technische universität
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Wireless Network Planning and Performance Analysis for Smart Grid Applications

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Presentation adapted from:
C. Müller, H. Georg, M. Putzke and C. Wietfeld, "Performance Analysis of Radio Propagation Models for Smart Grid Applications", 2nd IEEE International Conference on Smart Grid Communications (SmartGridComm), Brussels, Belgium, Oct 2011, pp. 96-101.

Agenda

- **Motivation**
  - Project Outline of Smart Grid Region E-DeMa
  - Wireless M2M Communication for the Smart Grid
- **Deployment (Position Aware) Scenarios**
- **Simulation Environment**
  - Ray Tracing Simulation
  - Geo-Based Scenario Generation
  - Radio Propagation Models
  - Link Budget
- **Analysis**
  - Performance Evaluation
  - Coverage Analysis
- **Conclusions and Outlook**

E-Energy Smart Grid Region E DeMa

Development and Demonstration of decentralized integrated energy systems on the way towards the E-Energy marketplace of the future

- One of six Smart Grid regions funded by:

Federal Ministry of Economics and Technology

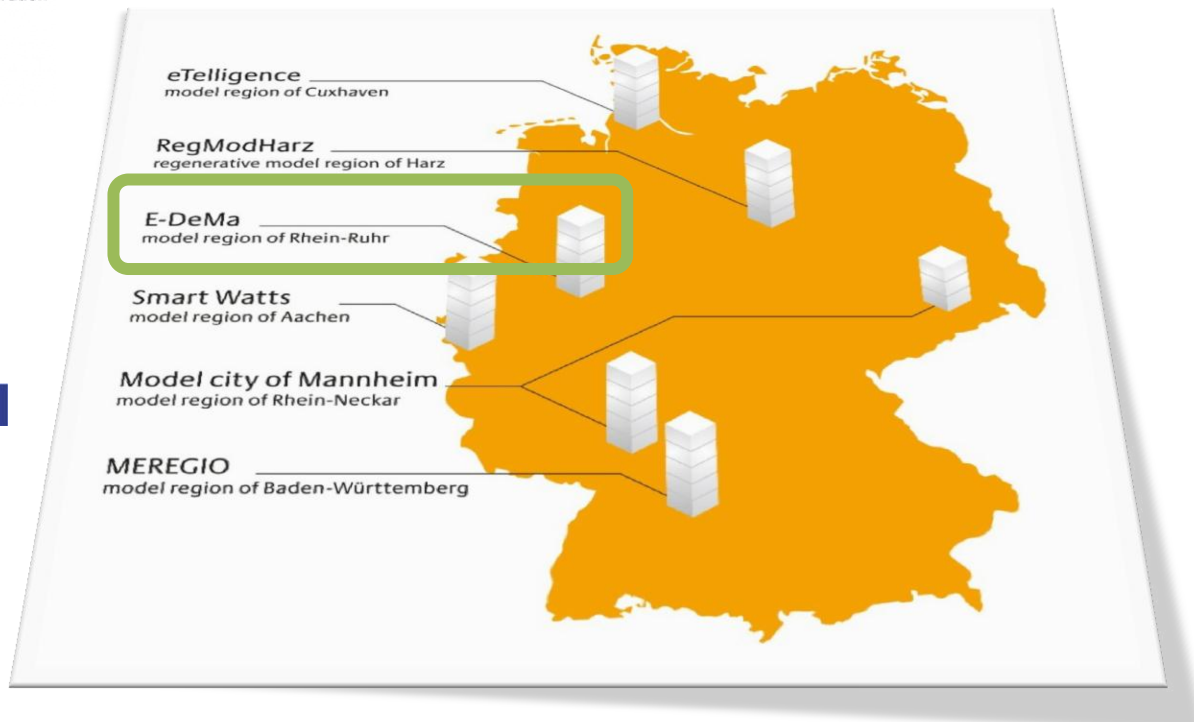
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

- Project consortium:

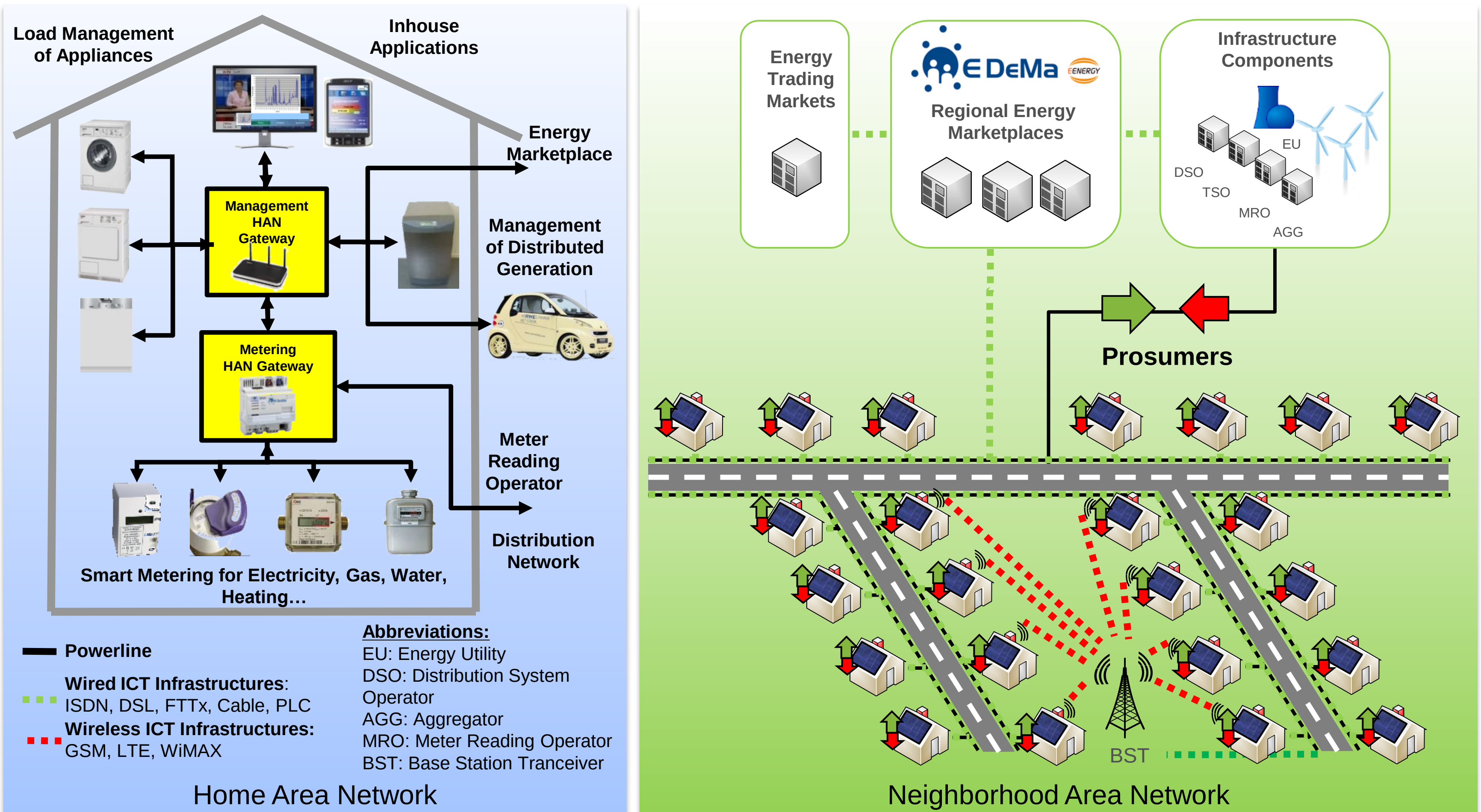
VORWEG GEHEN · SIEMENS · Miele IMMER BESSER · ProSyst · SWK · Fachhochschule Dortmund University of Applied Sciences and Arts · technische universität dortmund · UNIVERSITÄT DUISBURG ESSEN

- Sister Project *E-Mobility:*

IKT INTEGRATION DER ELEKTROMOBILITÄT IN DIE NETZSYSTEME DER ZUKUNFT



Smart Grid Scenarios for Wireless M2M Communications



→ Wireless technologies for Last Mile M2M connectivity and Distribution Network Automation

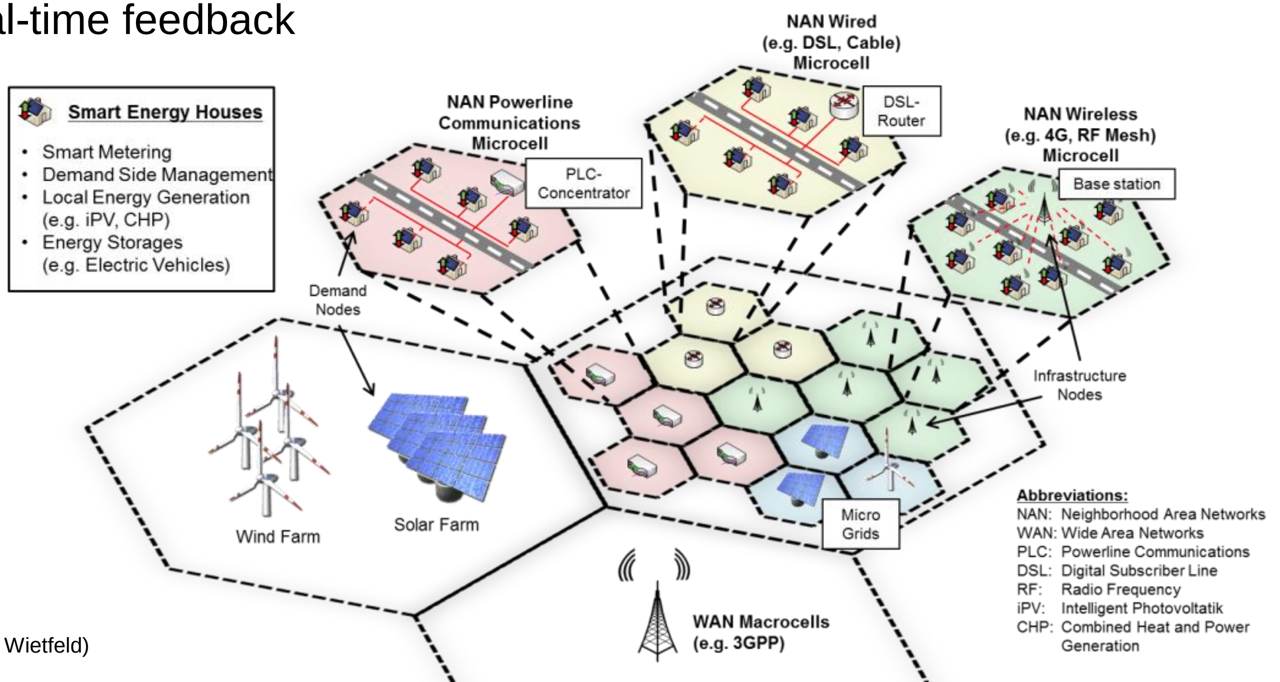
Smart Grid Region 2012 vs. Smart Grid Integration 2020

E-DeMa Model Region 2012

- Evaluation and demonstration of decentralized energy systems
- Model Region with
  - **4000** Gateways and Smart Meter
  - **100** Energy Management Gateways
  - **100** households with smart appliances and combined heat-power generation
  - Dynamic tariff and real-time feedback systems

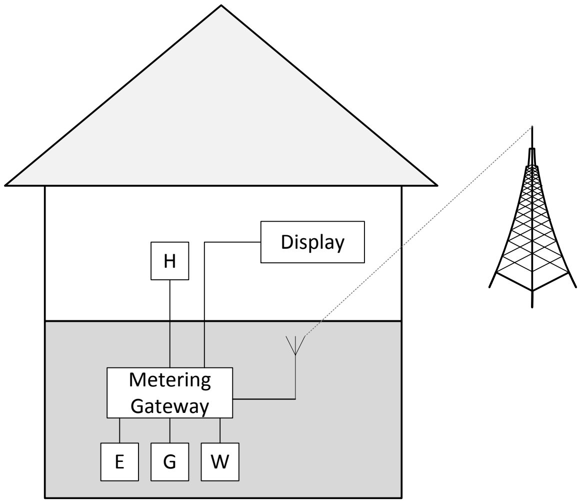
Smart Grid 2020

- Evaluation of heterogeneous network infrastructures for the scenario 2020
- Wireless Technologies for Smart Metering and Demand Side Management
- Wired Technologies (DSL, Fiber, PLC, BPLC)

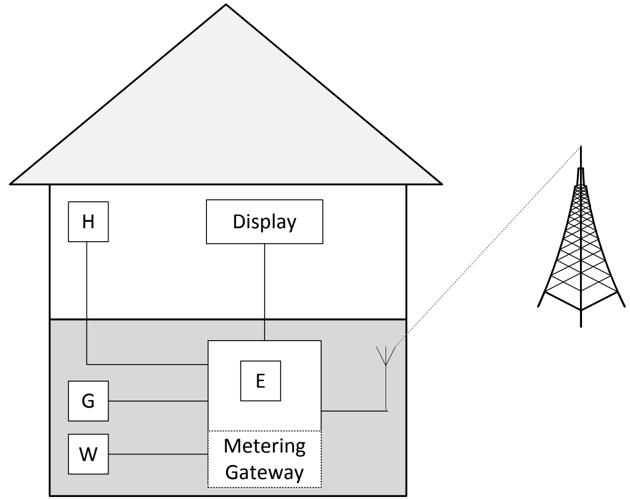


Smart Metering / Smart Grid Architectures

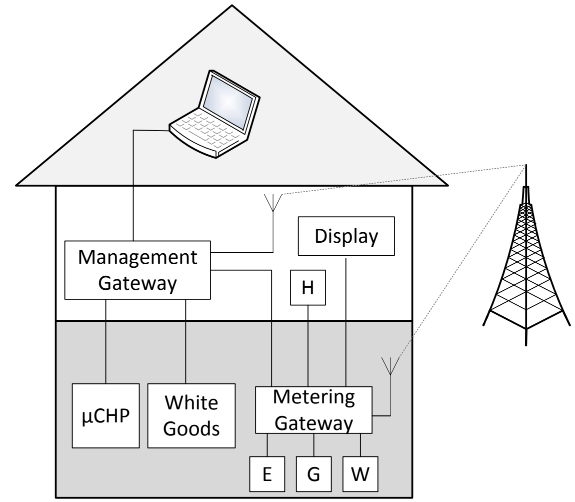
Modular AMR



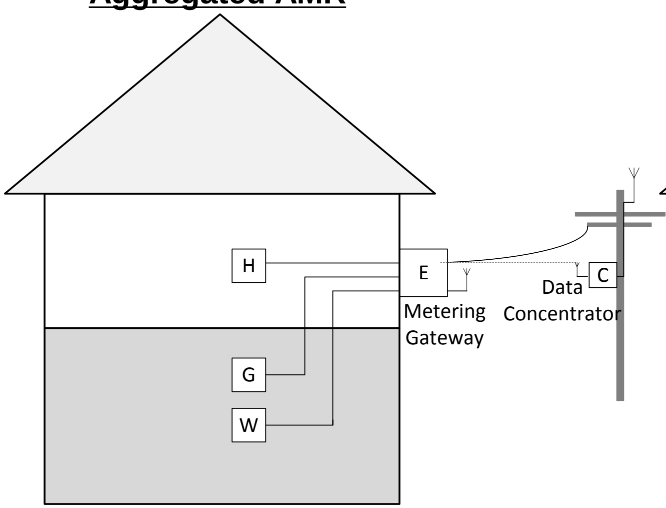
Integrative AMR



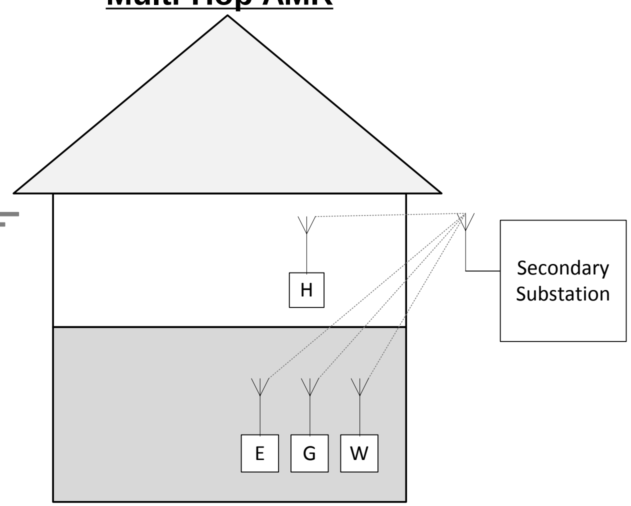
AMR + DSM



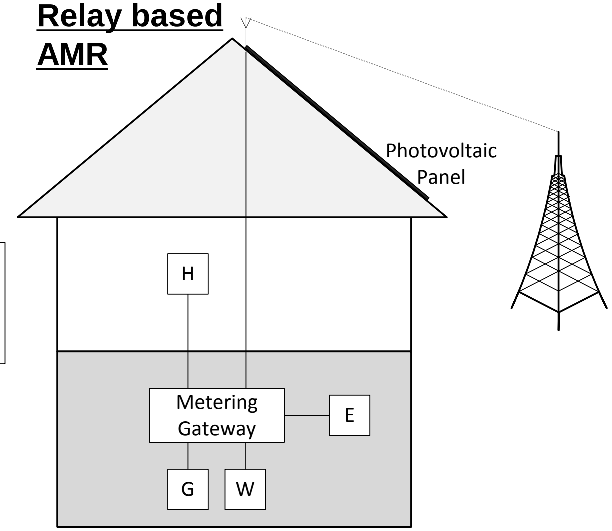
Aggregated AMR



Multi-Hop AMR



Relay based AMR



AMR- Automatic Meter Reading, DSM-Demand Side Mgmt.

Deployment Scenarios of Smart Meter and ICT Components

Real Life Scenarios

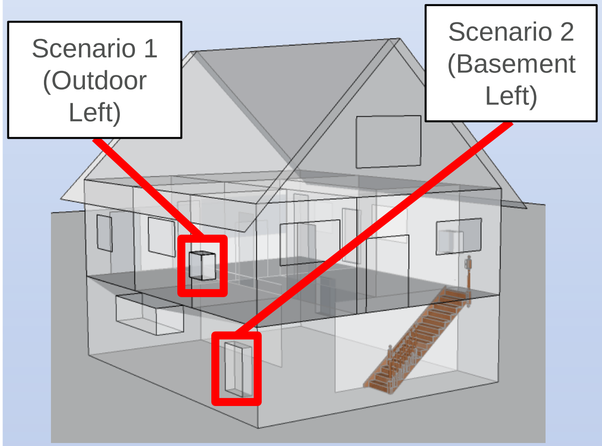


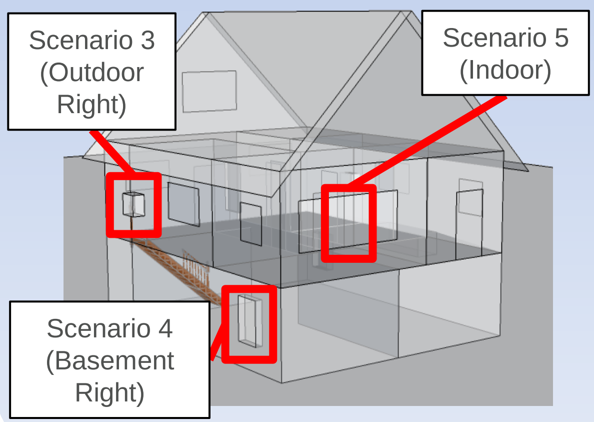
Outdoor Installation


Basement Installation

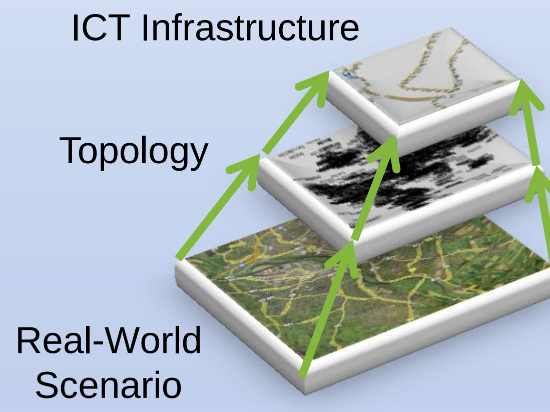
Indoor Installation

Simulation Scenarios



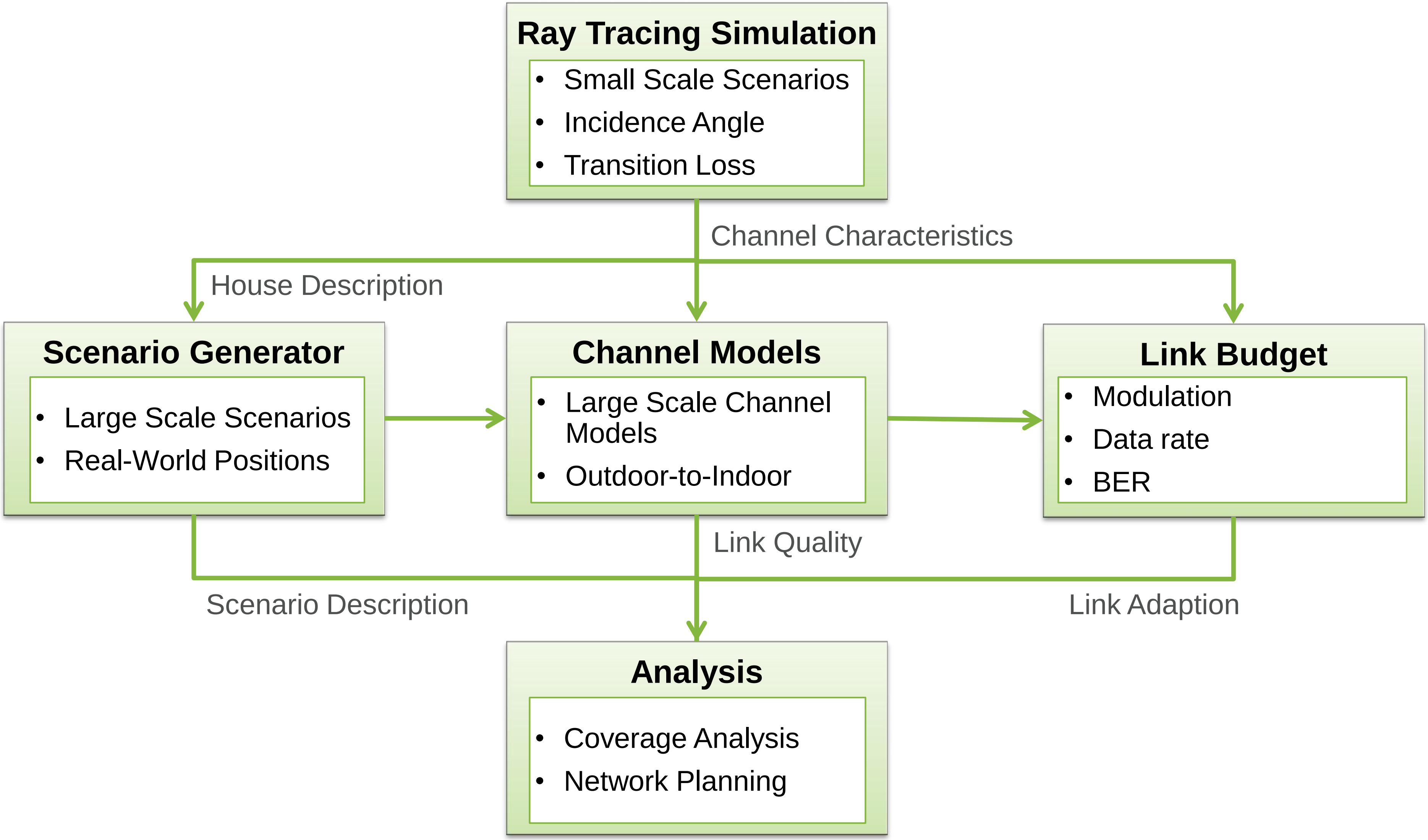


Topology Scenarios

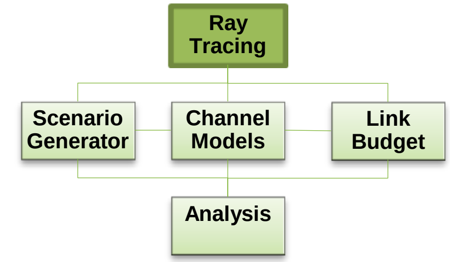


- Scalability analysis of communication concepts and technologies
- Complex geo-based scenarios with up to 12.000 households (Rural/Suburban/Urban)

Simulation Environment

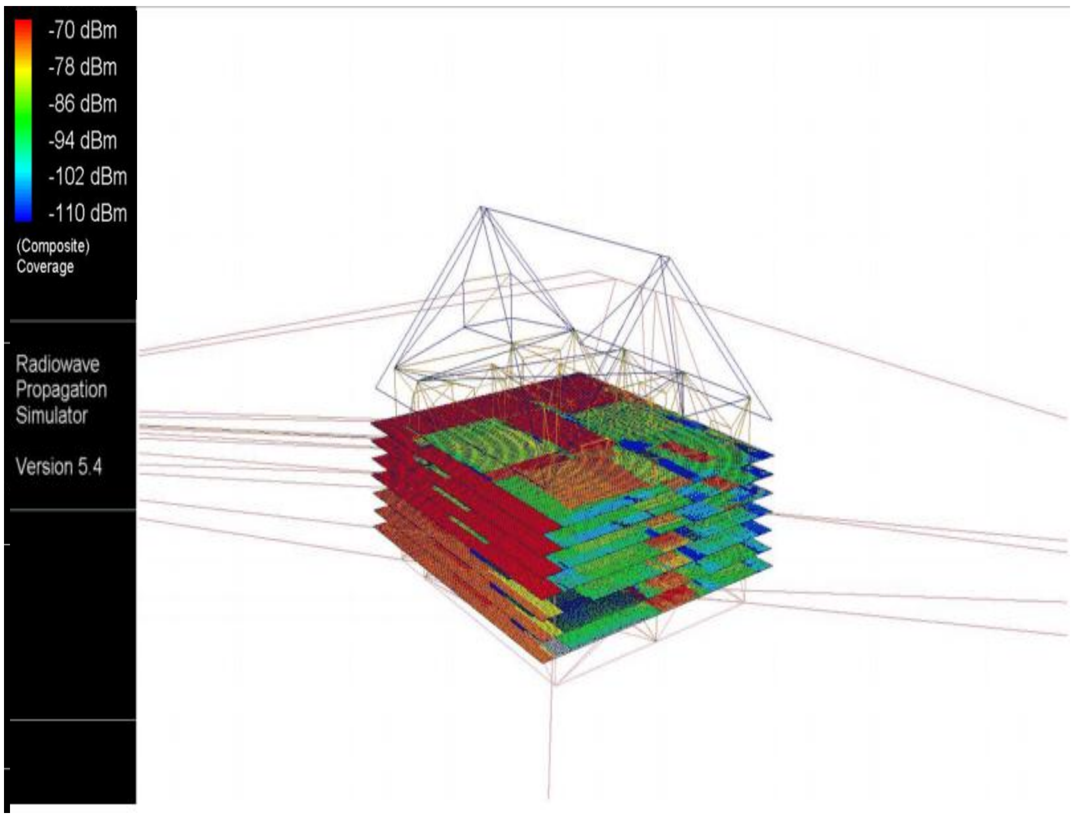


Ray Tracing Analysis

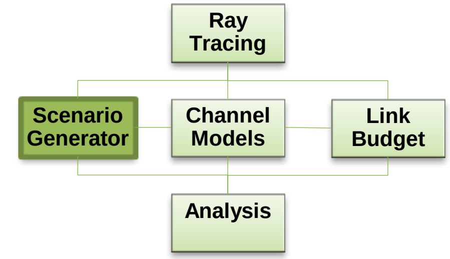


- 3D House Modell
- Different ICT component positions
- Stepwise base station positioning (1 degree steps)
- Calculating signal strength on previously specified Inhouse positions

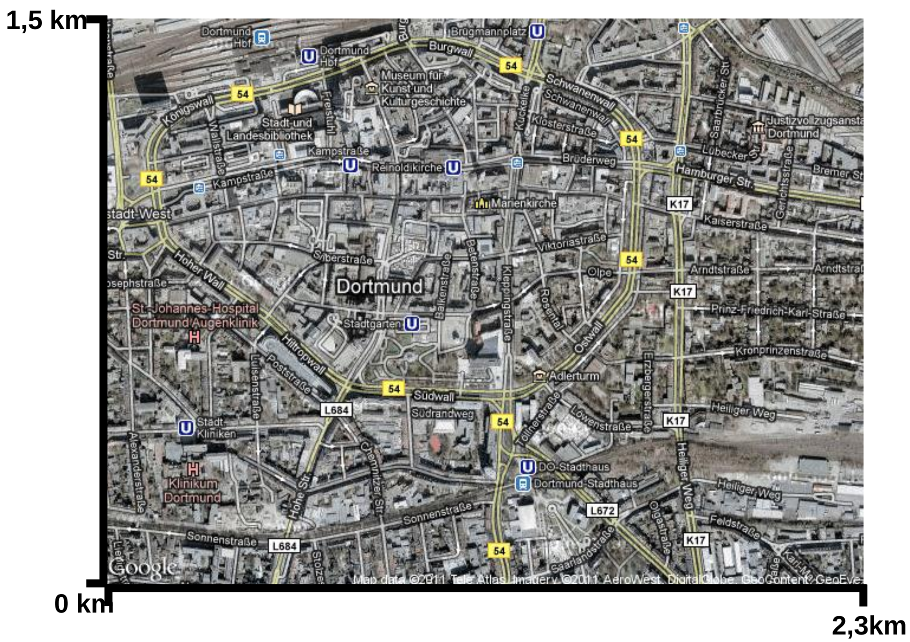
Basestation height:	20m
Distance:	200m Carrier
Frequency:	1.8 GHz
Transmission Power:	20 dBm
Basement:	w/o Metering box
Outdoor / Inhouse (corridor)	
Basement / First floor / Attic model	
Outdoor walls:	50 cm walls (Brick/Concrete)
Windows:	3 glass plates
Doors:	5 cm Wood

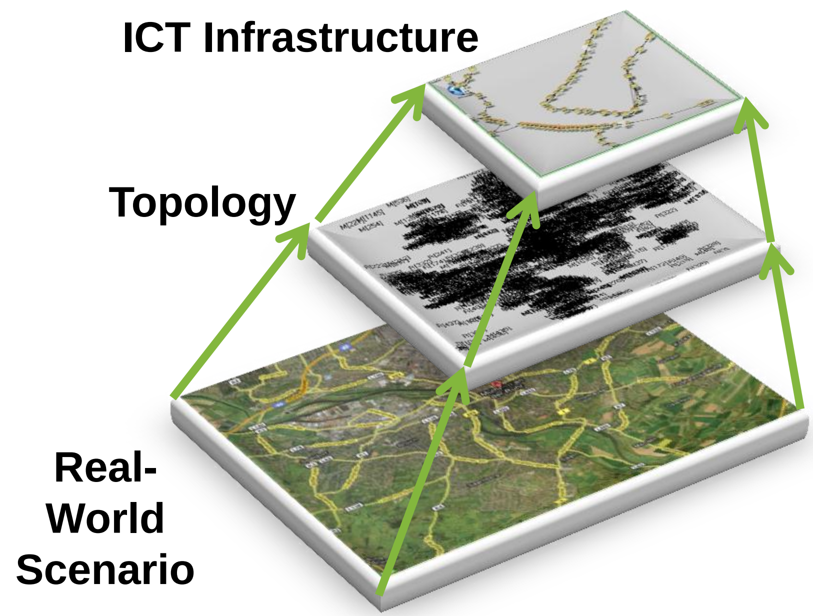


Large-Scale Simulation Generation

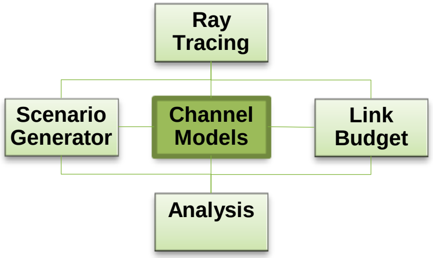


- Scenario generation based on geographic positions
- Urban topology (Dortmund, Germany):
  - 12.000 houses (Brick and Concrete)
  - Area: ~3,5 km²
- Considering the orientation of houses
- Predominant indoor/basement installation:
  - 20 % outdoor, 40 % indoor, 40 % basement





Radio Propagation Models – Selection

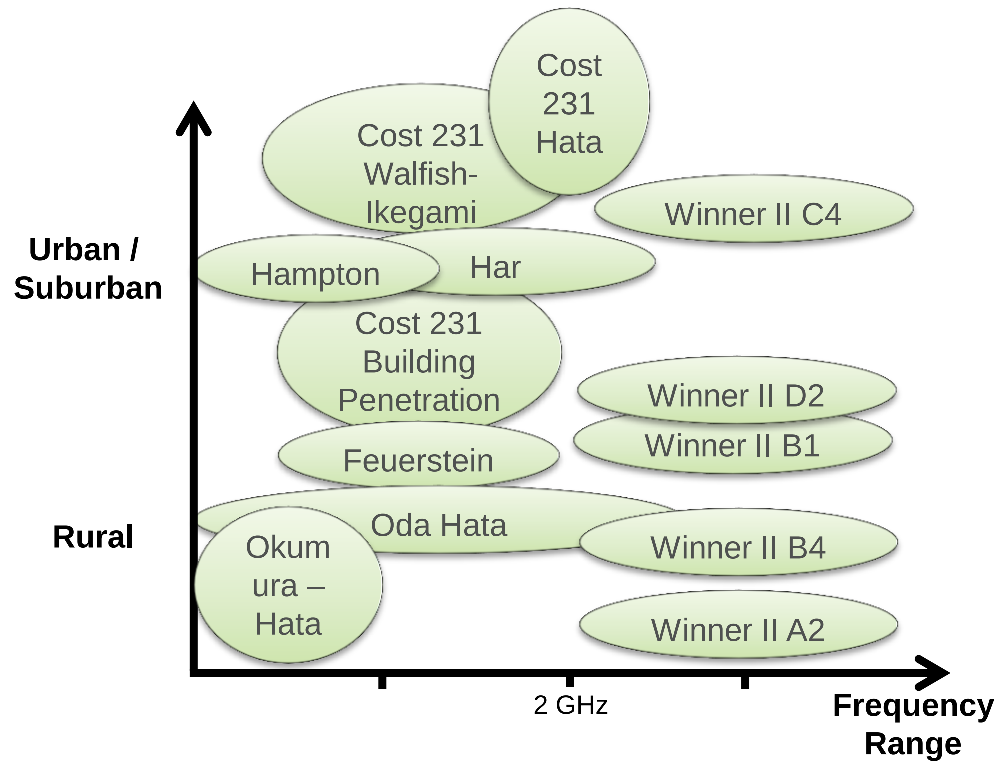


Requirements for Application Scenarios:

- Building Penetration
- Outdoor-to-Indoor Attenuation (Transition models)
- Attenuation within Buildings (Influence of Inner Walls)
- Position and Orientation of Houses (Distance, Incidence Angle)
- Different Topologies (rural, suburban, urban)
- Non-/LOS
- Different technologies / Frequencies

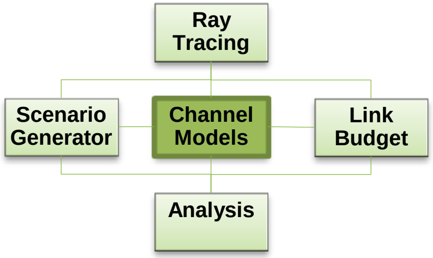
Outdoor-to-Indoor Propagation Models:

- COST231 WI / Building Penetration
- Winner II A2 / B4
- Winner II C4



State-of-the-Art Analysis of Radio Propagation Modells
Maintenance and restrictions

Radio Propagation Models – Selection



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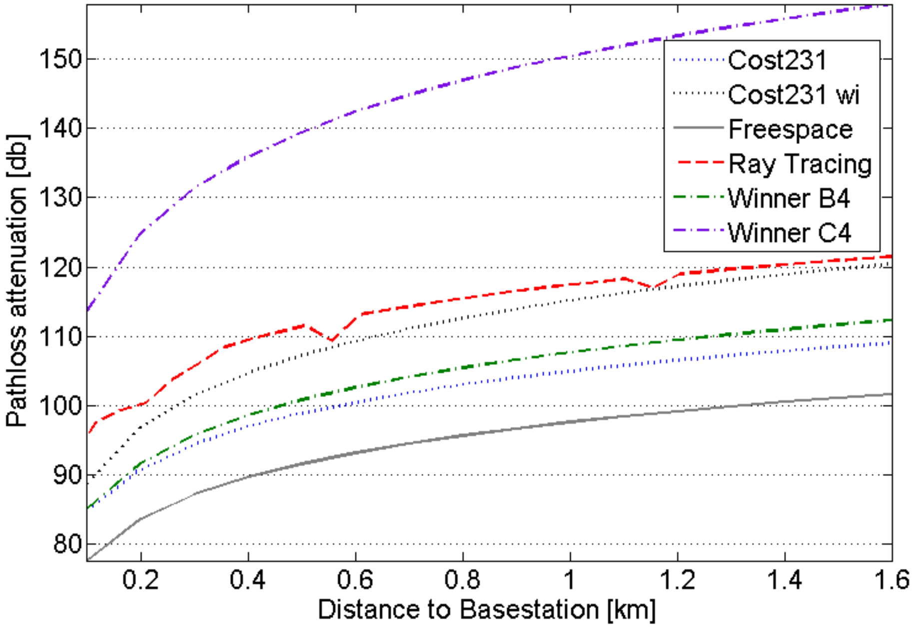
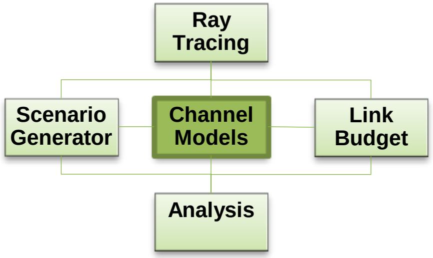


Pathloss vs. Distance – Comparison of Radio Propagation Models

[1] H. Okamoto, K. Kitao and S. Ichitsubo, “**Outdoor-to-Indoor Propagation Loss Prediction in 800-MHz to 8-GHz Band for an Urban Area**”, IEEE Transaction on Vehicular Technology, Vol. 58, No. 3, March 2009

Building Penetration Models

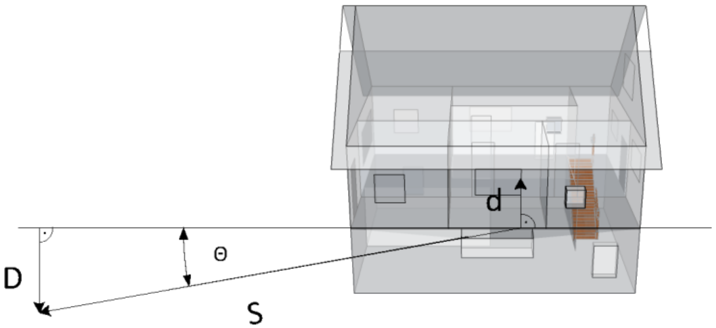


Cost 231 WI / Building Penetration

- LOS topologies
- Distance between 20m - 5km
- Different Building Types

$$L_{dB} = L_{fsp}(S+d)_{dB} + W_e + (1-\sin(\Theta))^2 \cdot W_{Ge} + \mathrm{Max}(\Gamma_1,$$

$$\text{with} \quad \Gamma_1 = W_i \cdot p \quad \text{and} \quad \Gamma_2 = \alpha \cdot (d-2) \cdot (1-\sin(\Theta))^2$$



Parameters for Cost 231 Building Penetration

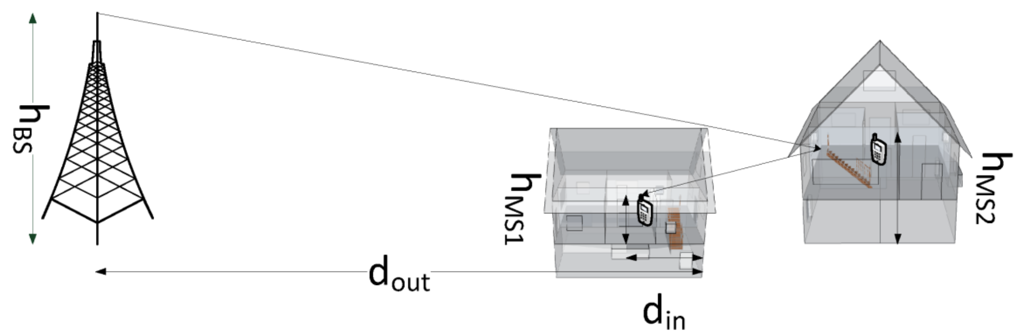
Winner II A2 / B4:

- Indoor-to-Outdoor / vice versa
- Urban Topologies
- Building Losses within Houses

Winner II C4:

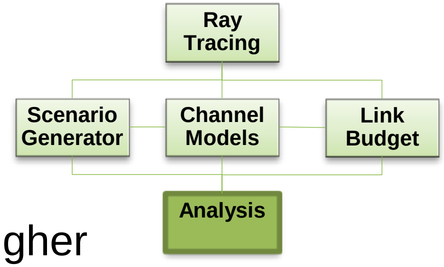
- Outdoor-to-Indoor
- Urban Topologies / NLOS
- Building Losses within Houses

$$PL_{tot} = PL_{B1}(d_{out} + d_{in}) + 15 + 15 \cdot (1-\cos(\Theta))^2 + 0.5 \cdot d_{in}$$

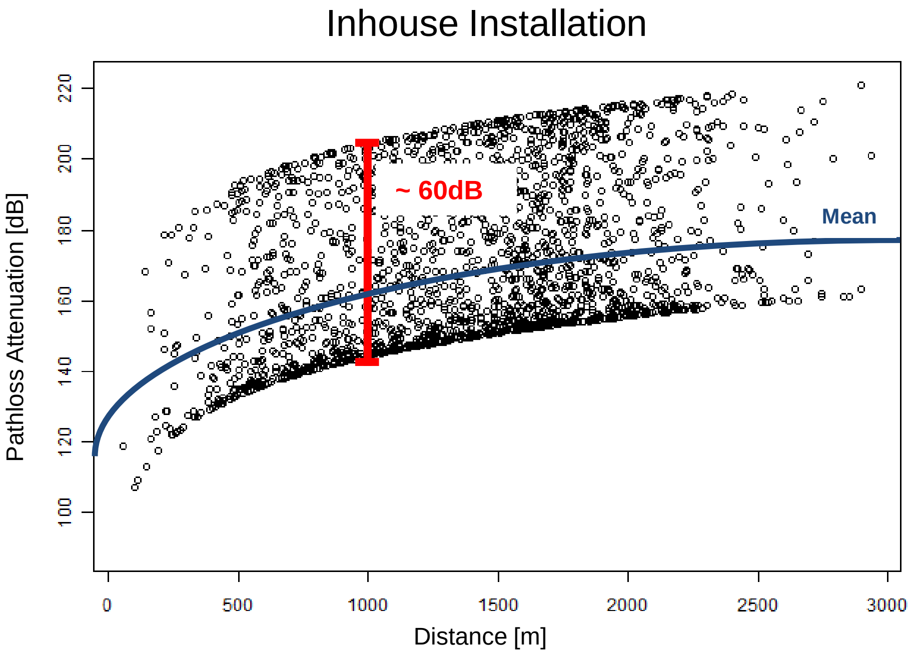


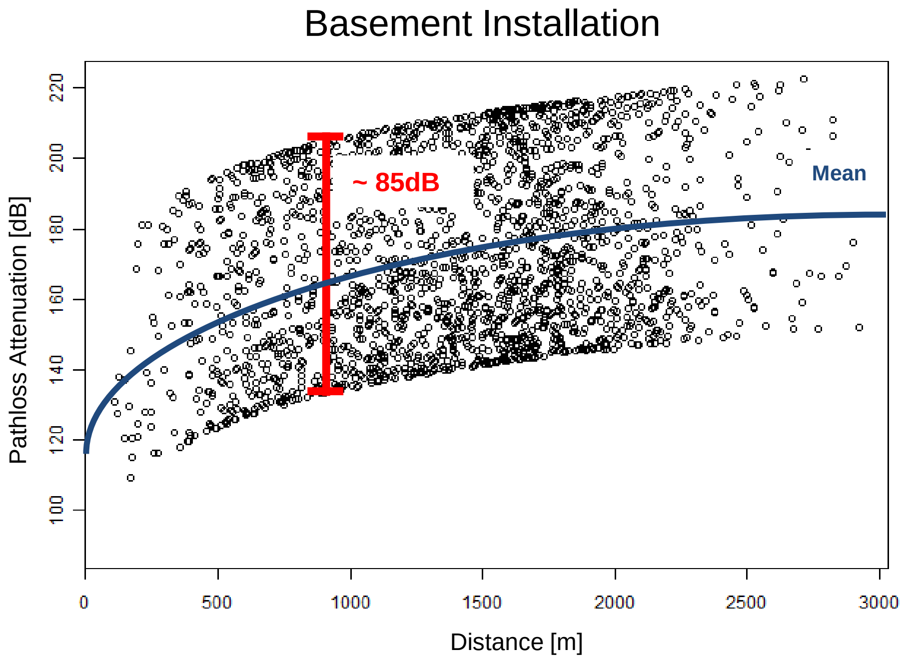
Parameters for Winner II C4

Performance Analysis – Deployment Scenarios

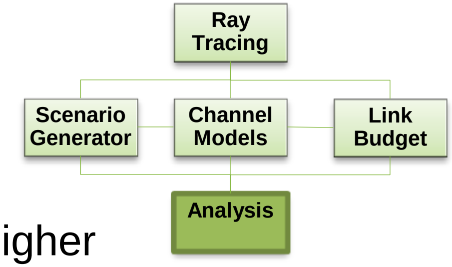


- Mean Attenuation for basement installations ~10 dB higher
- Variation of Pathloss Attenuation for basement installation ~25 dB higher
- Variation caused by reflection at outer walls (Incidence Angle)



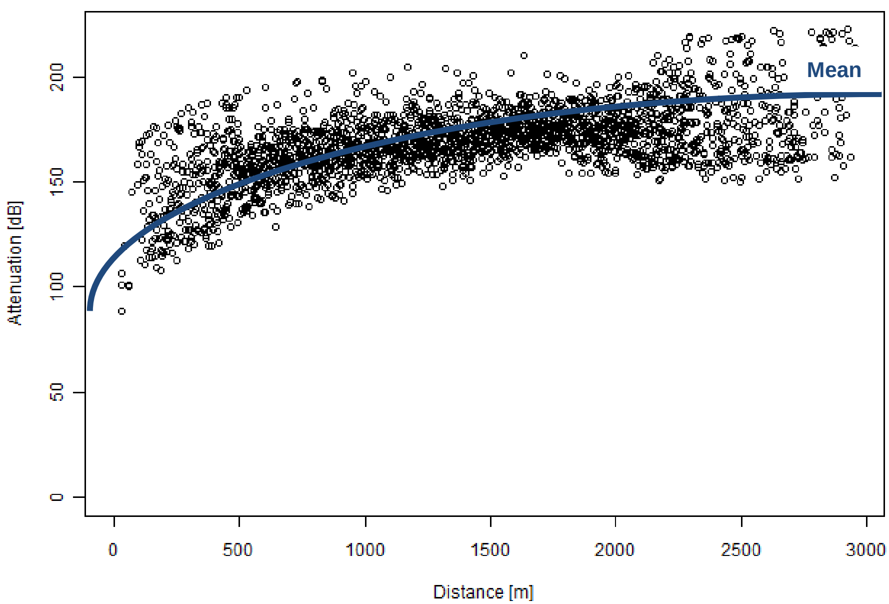


Performance Analysis – Deployment Scenarios

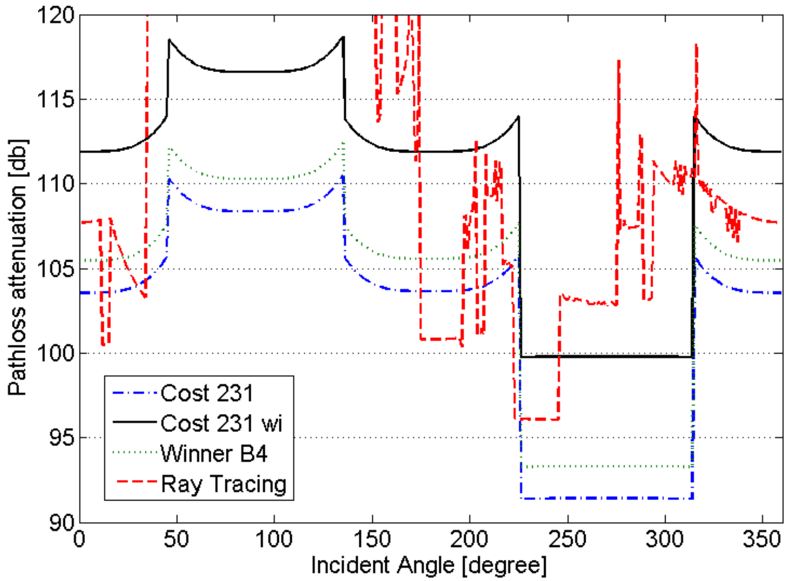


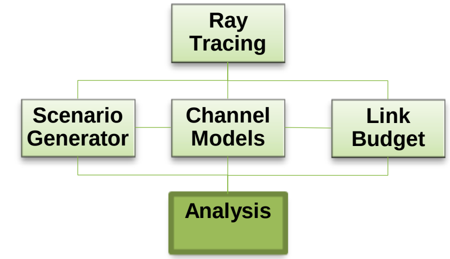
- Mean Attenuation for basement installations ~10 dB higher
- Variation of Pathloss Attenuation for basement installation ~25 dB higher
- Variation caused by reflection at outer walls (Incidence Angle)
- Ray Tracing simulation shows higher variation compared to propagation channel models
- Variation for all deployment scenarios ~ 85 dB

Pathloss Attenuation for different housetypes

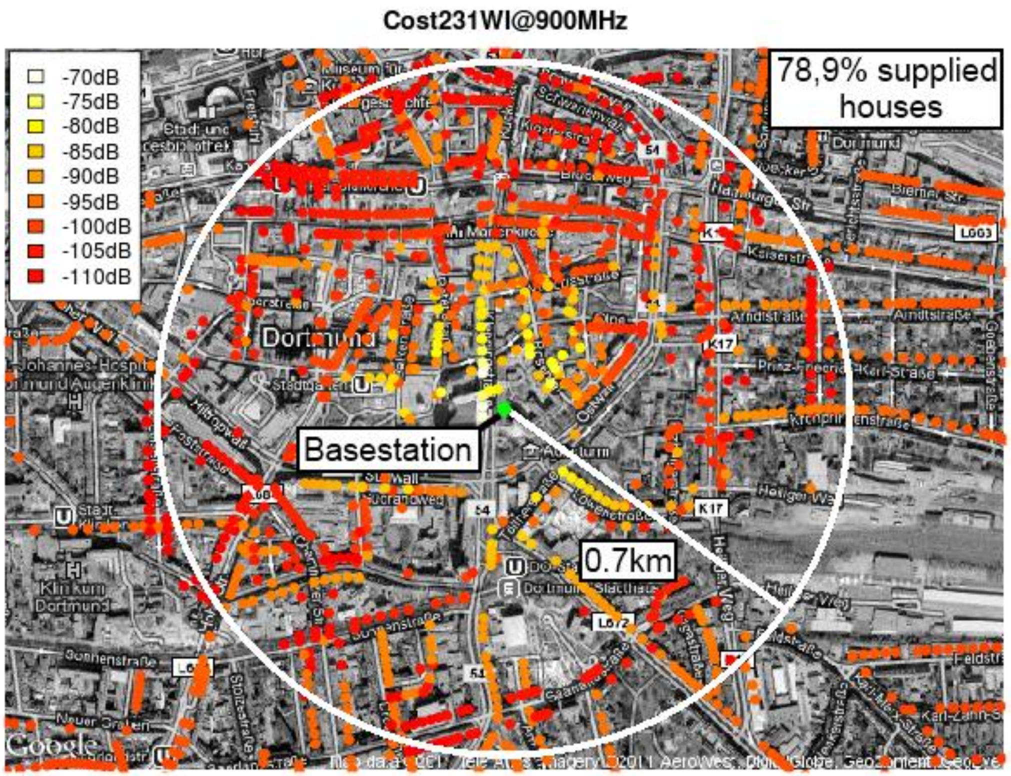


Pathloss in dependency of the orientation





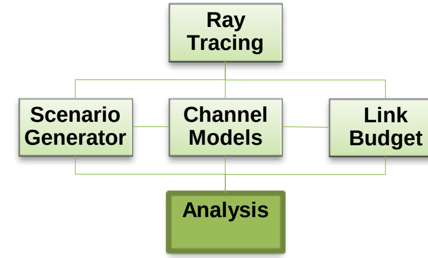
Coverage Analysis – Results 900 MHz



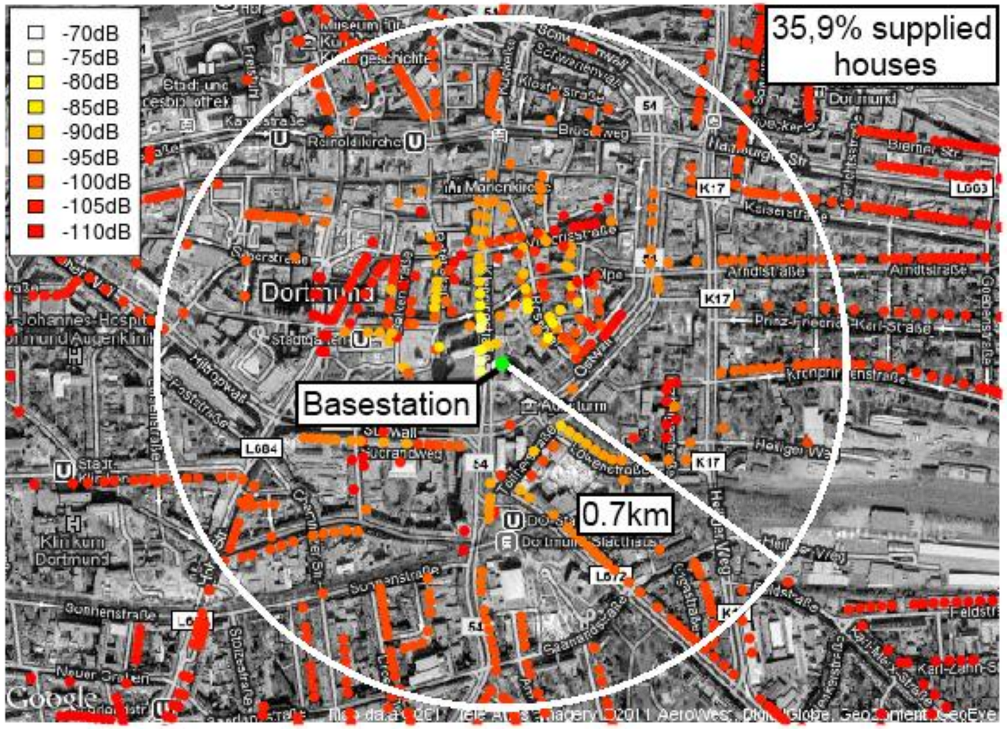
Coverage Analysis of Real-World Scenario using Cost 231 WI Building Penentration Channel Model at 900 MHz

- Reference scenario: Single Basestation for validation purpose without network infrastructure and sectorization
- Cost231 WI at 900 MHz:
  - Within a radius of 0,7 km 78,9% of Houses supplied
  - Threshold -110 dB

Coverage Analysis – Results 2100 MHz



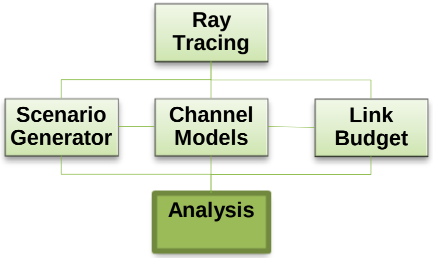
Cost231WI@2100MHz

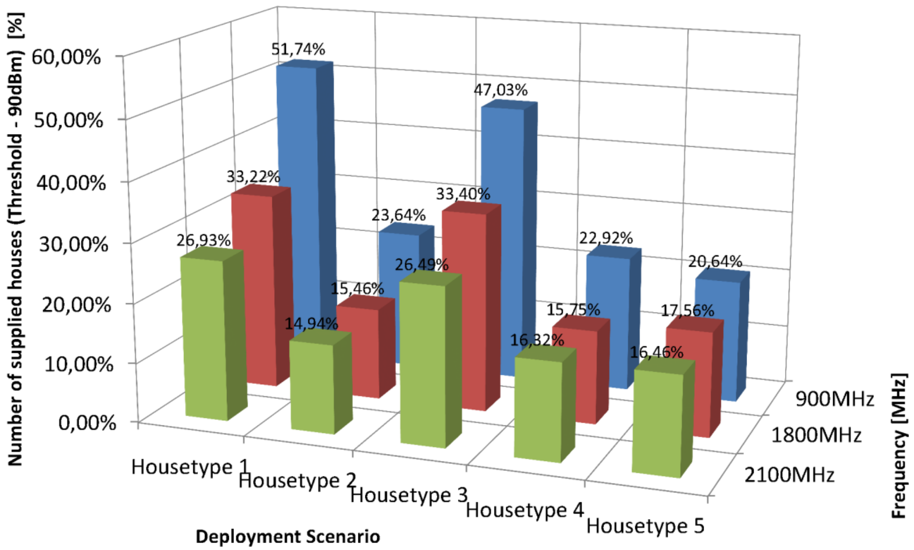


Coverage Analysis of Real-World Scenario using Cost 231 WI Building Penentration Channel Model at 2100 MHz

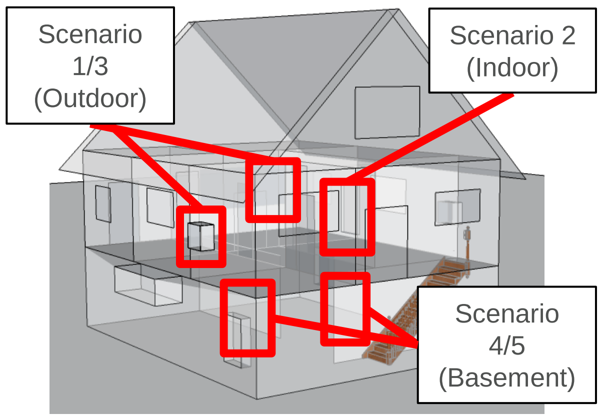
- Single Basestation for validation purpose without network infrastructure and sectorization
- Cost231 WI at 900 MHz:
  - Within a radius of 0,7 km 78,9% of Houses supplied
  - Threshold -110 dB
- Cost231 WI at 2100 MHz:
  - Within a radius of 0,7 km 35,9% of Houses supplied
  - Threshold -110 dB

Coverage Analysis – Results





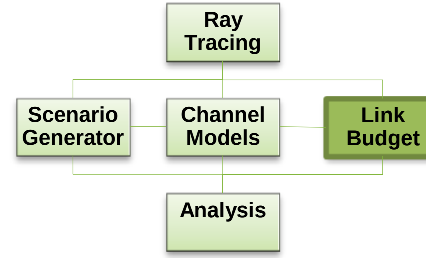
Coverage Analysis for Large-Scale Scenario using Cost 231 WI Building Penentration Channel Model

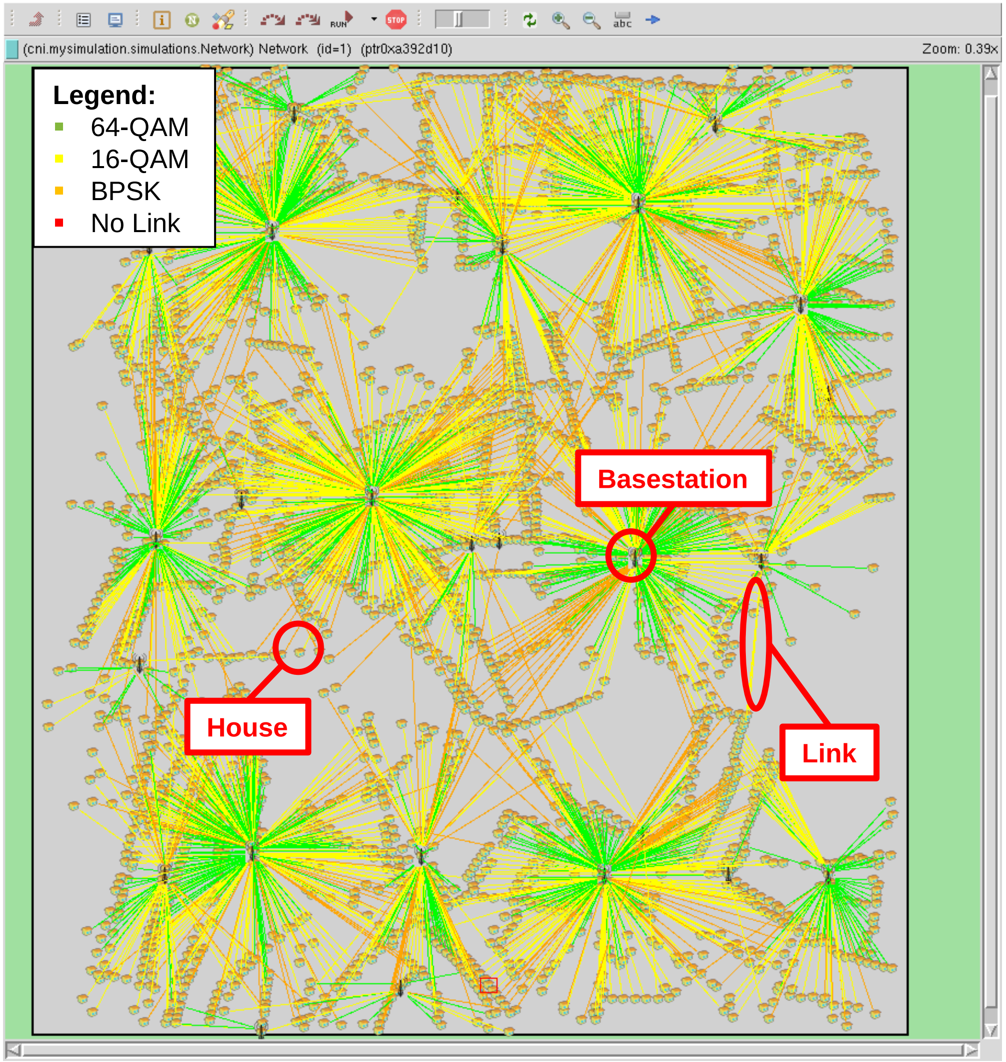


Installation Scenarios

- Single Basestation for validation purpose without network infrastructure and sectorization
- Comparison at threshold -90 dB
- **900MHz:**
  - Outdoor ~ 50 % supplied
  - Indoor ~ 24 % supplied
  - Basement ~ 20 % supplied
- **2100MHz:**
  - Outdoor ~ 27 % supplied
  - Indoor ~ 15 % supplied
  - Basement ~ 16 % supplied

Link Budget / Channel Capacity Calculation





Link Budget and Network Analysis for Real-World Scenario for Mobile WiMAX

- Link Adaption based upon antenna gain and pathloss

$$LinkBudget = P_{Sender} + G_{Antenne} - PL$$

- Bit Error Rate Calculation based upon modulation scheme

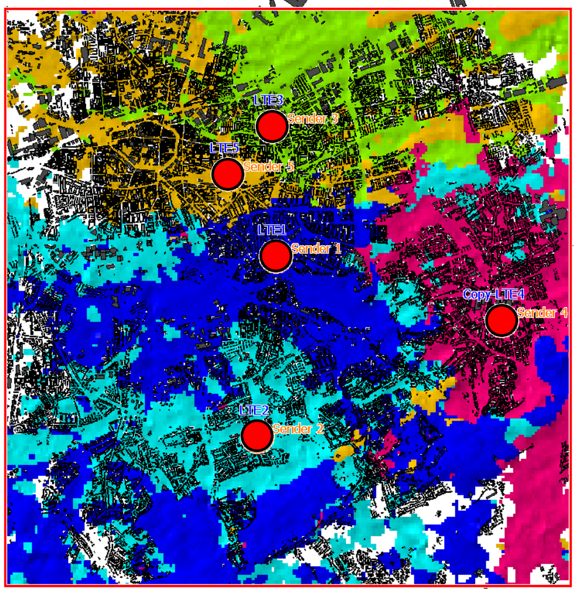
$$\mathrm{BER}(M-QAM) = \frac{\sqrt{M}-1}{\sqrt{M}} \cdot \frac{1}{\mathrm{ld}\sqrt{M}} \cdot \mathrm{erfc}\left(\sqrt{\frac{E_b \cdot \mathrm{ld}(\sqrt{M}) \cdot 3}{N_0 \cdot (M-1)}}\right)$$

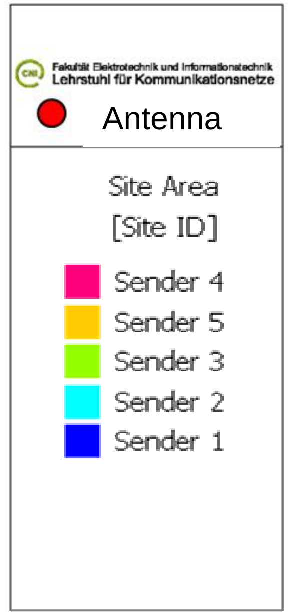
- Complex Scenario with network infrastructure (e.g. 802.16e network)

- Parameter:
  - Mobile WiMAX / 802.16e
  - COST231 Building Penetration
  - Threshold BER > 10^{-3}

Network Planning: Greedy vs. Genetic Algorithms

Greedy-Algorithm

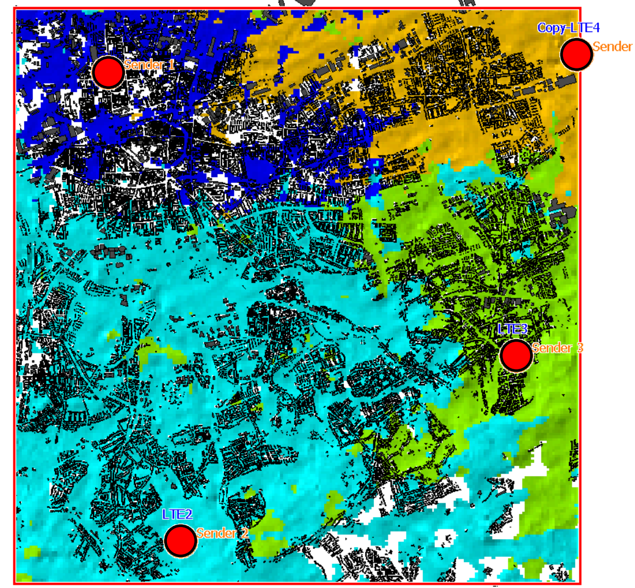




Example:
LTE800 in Dortmund

Sender Power: 15W EIRP
Antenna Gain: 0 dBi
Outdoor-Verbindung

Genetic Algorithm



Conclusions and Outlook

- Results show strong impact on reachability for indoor / basement installations with restrictions to:
  - Accurate antenna alignment for indoor installations required
  - Incidence angle has strong influence on signal strength
  - Transition loss for basement coverage adds up to 25 dB pathloss
  - Enhancements to existing propagation channel models required
- As expected, lower frequency ranges show better performance than usual mobile frequencies (up to 50 % coverage):
  - e.g. LTE / Mobile WiMAX at 800 MHz, TETRA, CDMA 450
- Results enable detailed network planning and optimization methods for wireless networks
- Current work focusses on the analysis of lower frequency ranges (169 MHz, 450 MHz)

On-going work

Laboratory and field testing

- Measurements under real conditions
- Comparison of network technologies under controlled conditions
- Latest network technologies available

Laboratory Equipment

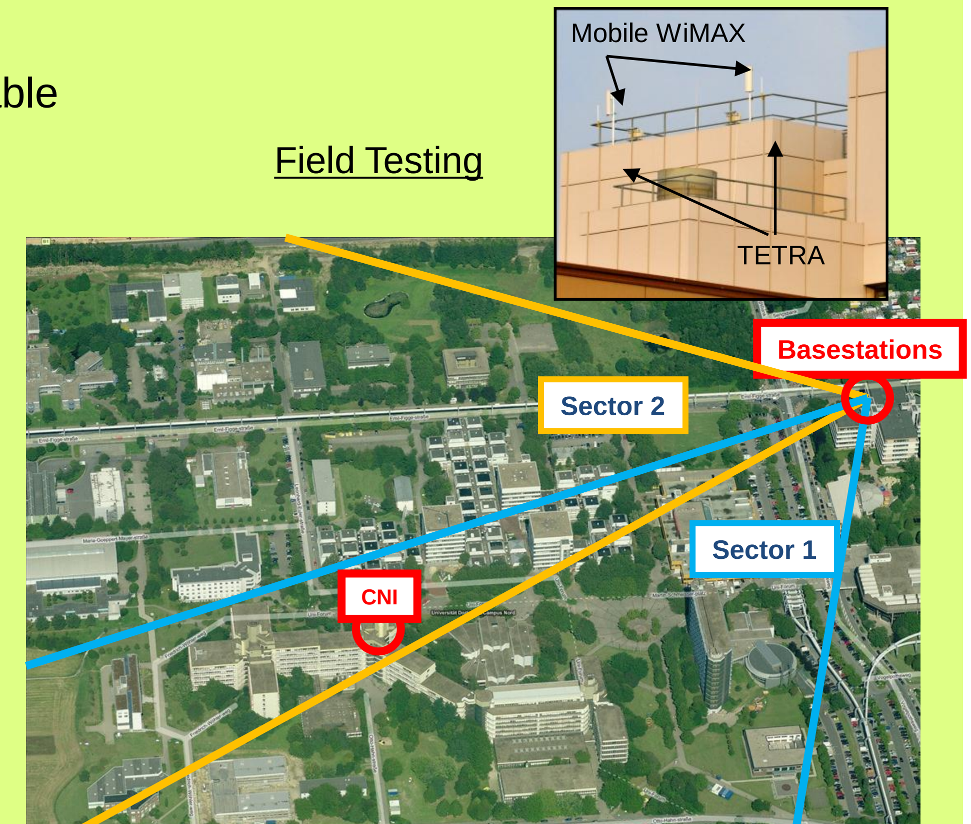
Basestation Emulator
(GSM, UMTS, LTE, Mobile WiMAX)

Deployment Scenario

Channel Emulator

Field Testing

Outdoor Units



CNI Radio Testing Site

Thank you for your Attention!

Contact Information

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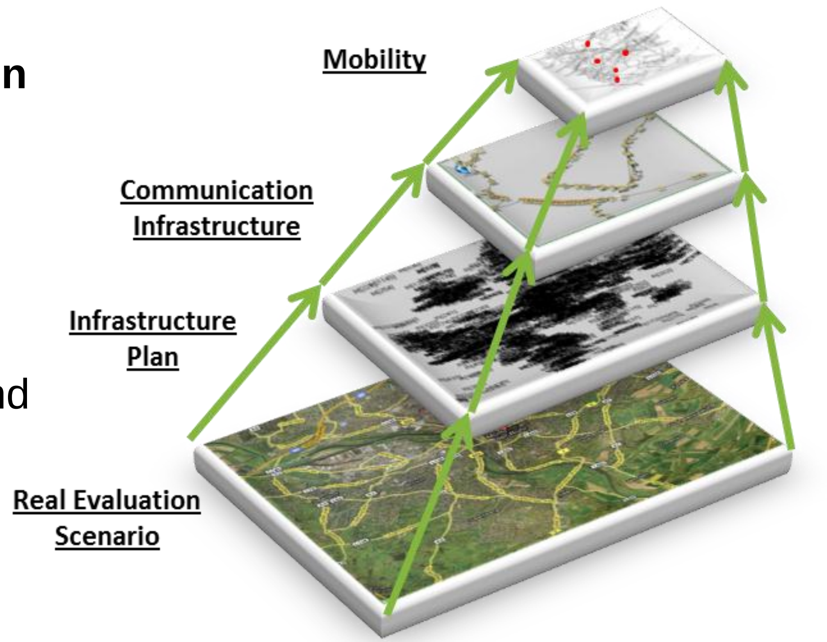
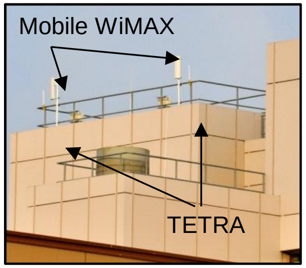
Competences and Activities regarding Smart Grid

- Design of **interoperable** Web Service based **Architectures for ICT** in Electric Vehicles and Smart Grid
- **Specification, Evaluation and Optimization** of System Characteristics and Protocols for various Smart Grid relevant Technologies
- **Model-driven Protocol Validation** and **Security Analysis**
- **PHY and MAC Layer Analysis** for Wired and Wireless Communication Technologies (e.g. PLC, IEEE 802, LTE, etc.)
- **Scalable Simulation Environment** for ICT Architectures and Technologies



- Contributions and active Participation in **ISO/IEC** for the ***Vehicle-to-Grid Communication Interface*** (in close Cooperation with RWE & Siemens)
- Participation in **Standardization of Embedded Web Services** (Device Profile for Web Services) at OASIS

CNI Resources



- **Research Labs and Tools**
  - Communication Network Emulators and Testbeds (2G/3G/4G, Fixed/Mobile WiMAX, LTE, Zigbee, WLAN mesh and PLC), Out-door Testing Site
  - Spectrum Analysis Laboratory Equipment
  - Multi-scale Simulation Environment (incl. Geo referenced Mobility Models)
- **Scientific Publications and Standardization**
  - Approx. 20 publications at major IEEE conferences per year
  - Regular TPC membership IEEE ICC, Globecom, VTC, Smart Grid Comm, Homeland Security, …
  - Contributions to IETF (Mobile IP), OASIS (Device Profile for Web Services) and ISO/IEC (Vehicle2Grid)
- **Regular European activities**
  - Several European-funded projects, Lead Scientist in the IST-MORE Project
  - Regular Review Expert of 7FP ICT and Security Call Project Proposals