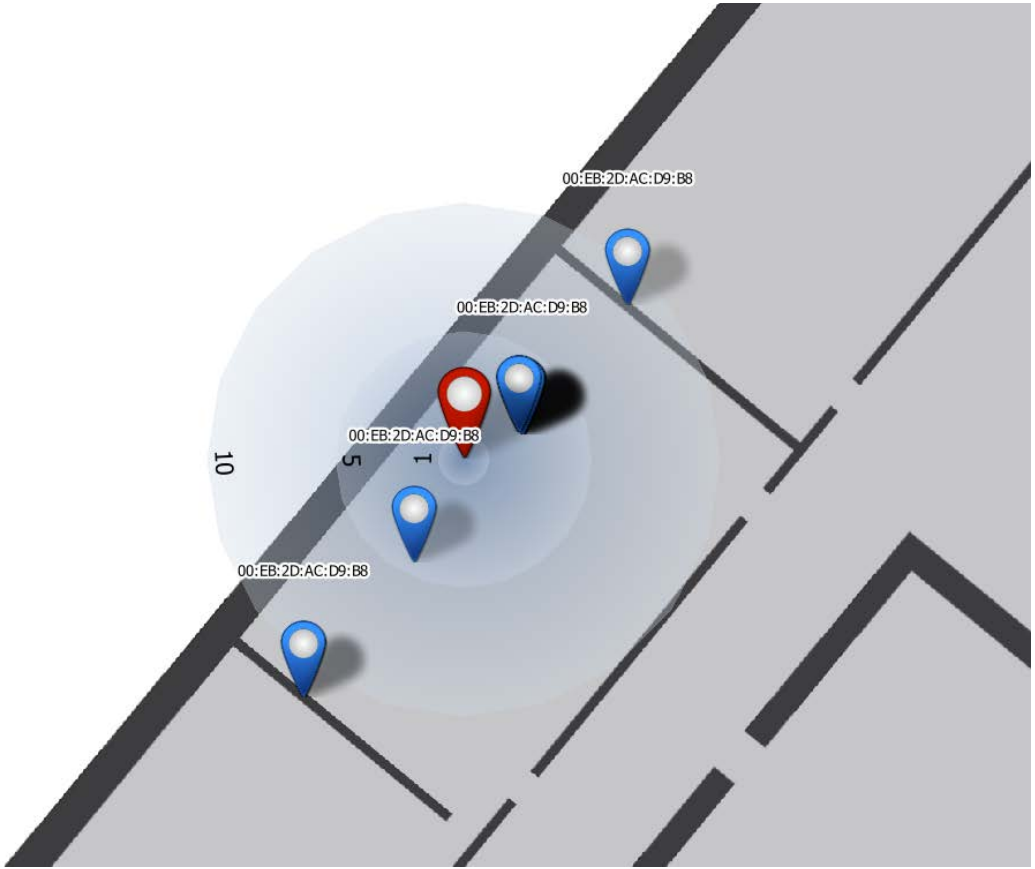
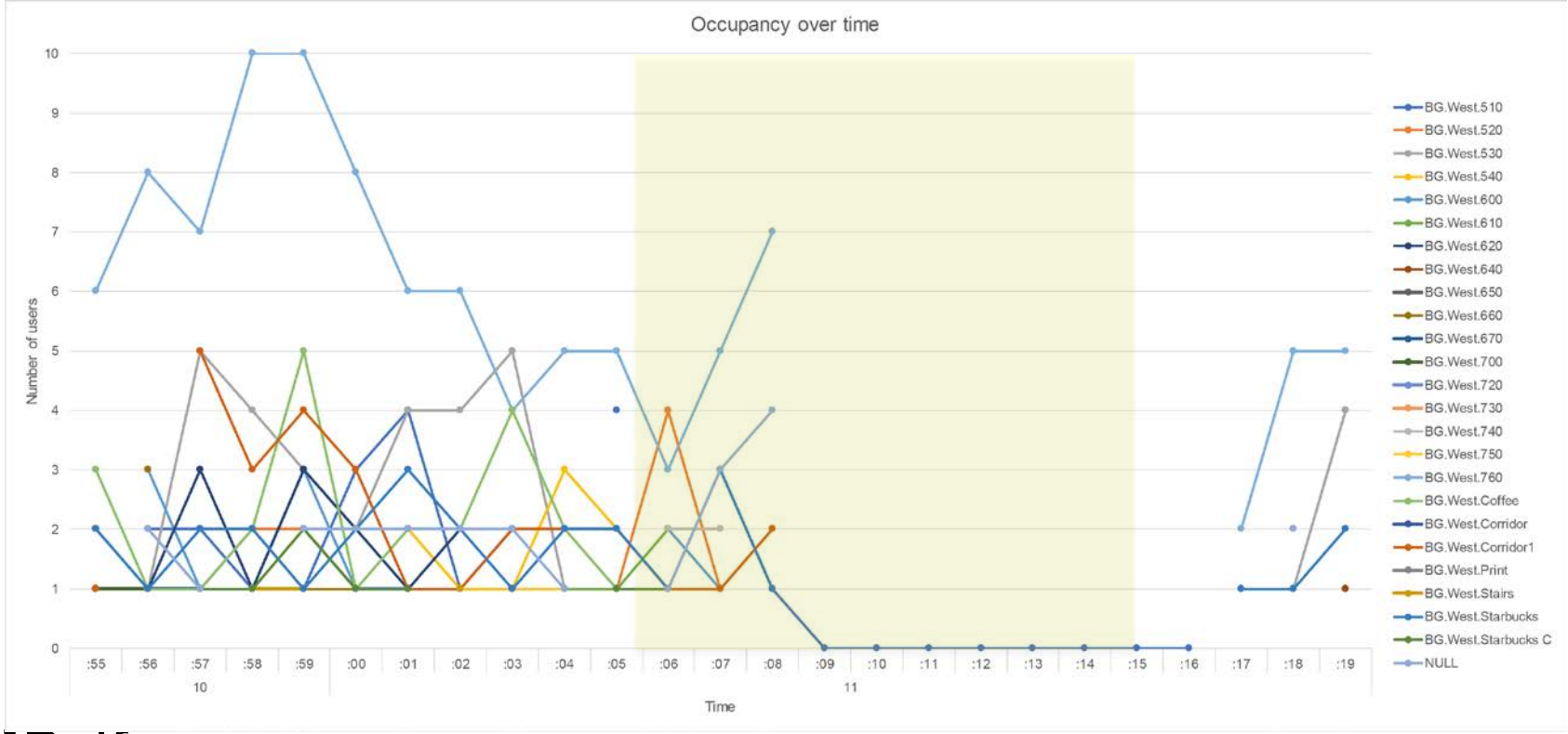
Positional accuracy

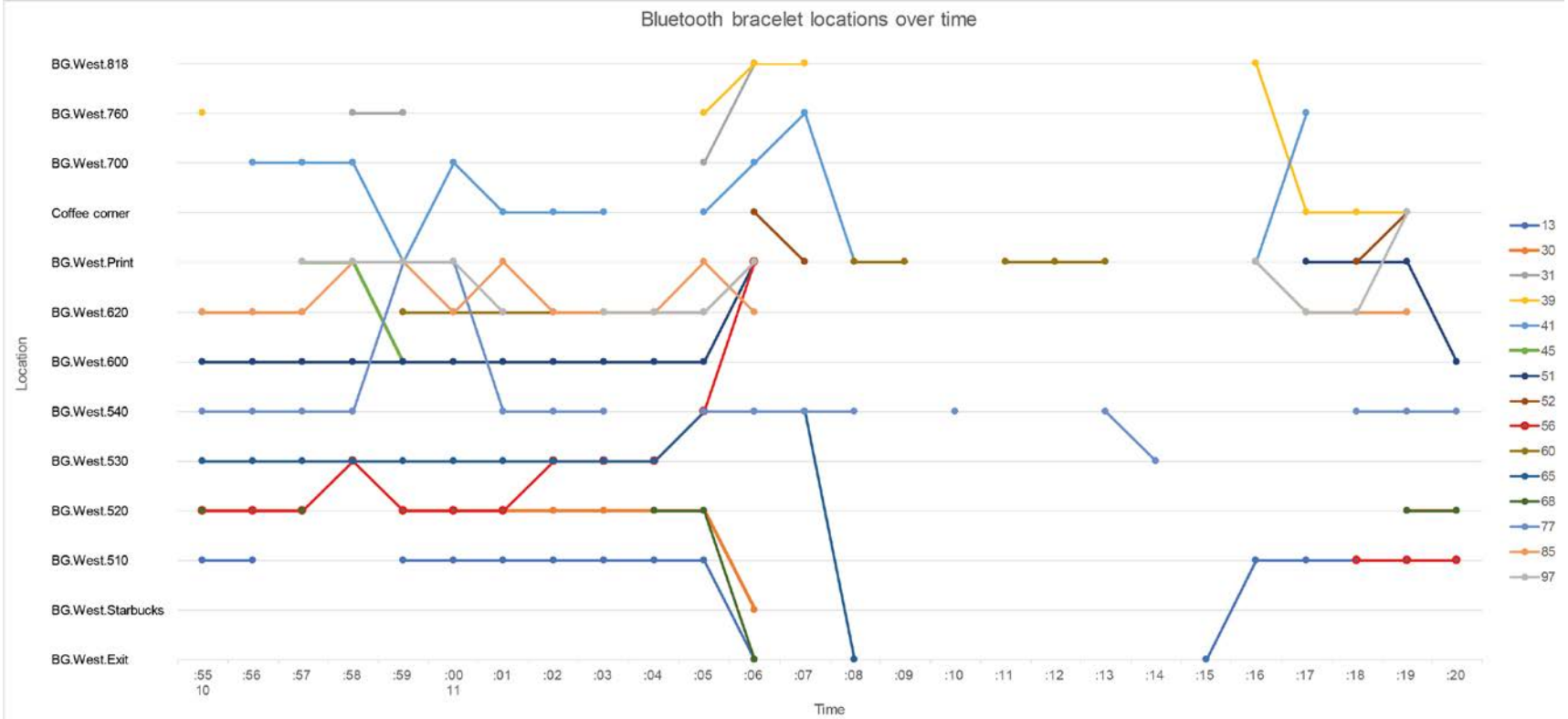


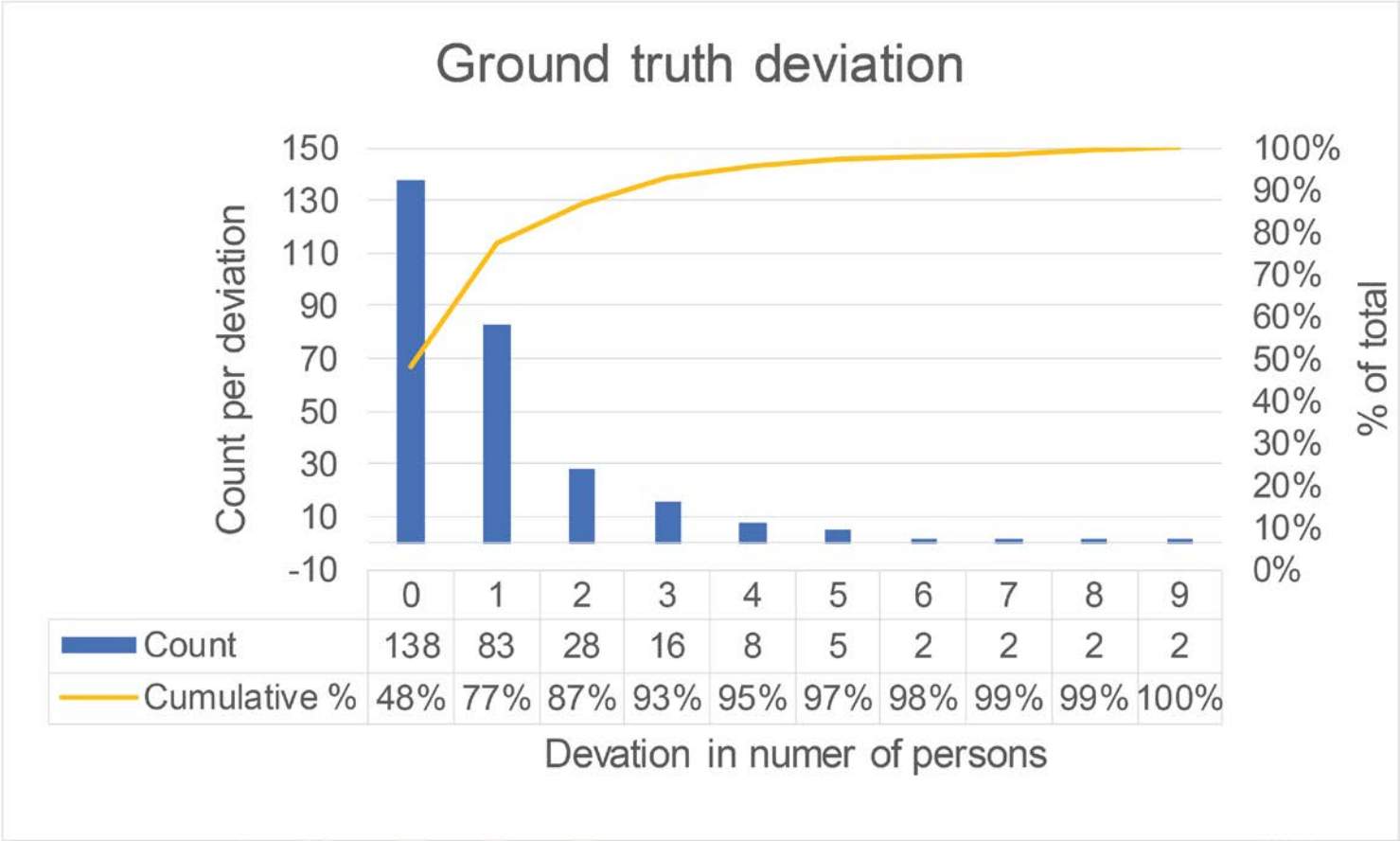
	Distances to reference point [m]
Android	2.17 2.54 4.60 8.54
iOS	11.54

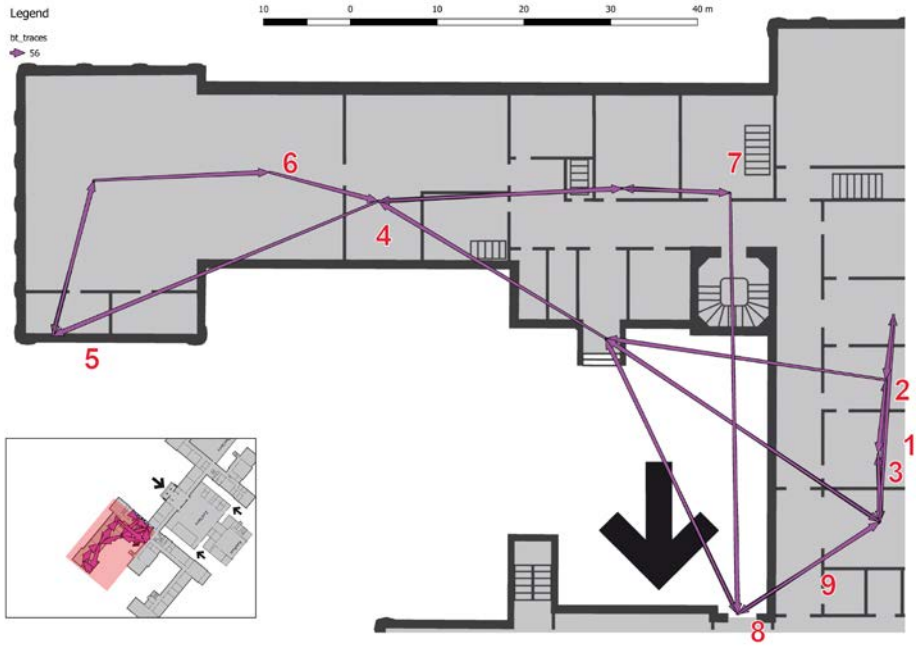
Occupancy rhythms

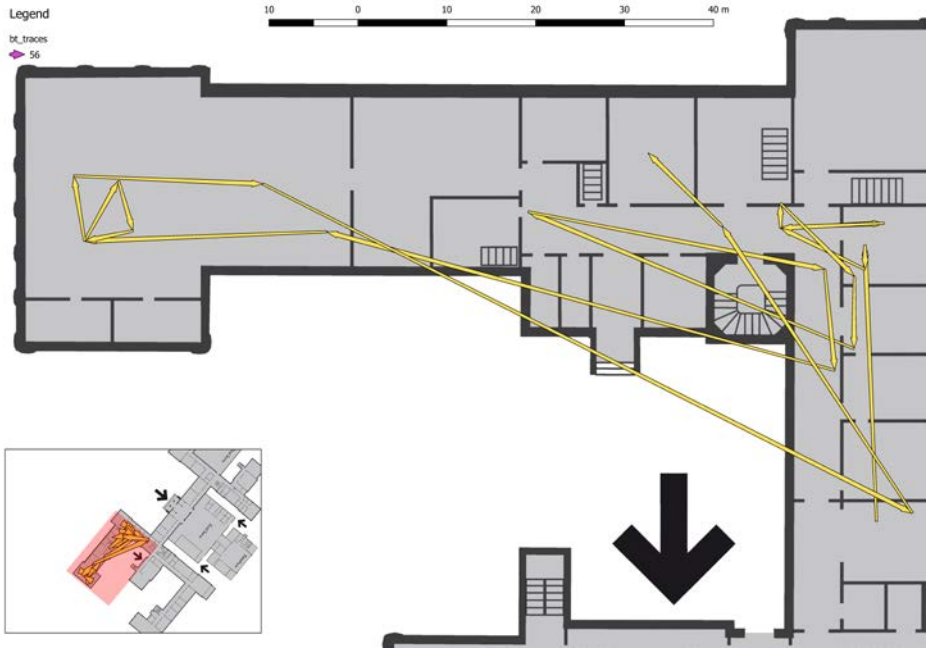


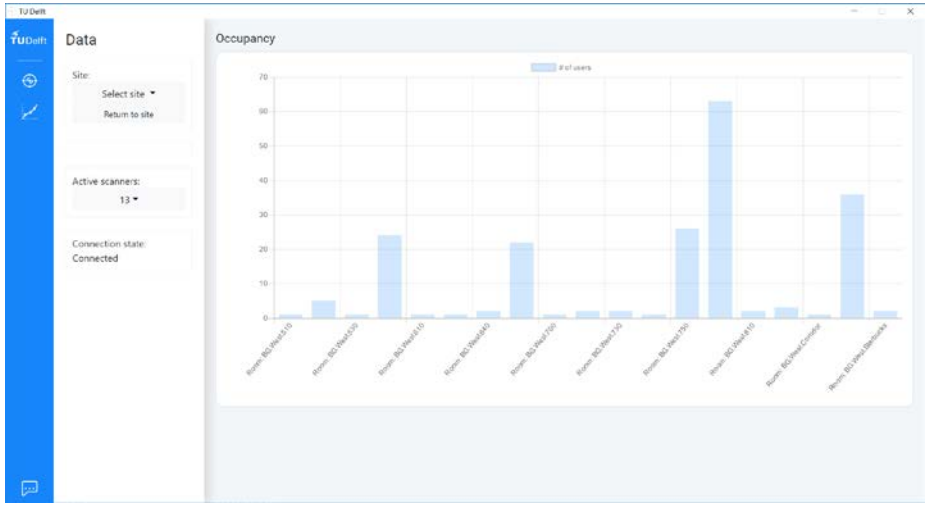
Bluetooth locations

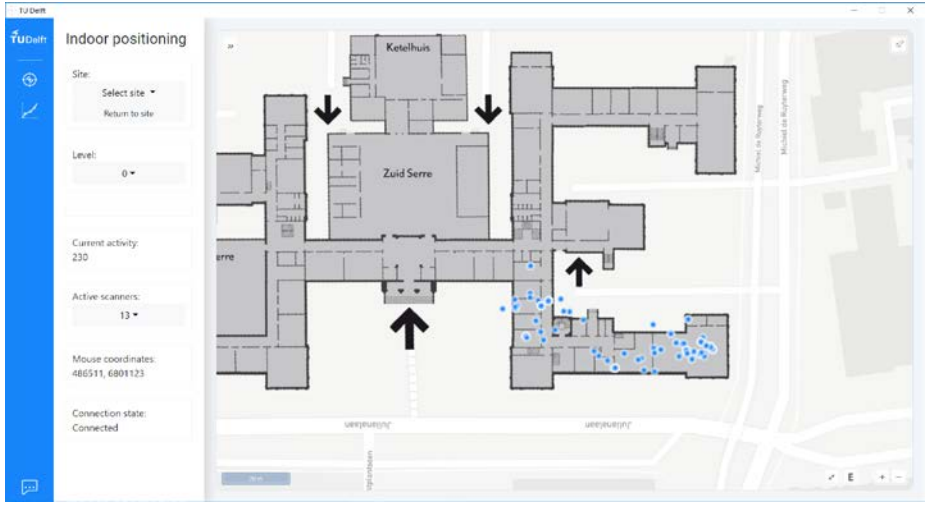



Ground truth deviation
Count per deviation
150
130
110
90
70
50
30
10
-10
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% of total
0 1 2 3 4 5 6 7 8 9
Count 138 83 28 16 8 5 2 2 2 2
Cumulative % 48% 77% 87% 93% 95% 97% 98% 99% 99% 100%
Devation in numer of persons


Legend
bt_traces
56
10
0
10
20
30
40 m
6
7
4
5
2
1
3
9
8


Legend
bt_traces
56
10
0
10
20
30
40 m


TU Delft
Data
Site:
Select site
Return to site
Active scanners:
13
Connection state:
Connected
Occupancy
# of users
70
60
50
40
30
20
10
0


TU Delft
Indoor positioning
Site:
Select site
Return to site
Level:
0
Current activity:
230
Active scanners:
13
Mouse coordinates:
486511, 6801123
Connection state:
Connected
Ketelhuis
Zuid Serre

Challenges

- Frequency of probe requests
- MAC randomisation

Conclusion

Occupancy

- Differential correction parameters improve the positioning accuracy to room-level
- Occupancy can be monitored in real-time through Wi-Fi on the scale of individual rooms
- Real-time information during emergencies

Movement patterns

- Movement patterns can be detected with the use of mobile devices

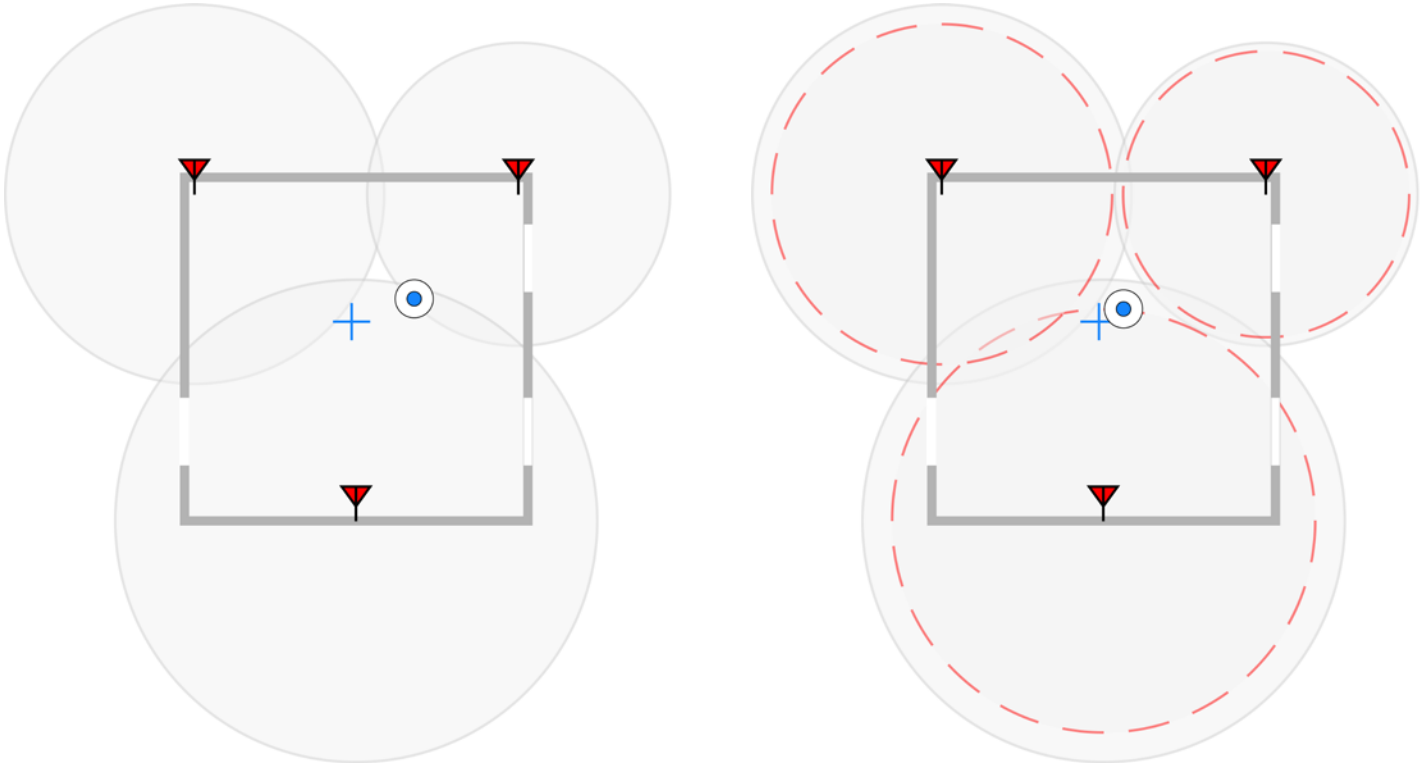
- Temporal resolution varies according to device activity and window size

Limitations of the system and future work

- No connection with existing Eduroam
- Current methods can be implemented on an existing infrastructure
- Movement patterns do not show abscence

Questions

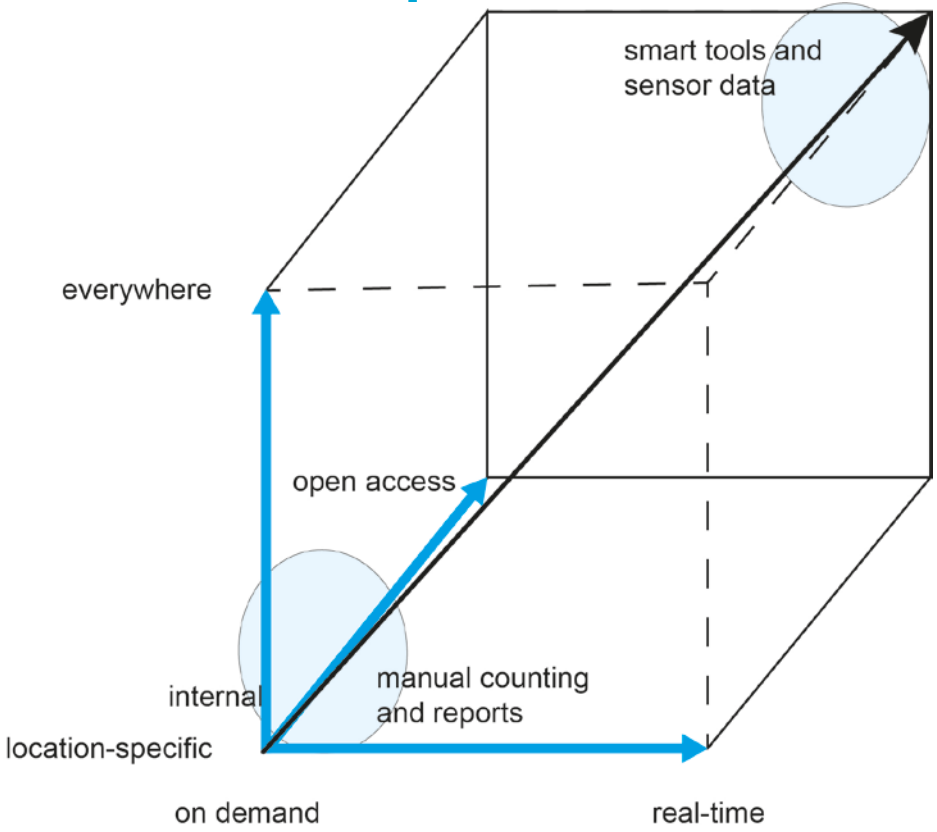
Differential correction and ranging



Sum of occupancy	Column Labels																												
Row Labels	BG.West.510	BG.West.520	BG.West.530	BG.West.540	BG.West.600	BG.West.610	BG.West.620	BG.West.640	BG.West.650	BG.West.660	BG.West.670	BG.West.700	BG.West.720	BG.West.730	BG.West.740	BG.West.750	BG.West.760	BG.West.Coffee	BG.West.Corridor	BG.West.Corridor1	BG.West.Print	BG.West.Stairs	BG.West.Starbucks	BG.West.Starbucks C	
10	6	7	15	6	8	1	9	5	0	5	2	2	1	2	4	1	41	12	0	13	0	3	8	4	
:55	0	2	2	0	0	0	1	1	0	0	0	1	0	0	0	0	6	3	0	1	0	0	2	0	
:56	2	0	1	2	3	0	1	1	0	3	1	1	1	0	0	1	8	1	0	0	0	1	1	0	
:57	2	1	5	1	1	0	3	1	0	0	1	0	0	1	1	0	7	1	0	5	0	0	2	1	
:58	1	2	4	1	1	1	1	0	0	1	0	0	0	0	2	0	10	2	0	3	0	1	2	1	
:59	1	2	3	2	3	0	3	2	0	1	0	0	0	1	1	0	10	5	0	4	0	1	1	2	
11	22	10	25	12	6	7	9	5	1	4	2	0	4	3	5	3	61	16	4	15	2	2	21	4	
:00	3	1	2	0	1	1	2	1	0	1	0	0	1	0	0	0	8	1	0	3	1	0	2	1	
:01	4	0	4	2	1	1	1	1	0	0	0	0	1	1	0	1	6	2	2	1	0	0	3	1	
:02	1	1	4	1	1	1	2	0	0	0	0	0	0	0	0	0	6	2	0	1	1	1	2	0	
:03	2	1	5	1	0	0	0	1	0	1	0	0	1	0	0	1	4	4	1	2	0	0	1	0	
:04	0	1	1	3	0	1	0	1	0	0	0	0	0	0	0	1	5	2	0	2	0	0	2	0	
:05	4	1	1	2	0	1	0	0	0	1	1	0	0	1	0	0	5	1	0	2	0	0	2	1	
:06	0	4	1	1	2	2	2	0	0	1	0	0	0	0	2	0	3	0	1	1	0	1	1	1	
:07	3	1	1	1	1	0	0	0	1	0	1	0	1	0	2	0	5	1	0	1	0	0	3	0	
:08	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	2	0	2	0	0	1	0	
:09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
:10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
:11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
:12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
:13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
:14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
:15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
:16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
:17	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	1	0	
:18	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	5	0	0	0	0	0	1	0	
:19	4	0	4	1	0	0	1	1	0	0	0	0	0	0	0	0	5	0	0	0	0	0	2	0	

TU Delft

Current practise and smart tools



Valks, Arkesteijn, Den Heijer, & Vande Putte, 2016