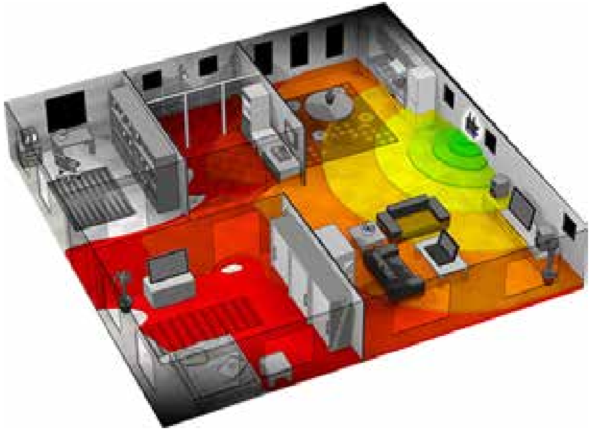
WIRELESS POSITIONING IN INDOOR ENVIRONMENTS



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Outline

- **Scope**
- **Definition - Usage Scenarios**
- **Cellular Positioning**
- **Fingerprint RSS based localisation**
  - Offline phase
  - Online phase
- **Improving overall RTLS performance**
  - Accelerate RTLS processes
  - Improve accuracy
  - Predicting Localisation Performance before deployment (!)
- **Conclusions**

Scope

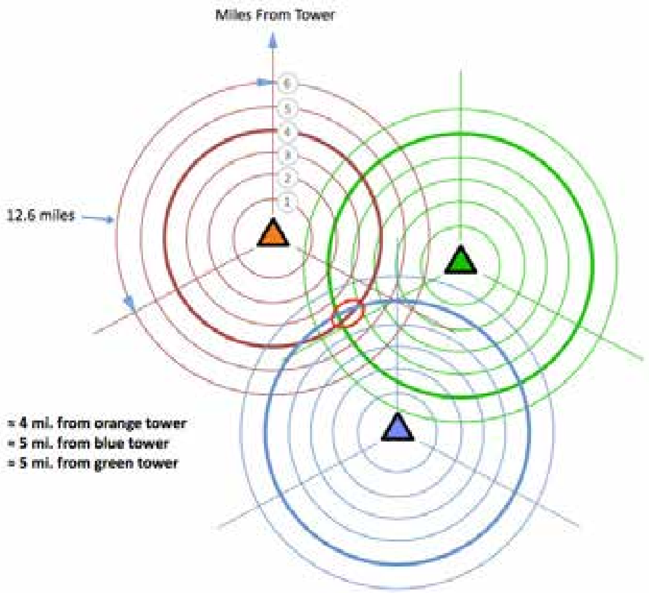
- To present and discuss radio based positioning techniques
- Expand on positioning techniques that can be used to localise wireless users (terminals) in indoor environments
- Will concentrate on Received Signal Strength (RSS) localisation methods
  - do not require special / complex hardware
  - can be implemented with off the shelf devices

Definition – Usage Scenarios

- In wireless networks localisation refers to the process of finding the location of a wireless user (terminal)
- Typical Terminology:Positioning, Localisation, Tracking
- There are many benefits when a user's position is known:
  - Users can be assisted in case of emergency
  - Novel applications can be developed (navigation, health social computing, geo-marketing etc.)
  - Wireless Network operation can be optimised (proactive handovers / load balancing)
  - Position of suspicious wireless users can be detected – Cybersecurity application extensions
  - etc...

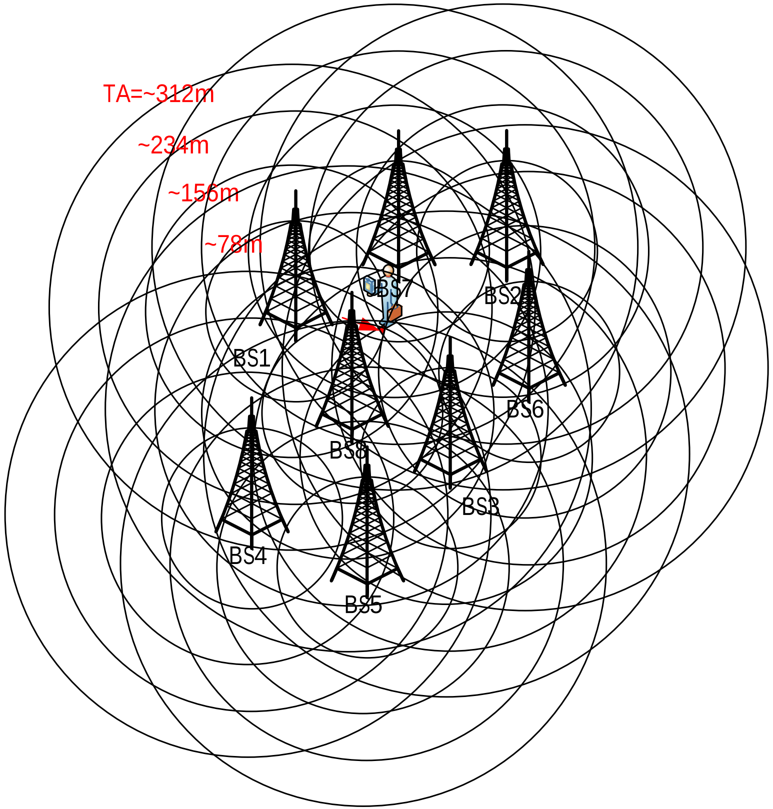
Cellular Positioning - Brief Overview

- Basic positioning methods:
  - Trilateration: Signal Strength analysis and Time of Arrival (ToA) from multiple base stations
  - Multilateration: Time Difference of Arrival (TDoA) from multiple base stations– Similar to ToA but doesn't need clock synchronisation
  - Triangulation: Angle of Arrival (AoA) from multiple stations
- Mobile or Network based techniques:
  - Mobile based techniques: Cell-ID, Timing Advance
  - Network based techniques: TDoA, AoA
  - Mobile Assisted techniques: Assisted-GPS, Advanced Forward Link Trilateration (AFLT), Enhanced / Observed Time Difference (OTD/EOTD)
- Typical cellular positioning methods can provide localisation accuracies of 10s of meters -> several km



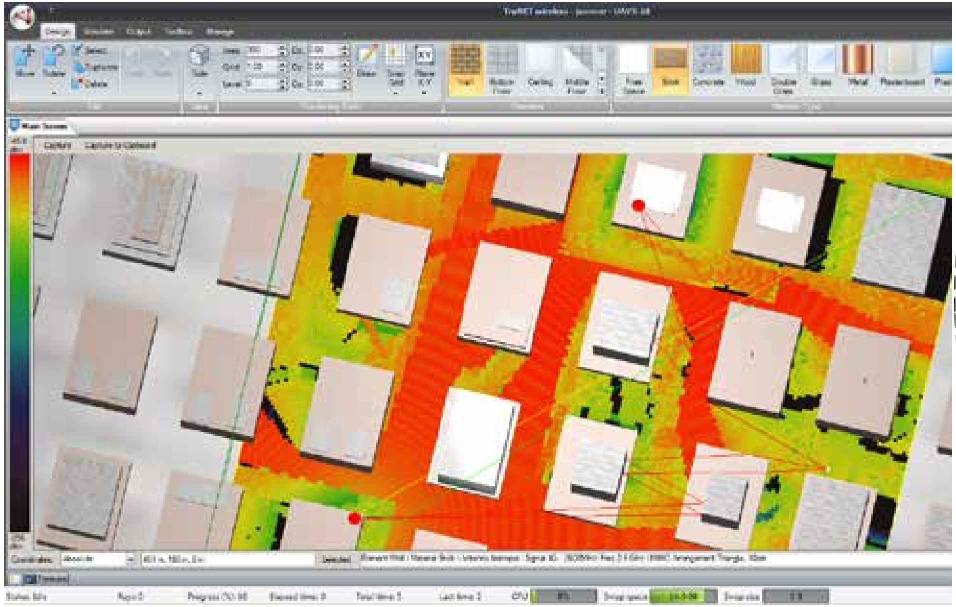
Cellular technologies and Indoor Positioning

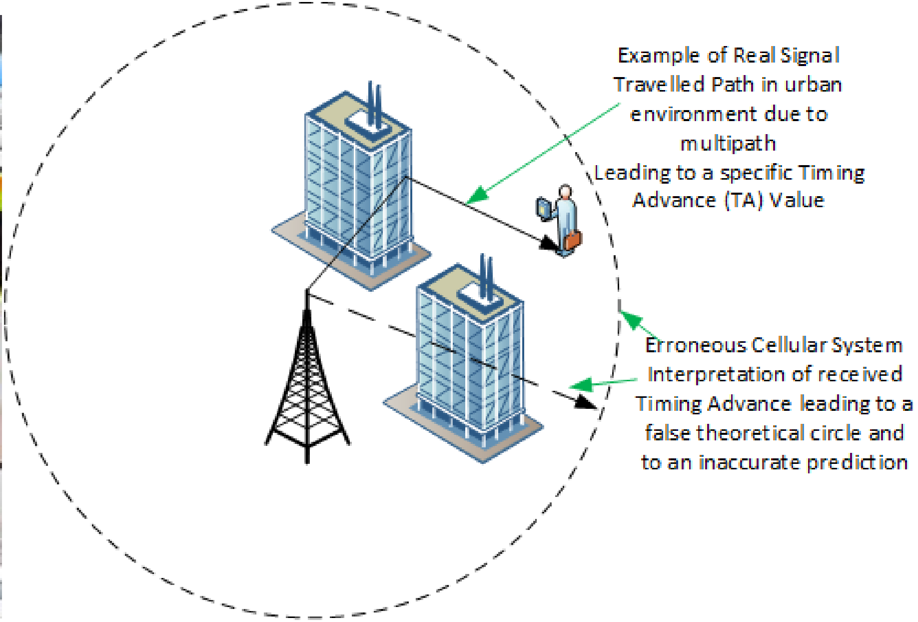
- Can it be currently used? Yes and No
- If network density is high - base stations relatively close to each other - one may currently identify the building a user is located (Positioning accuracy of several 10ths of meters) / a rough approximation of its location.
- If cost of infrastructure, and interference is not an issue, one can expect that in very high density networks (e.g. base station every 10ths of meters to a ~100m) positioning accuracy from trilateration techniques will further improve



Cellular technologies and Indoor Positioning

- To practically increase the positioning accuracy one has to consider though the building databases and the exact paths travelled through ray tracing pre/post processing path estimations

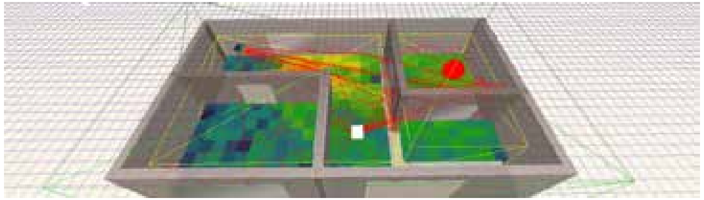




Ray Tracing Simulation of a real Environment with TruNET wireless

Fingerprint-based RSS indoor positioning techniques

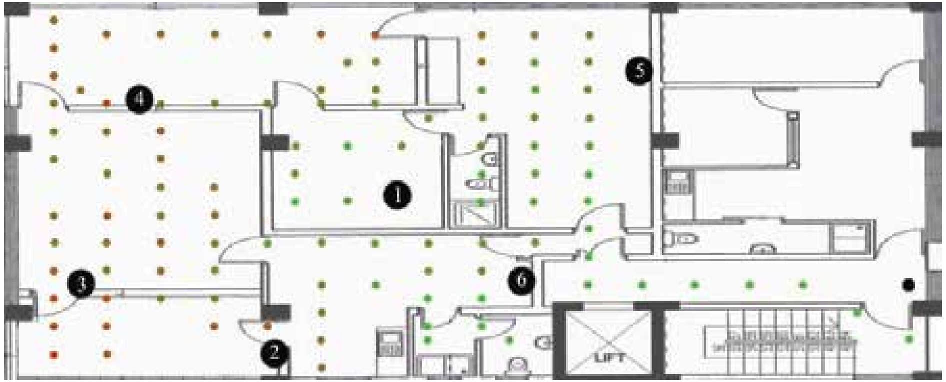
- If a few meter accuracy is required, e.g. for indoor navigation one has to look into non cellular localisation methods
- We will be looking into RSS fingerprint based methods (based on off the shelf technologies, e.g. 802.11, BLE)
- Typically require an offline and an online phase
- During the offline phase, the fingerprint radio-map is generated, either through RSS measurements or accurate / calibrated simulations
- During the online phase, real time RSS measurements are performed by the Mobile Station (MS) and are compared with the fingerprint entries of the fingerprint radio-map in order to estimate the location of the user



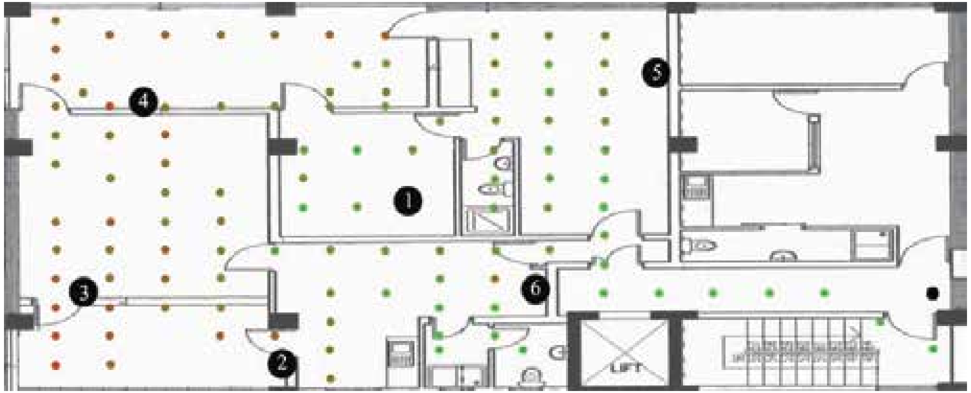
Offline Phase

- Offline Phase (Fingerprint Radio map Generation)
  - A database is constructed either by actual measurements or simulations
  - It includes a number of signal related parameters for a known set of coordinates

# X	Y	MAC Address of AP	RSS(dBm)
16.89368	9.98398	00:21:29:93:3b:a7	-78
16.89368	9.98398	5c:d9:98:20:0c:c6	-92
16.89368	9.98398	00:03:6f:88:a8:dd	-90
16.89368	9.98398	00:1e:58:ab:f5:05	-82
16.89368	9.98398	5c:d9:98:20:0c:da	-88



Online Phase



Online Phase – User (terminal) Localization

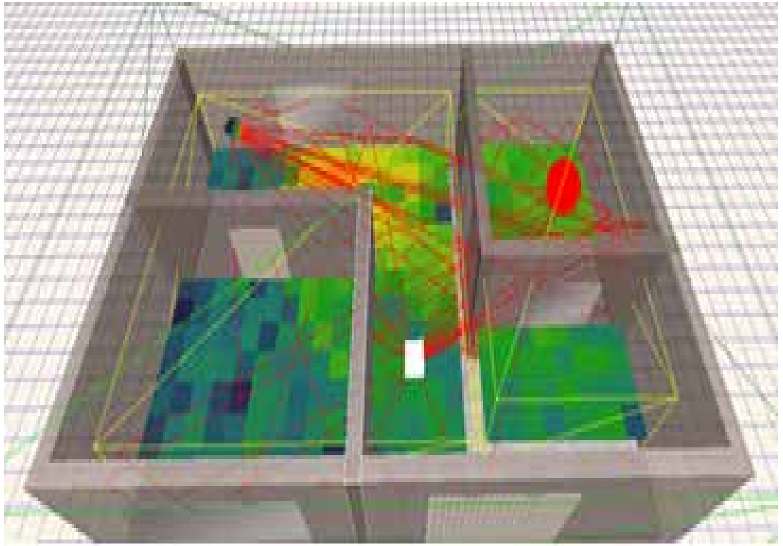
- The user's terminal, or the network infrastructure, measures and records the RSS for comparison purposes with the offline fingerprint database
- The user's position is estimated by localisation algorithms, e.g. K-Nearest Neighbour (KNN), Weighted K-nearest Neighbour (WKNN), Minimum Mean Square Error (MMSE)

Improving overall Real Time Location System (RTLS) performance

- In RSS based methods a number of issues has to be addressed to improve the overall performance. Some of the issues include:
  - Accelerating fingerprint database creation
  - Improving localisation accuracy and process
  - Developing Performance Evaluation Procedures for Predicting RTLS performance before RTLS deployment (!)
- 802.11 / BLE case studies

1. Accelerating fingerprint database creation

- Radio measurements for creating RSS fingerprint databases can be a lengthy and time consuming process for large environments
- Fingerprint databases have to be recreated in case of changes of the radio network setup or if the environment changes
- A good alternative is to utilise realistic radio planning tools based on calibrated ray tracing models
- Fingerprint databases can be easily updated in case of changes in the radio network setup or the environment



2. Improving RTLS Performance by Imposing Map Constraints

Methodology

- Potential accuracy improvements by imposing map-constraints into the positioning algorithm in the form of a–priori knowledge
- One can use a Route Probability Factor, which reflects the possibility of a user, to be located on one position and route instead of all others

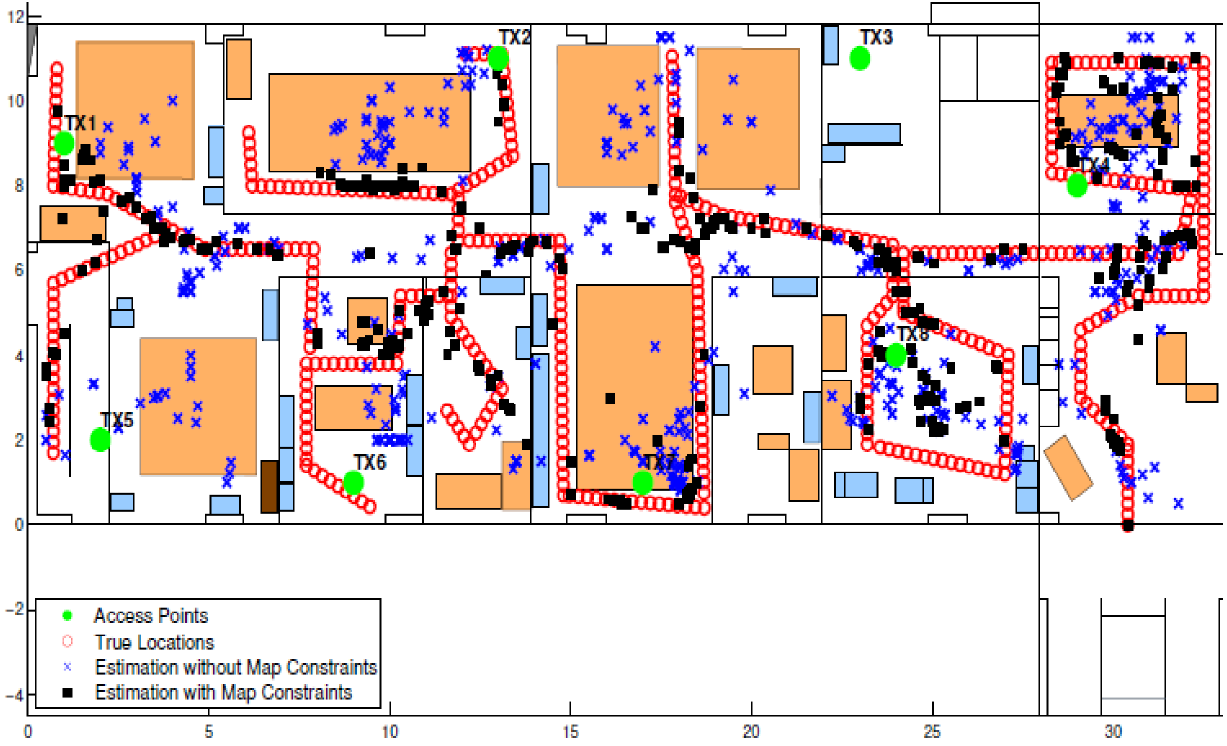
Generation of Fingerprint Database

Use of a 3D Ray Tracing simulator:

- Generated by **TruNET wireless** a deterministic 3D polarised Ray Tracing simulator (www.fractalnetworx.com)
- 1584 isotropic receivers (Rx) equally-spaced with a step of 0.5m, at a height of 1.5m
- 8 Wi-Fi (2.4GHz) APs /Omni-directional antenna at a height of 2.2m

2. Improving RTLS Performance by Imposing Map Constraints

Position Estimates Along the Test Route



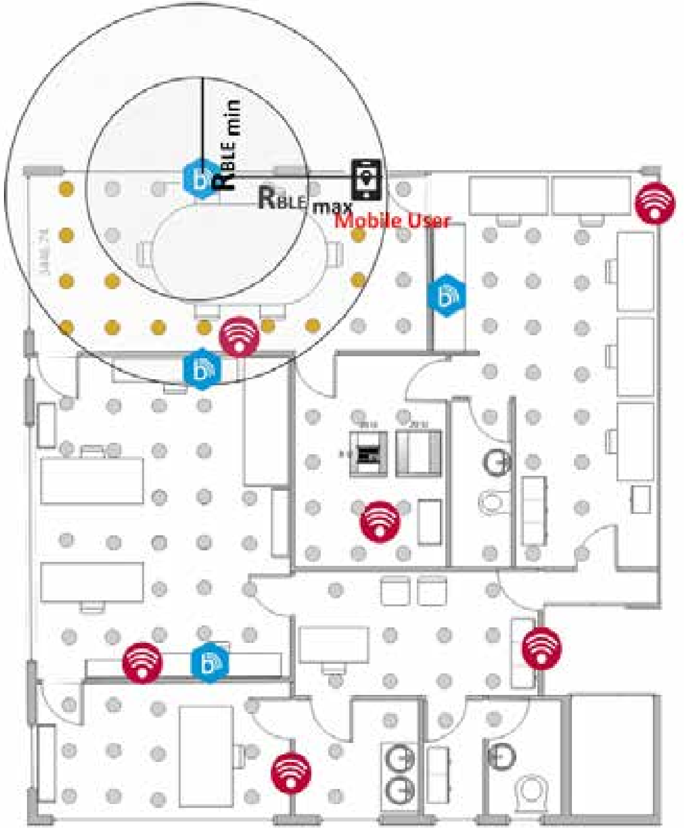
	Mean positioning accuracy (error) [WKNN Algorithm, K=5]
w/o Map Constraints	2.03m
with Map Constraints	1.46m

2. Improving RTLS Performance by Fusing other radio Data

- One can fuse and process RSS information from different radio systems such as 802.11 and BLE for the purpose of improving the localization process

- RSS fusion from a medium range radio system (802.11) and a short radio system (BLE) can provide to localisation algorithms smaller RSS fingerprint data subsets

- Procedure can lead to faster and more accurate localisation times.



2. Improving RTLS Performance by Fusing other radio Data

- Android Smartphone Localisation Application

Test Point	$e_{average}(m)$	σ	*Radiomap size (%)*
1	5.09	2.96	100
2	2.45	1.79	100
3	3.81	2.15	100
4	4.70	3.76	100
5	4.15	2.56	100
6	6.55	2.26	100
7	5.21	2.02	100
8	2.91	1.56	100
9	5.61	2.02	100
10	3.50	1.58	100
11	3.02	1.01	100
12	2.58	1.72	100

- Positioning error of WiFi RSS fingerprint based positioning system

Test Point	$e_{average}(m)$	σ	*Radiomap size (%)*
1	1.96	1.44	22
2	1.70	0.93	12
3	1.22	0.81	12
4	1.52	0.62	16
5	2.38	1.14	12
6	2.12	0.63	16
7	2.33	0.67	16
8	2.91	0.65	12
9	3.84	1.89	37
10	3.17	0.79	22
11	2.97	1.26	28
12	1.87	0.55	19

- Positioning error of Combined BLE and WiFi RSS fingerprint based positioning system

3. Evaluating Fingerprint Based RTLS Performance

- So … we are planning to deploy a Fingerprint based RTLS system. Can we evaluate its performance before deployment?

- A variety of factors can affect positioning accuracy:
  - Radio Network setup
  - Technology and equipment used
  - Positioning algorithms
  - Dynamic nature of the environment

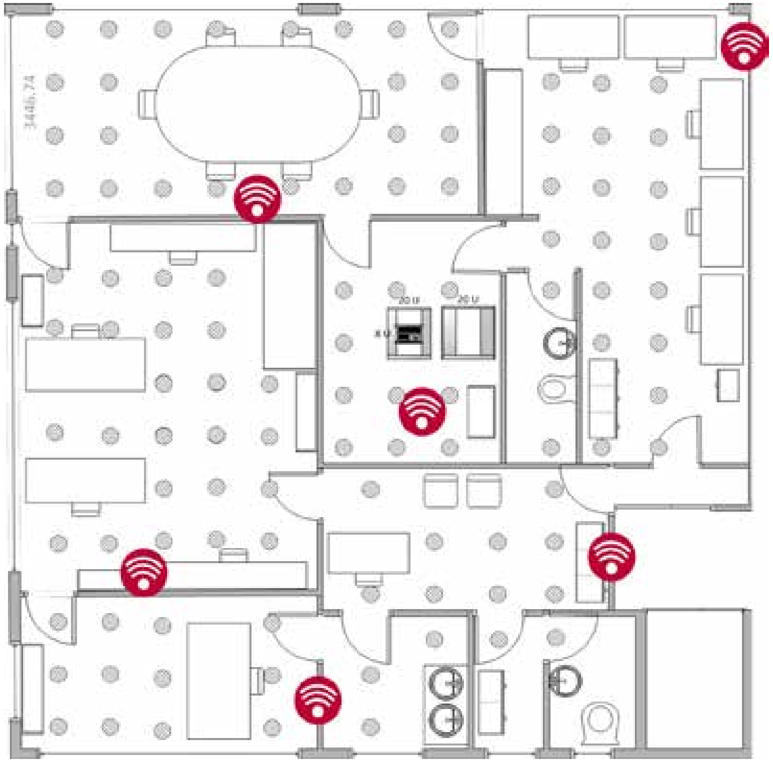
3. Indoor RTLS Evaluation in Literature

- In literature different suggestions have been made to classify and benchmark RTLS localization performance. Work presented in the literature tends to:
  - Categorize the environment in an effort to characterize performance in similar environments
    - approach cannot be generalized due to the variance of indoor environments
  - Create large databases of scenarios that can be used to analyze similar scenarios
    - one still cannot describe all possible scenarios
  - Enumerate critical factors, describe the influence of building structures / scenario layout vs the performance of positioning algorithms
    - work does not examine the impact and the relation to each other.
- We need to somehow be able to generically evaluate and optimize localization setups **before deployment**

3. Evaluating RTLS performance For New Deployments

- Solution?
- Developed an algorithm that evaluates the fingerprint data, without having to evaluate the final output accuracy of the positioning algorithms
- Estimates the degree of correlation between each pair of fingerprint entries in the radiomap in order to assess their uniqueness.
- One is able to assess the impact of how network or environment modifications influence the performance of the RTLS, and then decide which is the best RTLS configuration to deploy
- By applying this process, one has the opportunity to modify the network infrastructure and improve the "positioning quality" of the initial input data

Test Scenarios

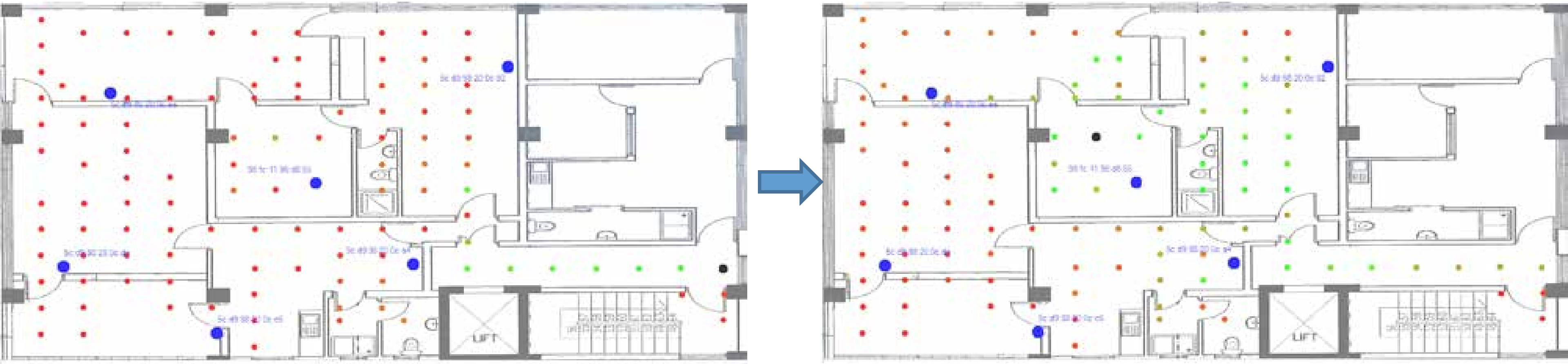


Study Area: 160 m^2

Wireless Network: 6 APs

- Evaluation Tool
  - Developed to implement the proposed algorithm and graphically generate the radio-map signatures
    - Can be populated either through measurements or realistic ray tracing simulated data

3. Evaluating RTLS performance For New Deployments

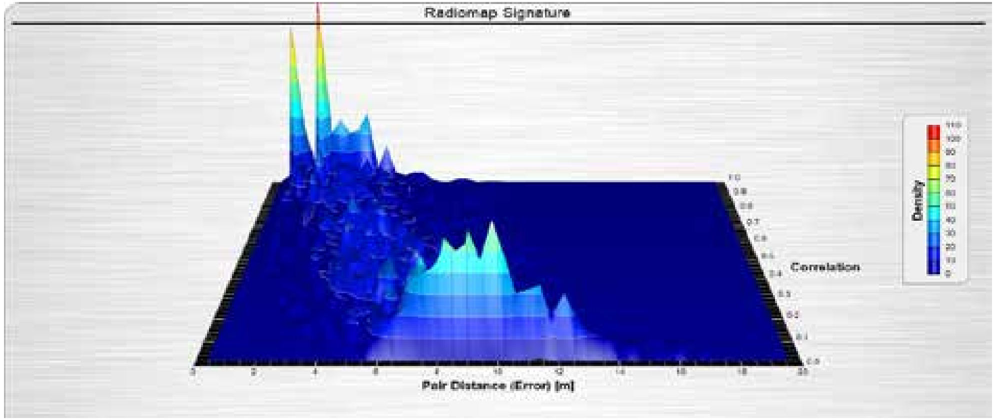


- Large blue dots illustrate position of Aps
- Medium black dot illustrate selected fingerprint
- Small Green to Red dots indicate other fingerprints and level of correlation w.r.t. black dot. Green means high correlation, Red means low correlation

Performance Evaluation

- The **effectiveness** of the proposed algorithm was assessed by comparing the changes in the quality of radiomap signatures with respect to:
  - Different numbers of APs
  - Various levels of RSS tolerance
- The outcome is also **compared** with the resulting positioning error, when Weighted K-nearest Neighbour (WKNN) and Minimum Mean Square Error localization algorithms are implemented.

Performance Evaluation



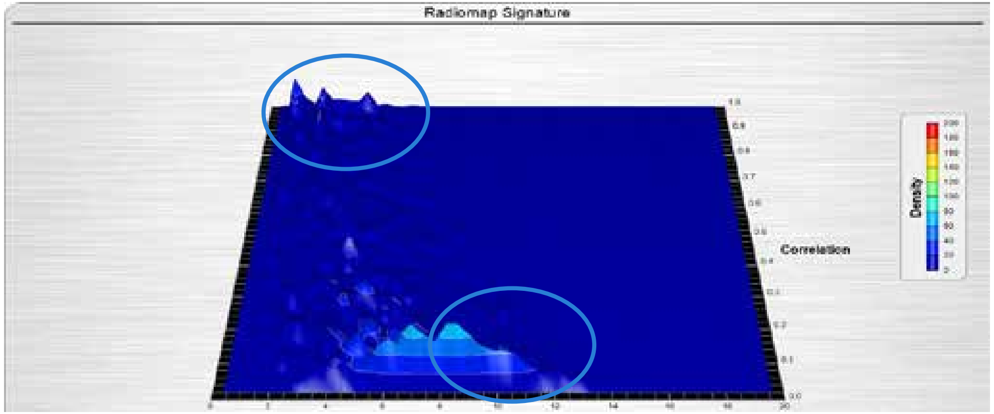


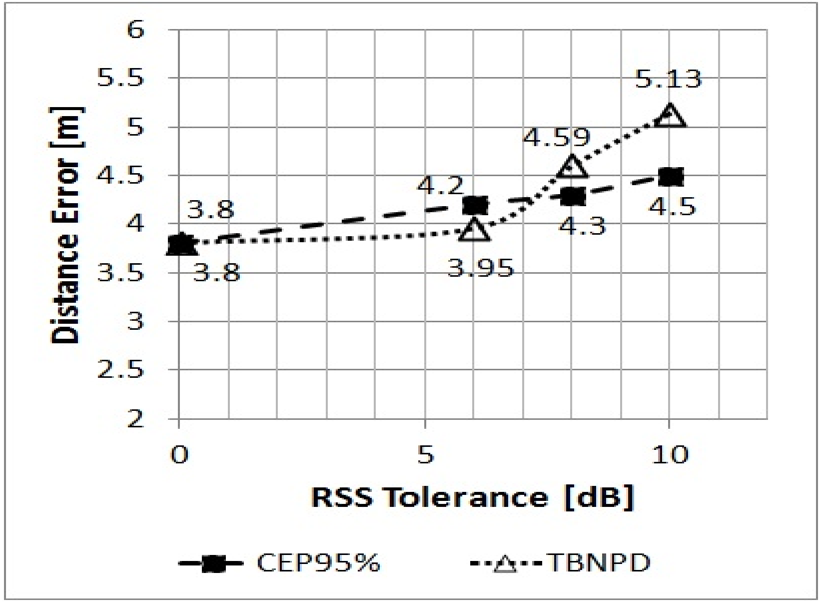
TABLE II
RADIOMAP QUALITY EVALUATION USING TBNPD ALGORITHM: NUMBER OF APS: 3 APS VS. 6 APS AT $RSS_{tol} = \pm 2dB$

Radio map	APs	$E_{weighted}$	σ_E
Empirical	**3**	4.60	2.46
	6	3.96	2.19
Simulated	**3**	4.61	2.47
	6	3.65	2.16

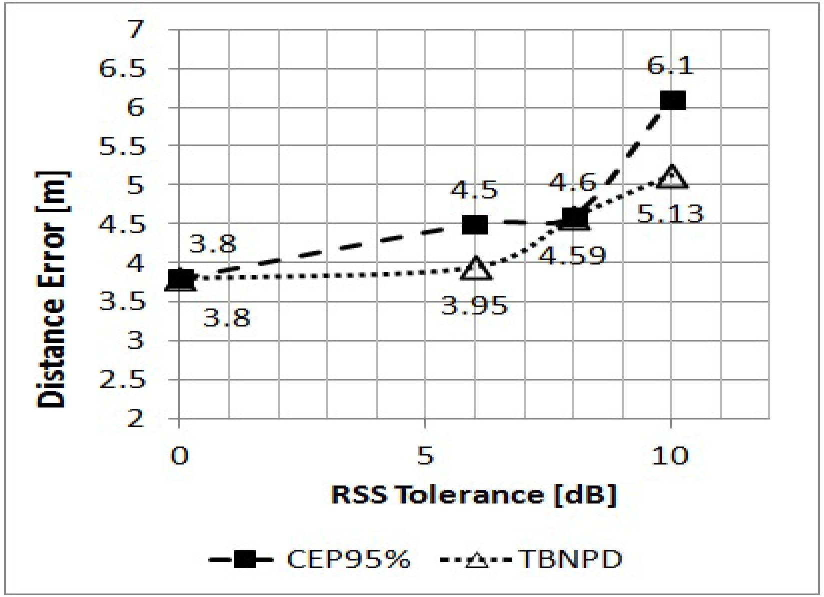
HIGH Correlation LOW Error	HIGH Correlation MEDIUM Error	HIGH Correlation HIGH Error
MEDIUM Correlation LOW Error	MEDIUM Correlation MEDIUM Error	MEDIUM Correlation HIGH Error
LOW Correlation LOW Error	LOW Correlation MEDIUM Error	LOW Correlation HIGH Error

Performance Evaluation

Comparison with WKNN and MMSE localization algorithms



Weighted K-nearest
Neighbor (WKNN)



Minimum Mean
Square Error (MMSE)

Conclusions

- In the near future cellular communications might be used for indoor localisation purposes
- Currently, to achieve radio based localisation in indoor environments 802.11 and BLE off the shelf networks can provide good results
- The usage of advanced ray tracing tools can assist cellular, 802.11 and BLE technologies to optimise localisation processes
- Equally important to the RSS localisation process are methods that evaluate the RTLS performance before deployment. Correlation algorithms like the one presented can **evaluate the input fingerprint data**, rather than the **output of the positioning algorithms**
- The proposed methodology provides the possibility to assess the quality of any radiomap with respect to: (a) number of active APs, (b) different geometrical deployments, and (c) various RSS fluctuation levels
- Different fingerprint radiomaps can be compared and **best performer can be chosen to be the input to the RSS based RTLS platform**, in order to improve its positioning accuracy.

Thank You

Questions?