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Impact of Realistic Indoor Mobility Modelling in the Context of Propagation Modelling on the User and Network Experience

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Outline

1. **Introduction**
   - Motivation
   - Modelling of Individual User Behaviour
   - Analysis Methodology
   - Simulation Scenario
   - Prediction Modelling
2. **Developing the Indoor Mobility Model**
3. **User Experience**
4. **Network Experience**
5. **Conclusion and Outlook**

Introduction and Motivation

Usage of mobile terminals has changed

- Approx. 80% of the mobile traffic is delivered to indoor environments
- Forecasts say that this trend will even continue

Networks need to adapt to the situation

- Deploy new technology, more spectrum, smaller cells (femto cells) etc

→ Much more complex network planning and network architecture

→ Need for Self-Organising Networks (SON)

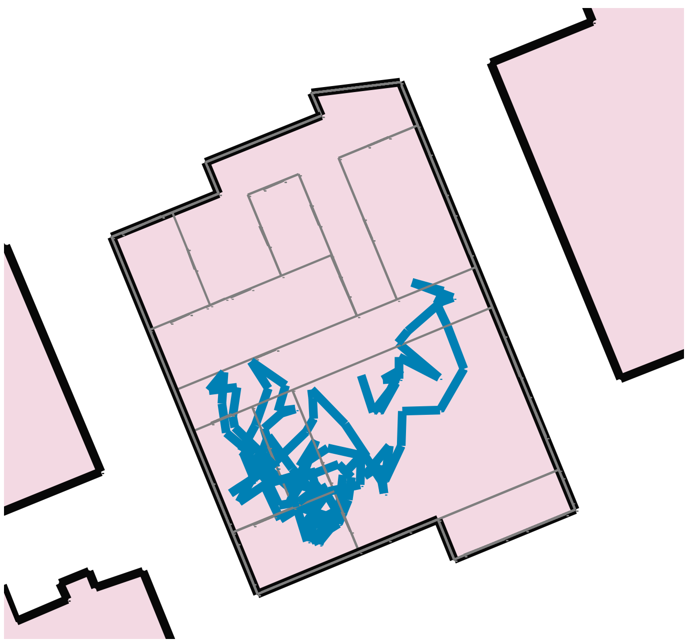
What is necessary to simulate and design such networks realistically?

- Accurate predictions for site planning
  → e.g. Ray-optical models (state of the art)
- Modelling of individual user behaviour
  → Random walk, random waypoint, ETSI indoor office model → realistic?
  → Proposal for a new three dimensional indoor mobility model

Modelling of Individual User Behaviour

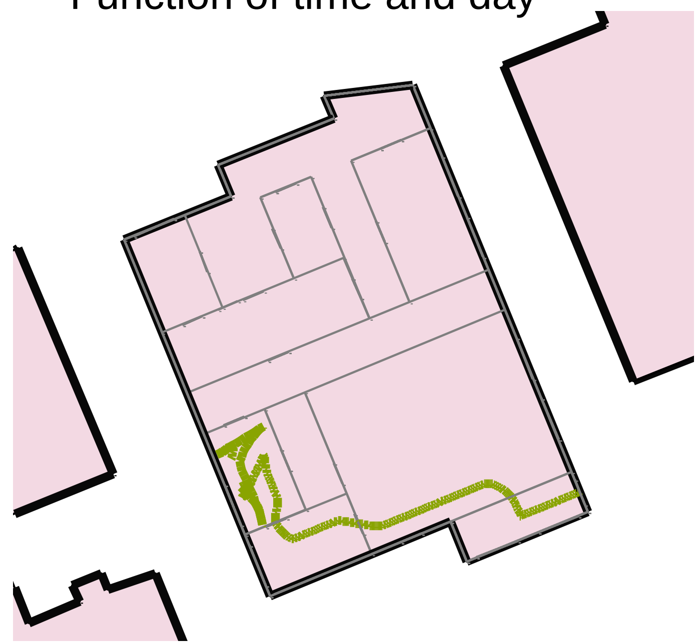
Random walk model

- Random direction and speed
  - Permanent movements
  - Movements not constrained by buildings or walls



Indoor mobility model

- Realistic user movements and behaviour
  - Real building data
  - Times of movement and stationarity
  - Differentiation of living/working areas
  - Function of time and day



[1] Rose, Dennis M.; Jansen, Thomas; Hahn, Sören; Kürner, Thomas, "Impact of realistic indoor mobility modelling in the context of propagation modelling on the user and network experience", 7th European Conference on Antennas and Propagation (EuCAP), 2013

Analysis Methodology

"Impact of Realistic Indoor Mobility Modelling in the Context of Propagation Modelling on the User and Network Experience"

Methodology

- Individual analysis of the user experience
  - Predicted signal strength over time
  - Statistical comparisons of signal strength and best server changes
- Analysis of the network experience
  - Number of handover events, depending on hysteresis and time-to-trigger

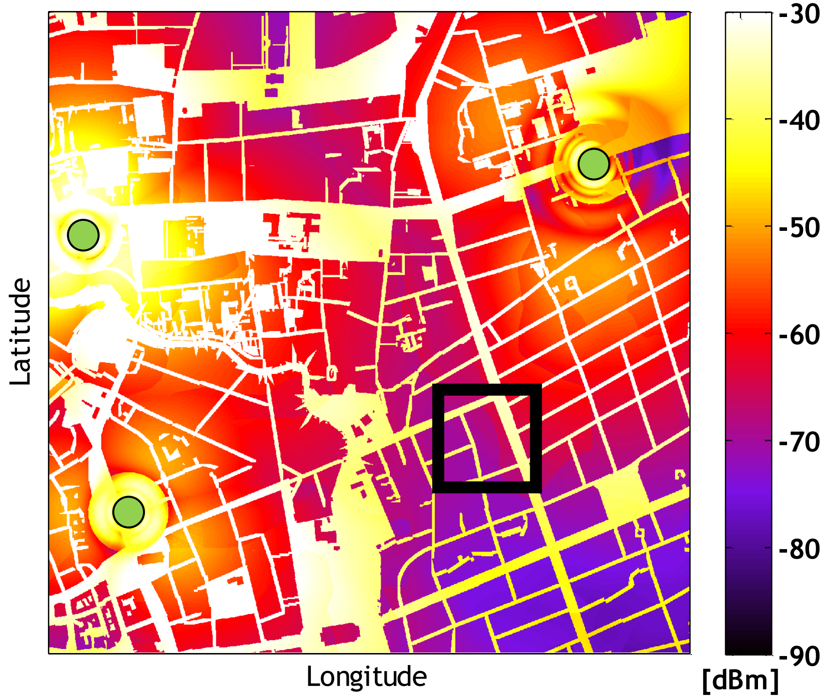
Considering all combinations of

	Random walk	Indoor mobility
Extended Hata	x	x
Ray-optical with O2I mapping	x	x

Simulation Scenario

Based on a real network (GSM 1800)

- Small part of the city of Braunschweig, Germany (1.5x1.5 km²)
- Covered by several macro cells
  - The 8 strongest sectors in the marked area have been considered (3 sites)
  - Approximately equal distance to the sites
  - Area: 200x200 m²
- EIRP ranges from 59 to 62 dBm
- Equal antennas
  - Gain of 18 dBi
  - Horizontal half-power beamwidth of 65 degrees



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Prediction Modelling

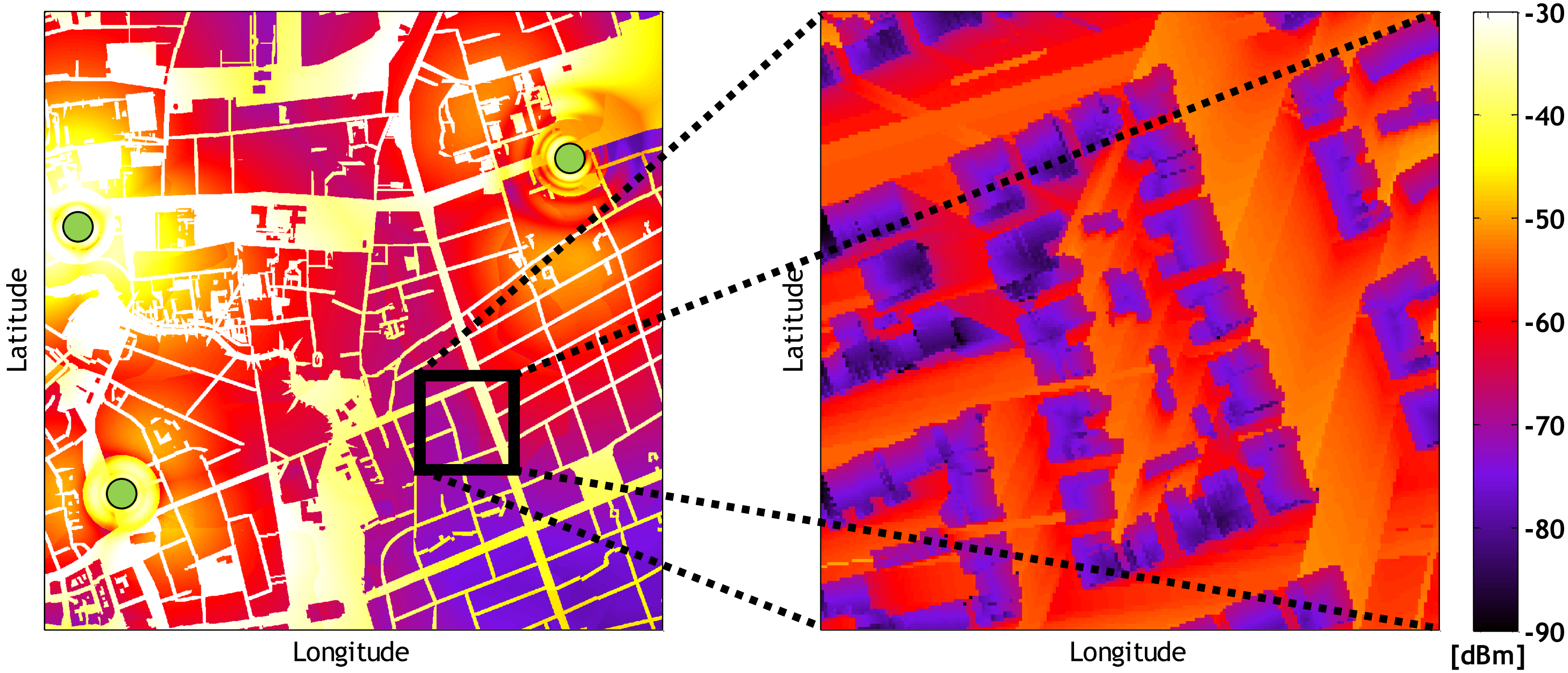
Spatial resolution of 1 m

Extended Hata model

- Spatially homogenous coverage

Ray-optical model with O2I mapping

- More heterogeneous coverage



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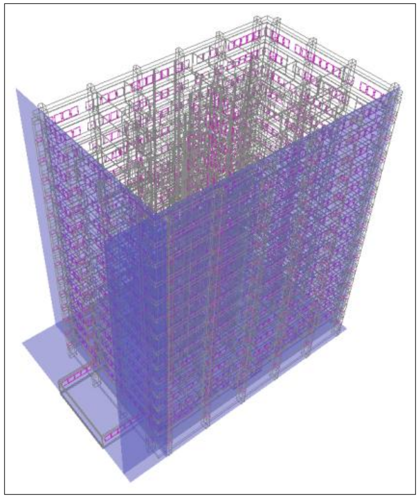
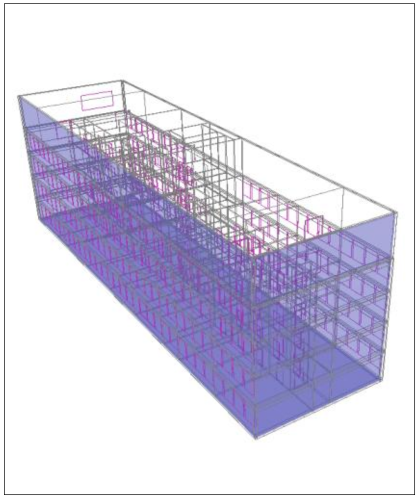
1. Introduction
2. **Developing the Indoor Mobility Model**
   - 3D Building Models
   - Room and Accommodation Identification
   - Distance Requirements
   - Final User Positioning
   - Times of Movement and Stationarity
   - Additional Issues
   - Exemplary Video
3. User Experience
4. Network Experience
5. Conclusion and Outlook

3D Building Models

Based on

- Actual CAD plans (vector data)



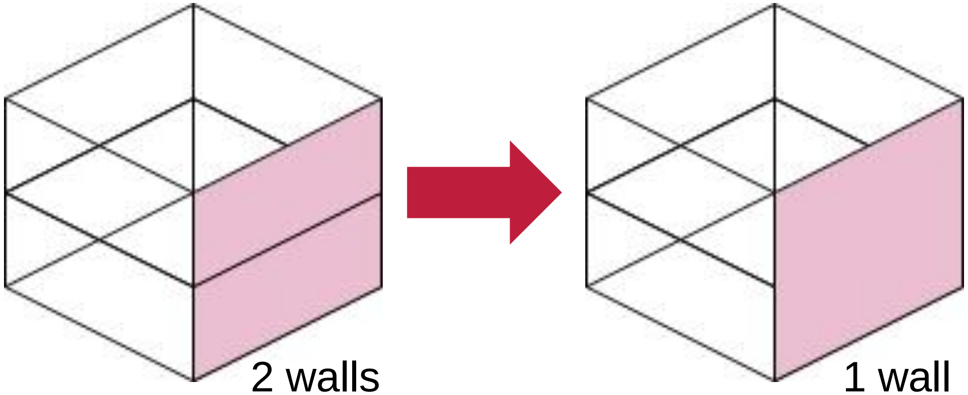


Every building includes

- Windows
- Doors
- False ceilings
- Light weight construction
- And more

Room identification

- Huge amount of elements
- Severely complex



Reduction of complexity necessary

- Concatenation of elements (walls)

Room Identification in the Building Model

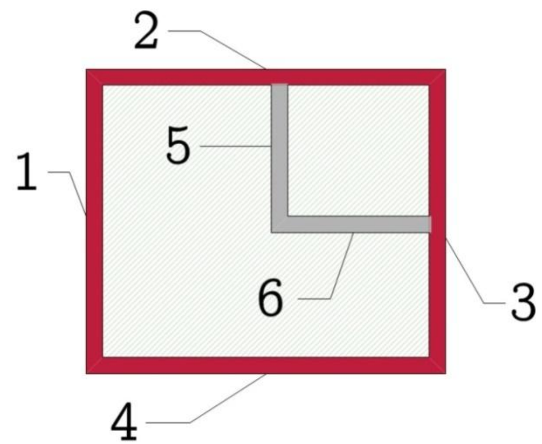
The building is represented as an undirected graph

- Circles within this graph are potential rooms inside the building

→ A search for circles with the length of *k* represents a search for rooms with *k* walls

$$
\begin{array}{c}
\begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array} \\
\begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{array}
\begin{bmatrix}
0 & 1 & 0 & 1 & 0 & 0 \\
1 & 0 & 1 & 0 & 1 & 0 \\
0 & 1 & 0 & 1 & 0 & 1 \\
1 & 0 & 1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 1 \\
0 & 0 & 1 & 0 & 1 & 0
\end{bmatrix}
\end{array}
$$

1-2-3-4-1



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Room Identification in the Building Model

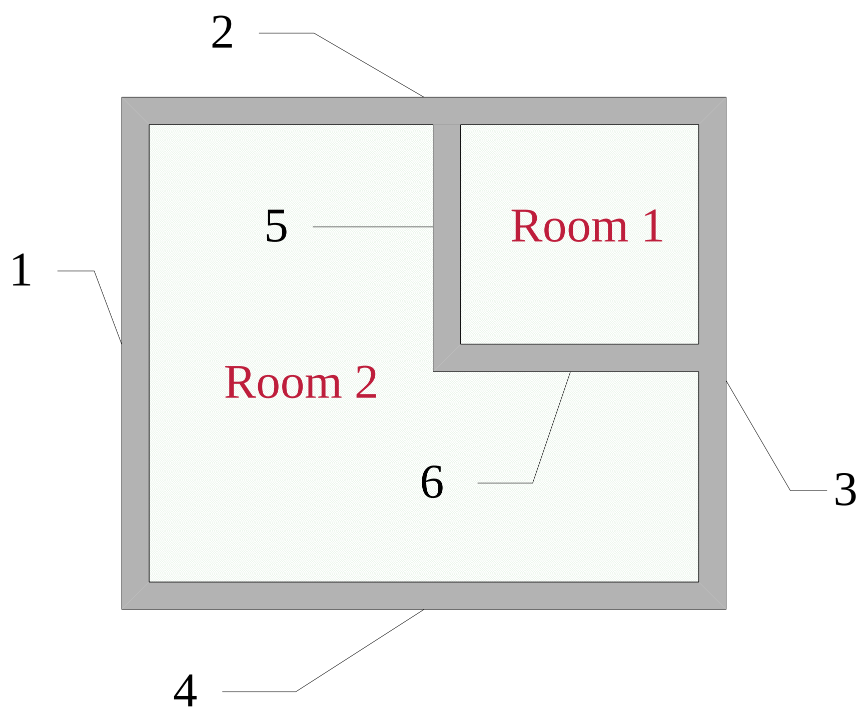
The building is represented as an undirected graph

- Circles within this graph are potential rooms inside the building

→ A search for circles with the length of *k* represents a search for rooms with *k* walls

After plausibility check

- Room 1 with 4 walls (2-3-5-6)
- Room 2 with 6 walls (1-2-5-6-3-4)



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Accommodation Identification for Multi-Family Homes

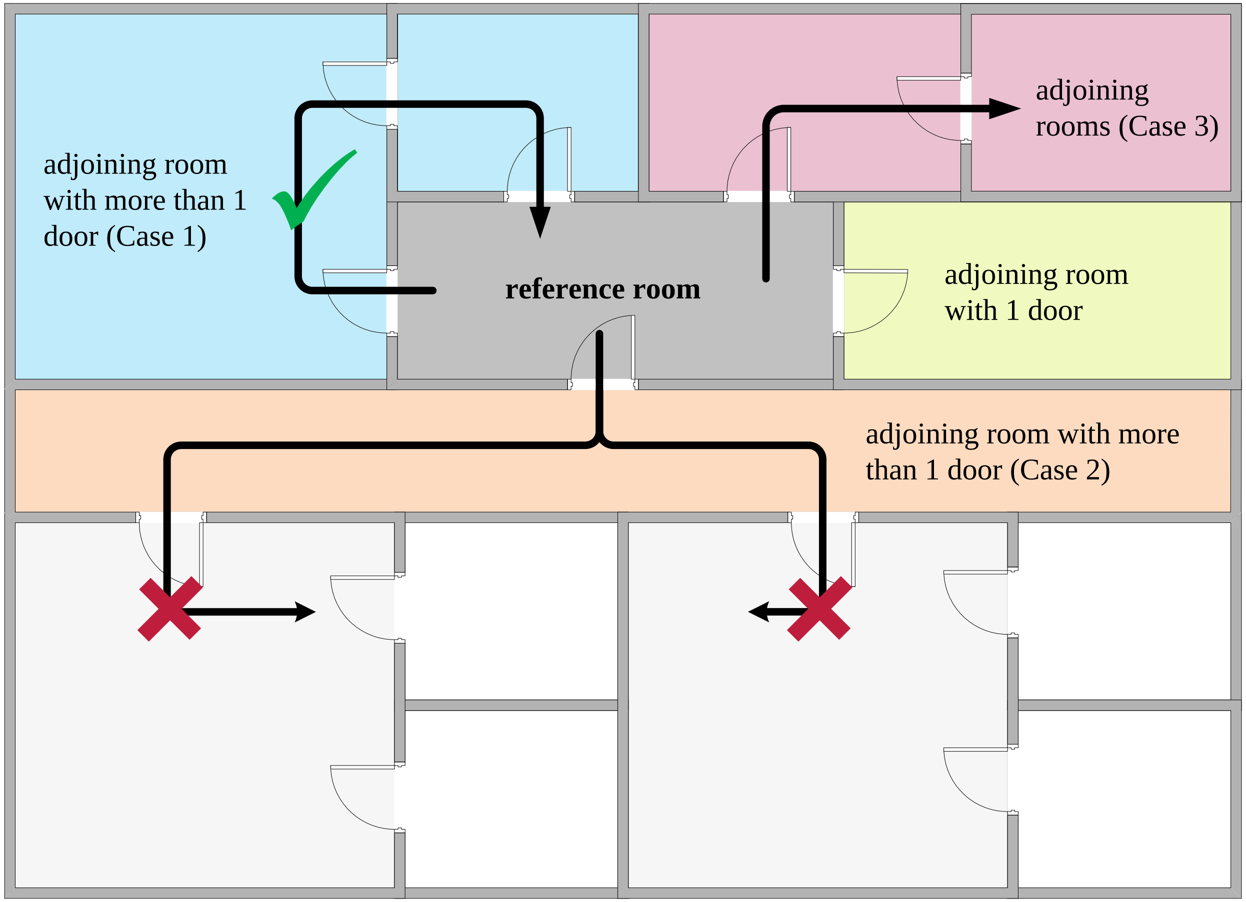
Select a reference room

- With more than 1 door

Associate it with all adjoining rooms ...

- With 1 door
- With more than 1 door, but which reach the reference room again
- With two doors and a subsequently adjoined room with 1 door

Iterative process (trial and error)



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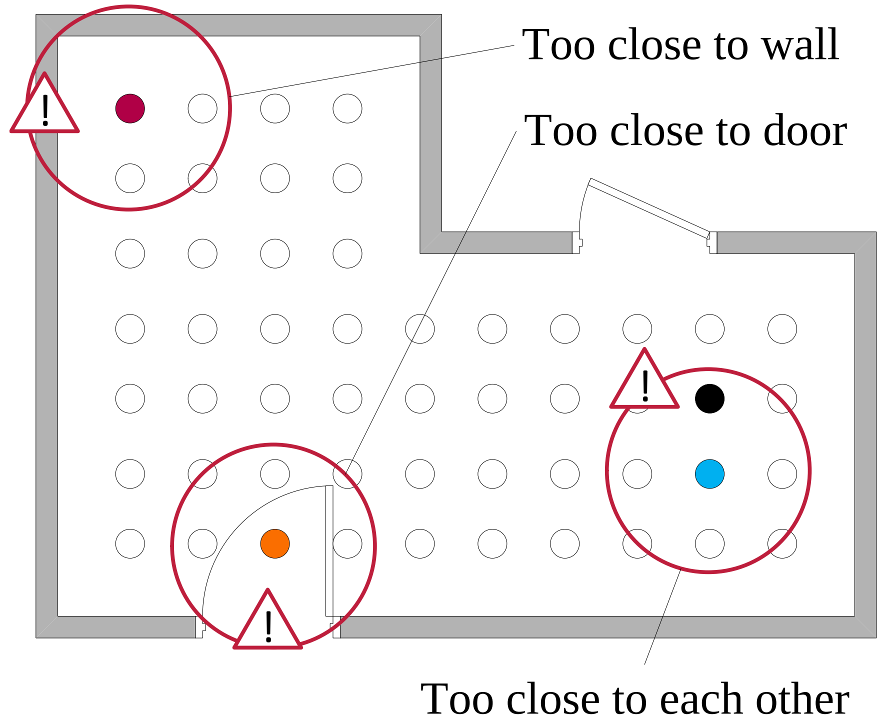
Distance Requirements for User Placement

User placements in one room of an office building

Avoid unnatural placement

- Near walls
- Near doors
- Too close to other users



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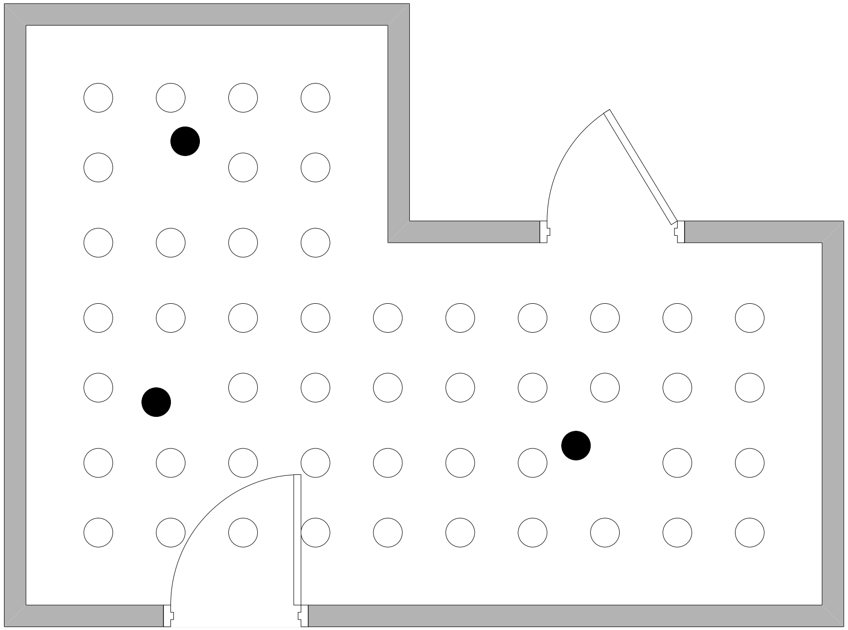
Final User Positioning

Positions for three users in one room of an office building

- Original positions are randomly shifted
- To avoid a regular pattern



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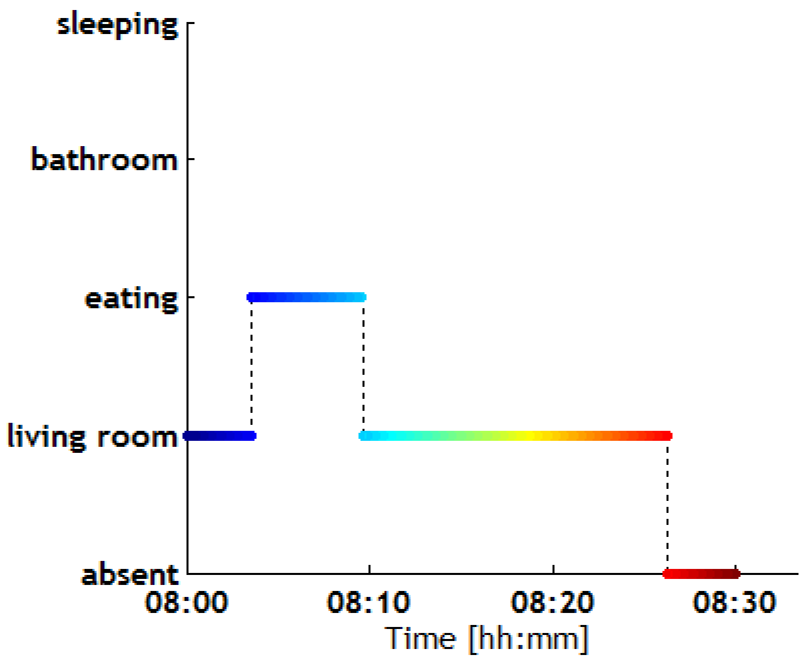
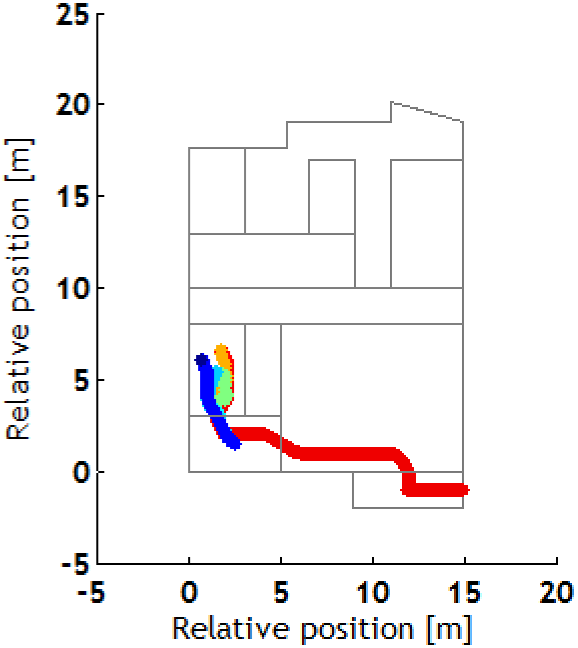
Times of Movement and Stationarity

Usage of a Markov-Jump process to model user activities

Indoor mobility is dominated by

- Long times of stationarity
- Short periods of motion





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Additional Issues towards Mobility

“Spontaneous” motion within a room

- Randomly added motion, depending on the area, time and day

Type	Multi-Family Home	Office/Industry
Walking around	x	
Change position	x	
Somewhere and back	x	x
Visit of another office		x

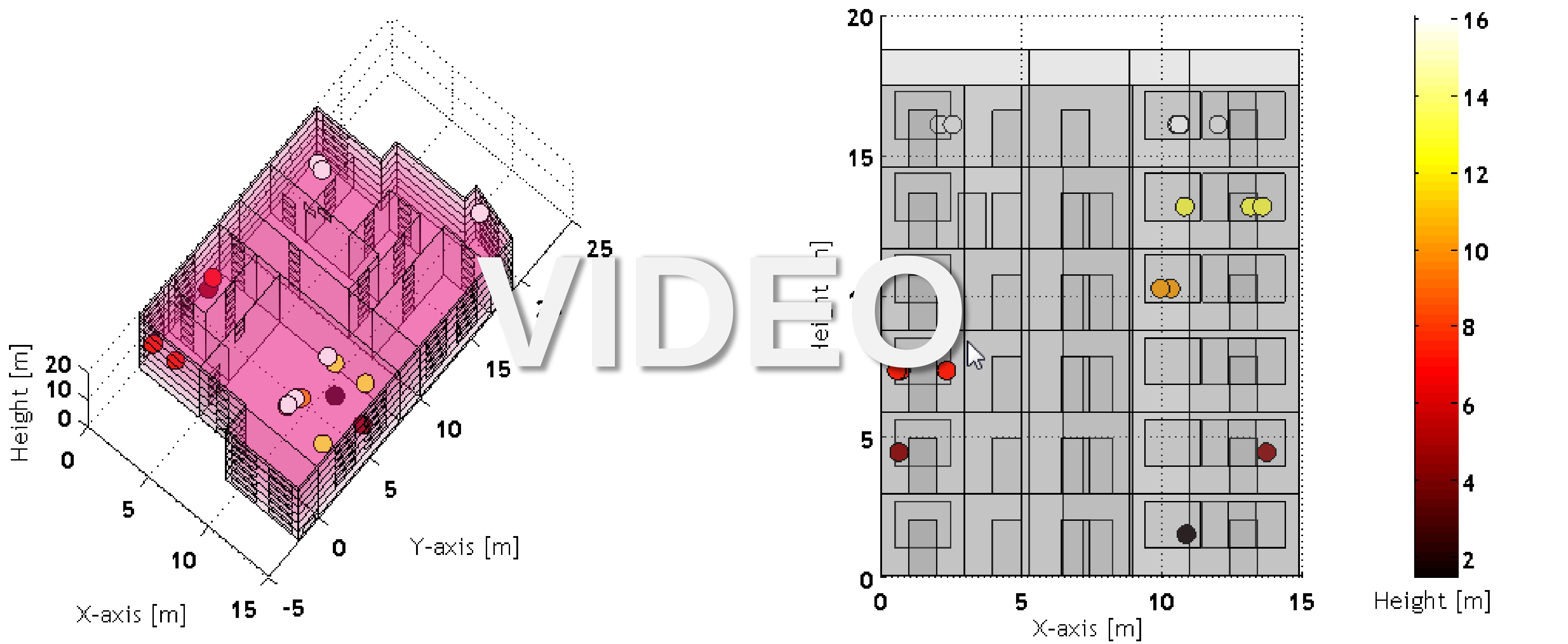
3D motions

- Motion between floors
- Entering and leaving a building

Interpolation of a user trace

- Under consideration of walls and doors

Multi-Family Home Between 08:00 and 08:05 in the Morning



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3. **User Experience**
   - Comparison of Predicted Signal Strength
   - Statistical Comparisons
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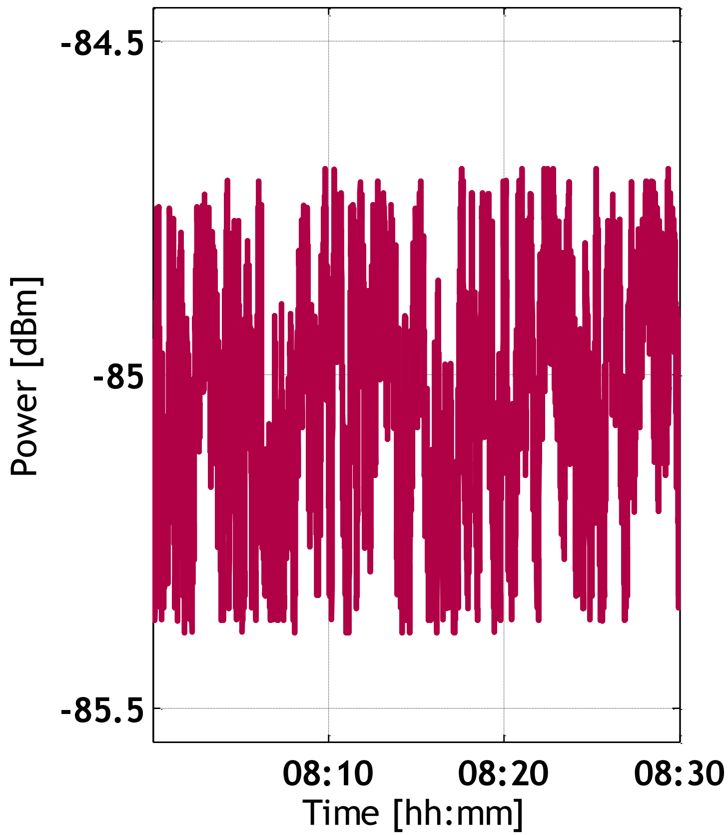
Comparison of Predicted Signal Strength: Extended Hata

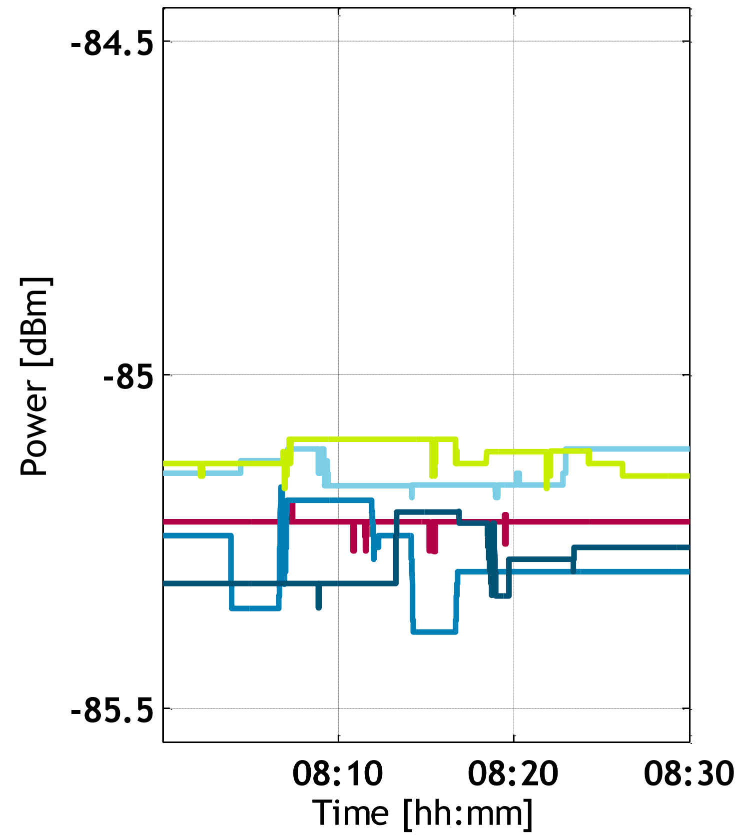
Random walk mobility

- 1 user



Indoor mobility model

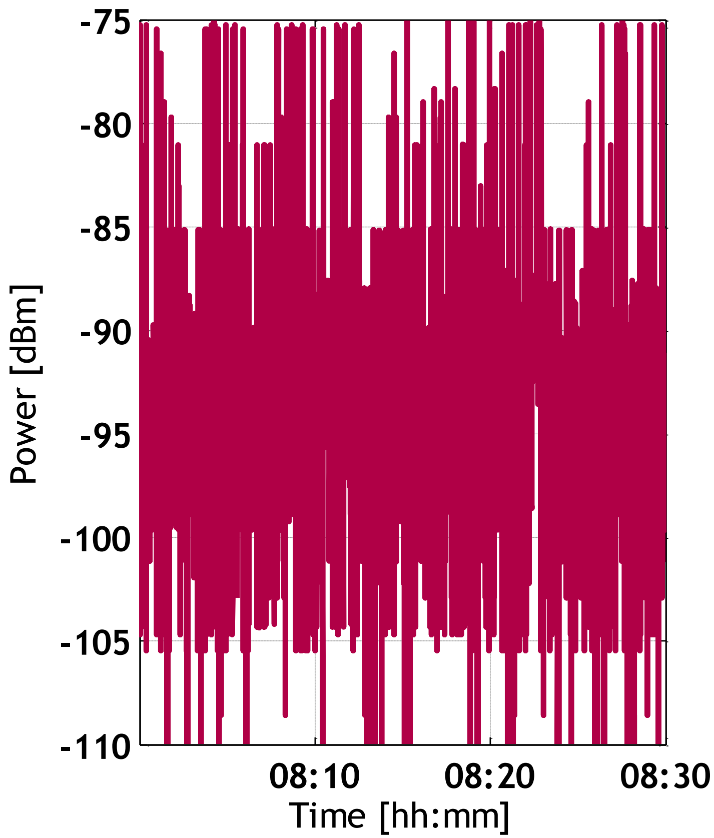
- 5 users



Comparison of Predicted Signal Strength: Ray-Optical + O2I

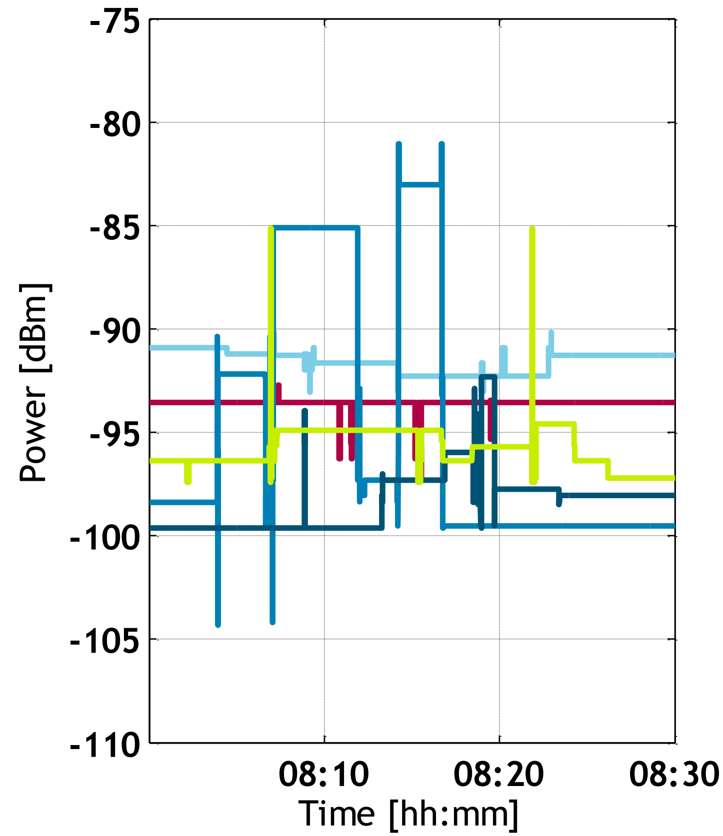
Random walk mobility

- 1 user



Indoor mobility model

- 5 users



Statistical Comparison of Predicted Signal Strength

Extended Hata model

	RW	ø IM	IM 1	IM 2	IM 3	IM 4	IM 5
Mean [dBm]	-85.03	-85.21	-85.22	-85.14	-85.28	-85.28	-85.12
Std [dB]	0.17	0.03	0.00	0.02	0.06	0.04	0.02

→ No difference (due to the spatially homogenous coverage prediction)

Ray-optical model with outdoor-to-indoor mapping

	RW	ø IM	IM 1	IM 2	IM 3	IM 4	IM 5
Mean [dBm]	-94.29	-94.82	-93.58	-91.56	-94.81	-98.36	-95.80
Std [dB]	3.89	1.93	0.28	0.50	6.30	1.49	1.05

→ Small difference in 2nd order statistics (due to a more heterogeneous coverage prediction)

Statistical Comparison of Best Server Changes

Number of changes in 30 minutes

	RW	ø IM	IM 1	IM 2	IM 3	IM 4	IM 5
Extended Hata model	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ray-optical model	3647.00	15.60	10.00	6.00	16.00	17.00	29.00

2 per second!

Huge dependency on the prediction model

Predictions based on the Extended Hata model

- Not influenced by any mobility model

→ A realistic indoor mobility model in connection with Extended Hata shows no impact!

Predictions based on ray-optical modelling

- Best server changes depend strongly on the used mobility model

→ Unrealistically high number of best server changes for random walk model

→ Is random walk mobility suitable for handover modelling??

Outline

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   - Number of Handover Events
5. **Conclusion and Outlook**

Handover Events for Predictions based on Extended Hata

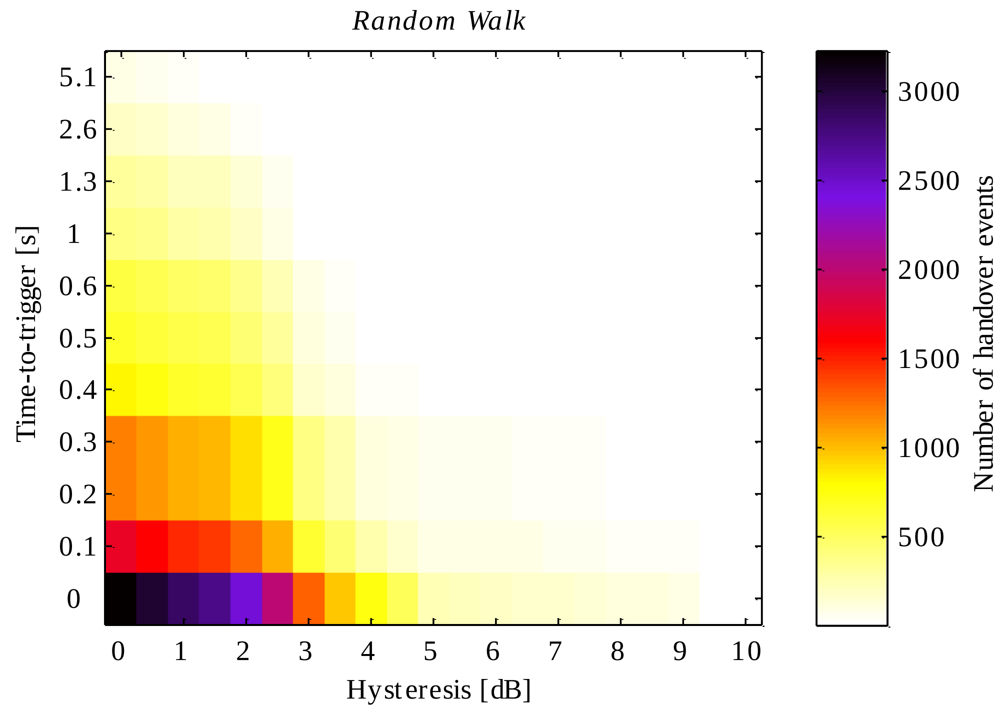
No best server changes monitored

→ No handover events

Number of Handover Events with Random Walk Mobility

Ray-optical propagation modelling

- 1 random walk user within 30 minutes



High number of handover events for low hysteresis and time-to-trigger values

- Decreases significantly for higher hysteresis or time-to-trigger values
- Generally, same behaviour as for mobile outdoor users

→ But still, huge number of handover events can only be explained by the unrealistic and permanent movement of the user and the high number of changes in rooms

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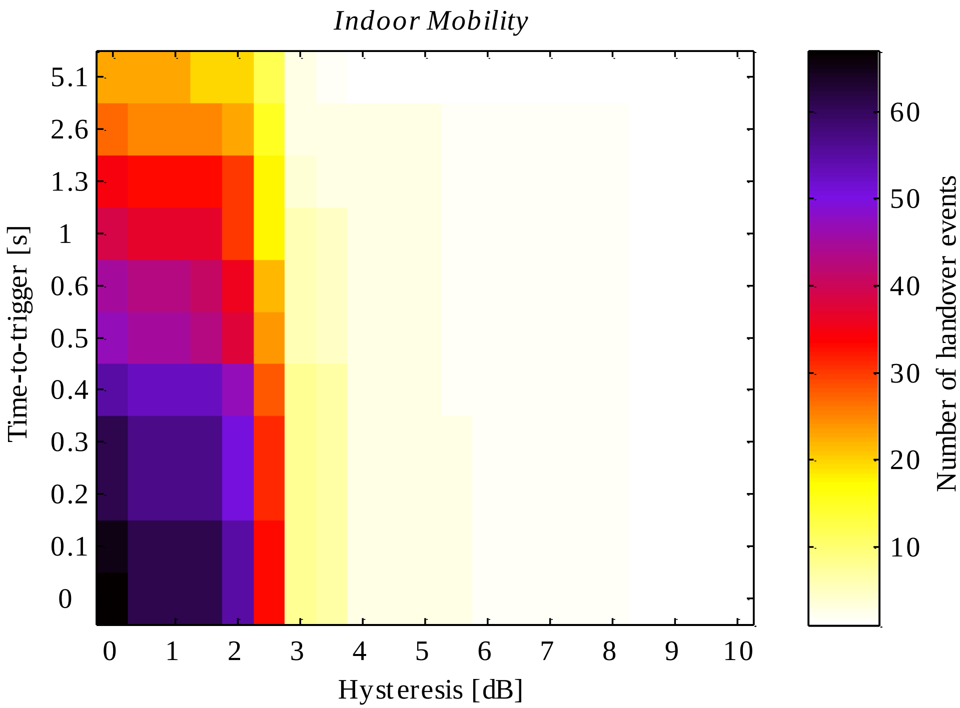
Number of Handover Events with Indoor Mobility

Ray-optical propagation modelling

- 5 different users within 30 minutes



Number of handover events is less affected by time-to-trigger variations

- Depends on the user paths inside the building
- Users follow the floor for some time or enter a new room and wait for a while

→ Overcoming of the hysteresis is usually fulfilled when a user leaves/enters a room

→ Time-to-trigger settings do not matter much due to the directed movement

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Conclusion

New sophisticated three-dimensional indoor mobility model has been introduced

- Works with real 3D building models
- Automatic identification of rooms and accommodation units
- Distinguishes between multi-family homes and office/industry buildings
- Implements activity-based user movements

Modelling impact on the user and network experience

- Statistical comparison of signal strength reveals only slide differences for all combinations
- Number of best server changes and thus the number of handover events differ significantly

→ Results of system level simulation strongly depend on both, the propagation model and the mobility model

	Random walk	Indoor mobility
Extended Hata	**Effective**	**Not effective**
Ray-optical with O2I mapping	**Not effective**	**Effective and accurate**

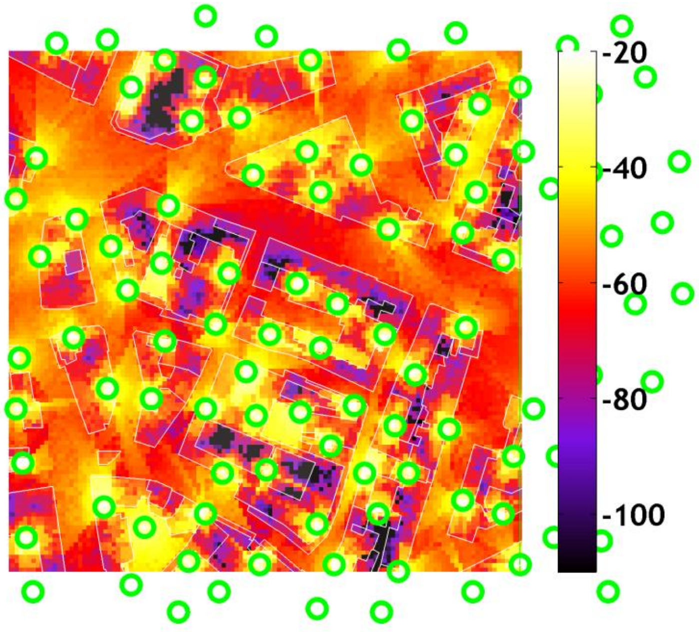
Outlook

Mobility model improvements

- Users (groups) are not yet interacting with each other

The mobility model will be applied to scenarios with dense femto cell deployments

- Analyse the performance of such networks in a more realistic way



Chosen for the FP7 STREP Project „SEMAFOUR“

- Self-Management for Unified Heterogeneous Radio Access Networks
  - September 2012 - August 2015

Thank you for your attention!

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