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Performance Evaluation of Wireless M2M Communication Technologies for Smart Grid Applications

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Agenda

- **Introduction**
  - Requirements for ICT systems in Power Grids
  - Wireless M2M Technologies for Smart Grids Applications
  - Automated Meter Reading and Smart Grid Architectures
- **RF Mesh Systems for Automated Meter Reading**
  - Frequency / Coverage Analysis
- **Integration of Customers into Smart Distribution Grids (Access Networks)**
  - Frequency / Coverage Analysis (Small-Scale vs. Large Scale)
  - Performance Evaluation of Access Technologies
  - Additional Installation Scenarios and Performance Evaluation
- **Conclusion and Outlook**

Requirements for ICT Systems in Power Grids

Scalability of systems, technologies and applications:

- *Coverage*
- *Data Traffic*
- *Interoperability*
- *Availability*
- *Quality of Service*
- *Security*

Inhouse
(~10 entities, m)

City
(10^3 - 10^5 entities, km)

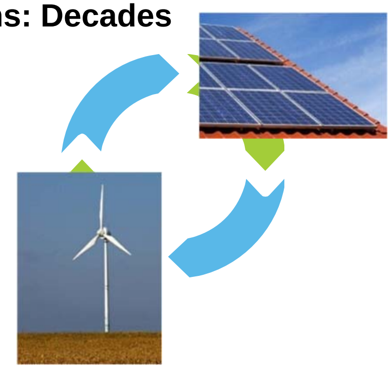
Countries / Continental
(>10^6. entities, 1000 km)

Different Technology Life-Cycles:

ICT Systems: Years

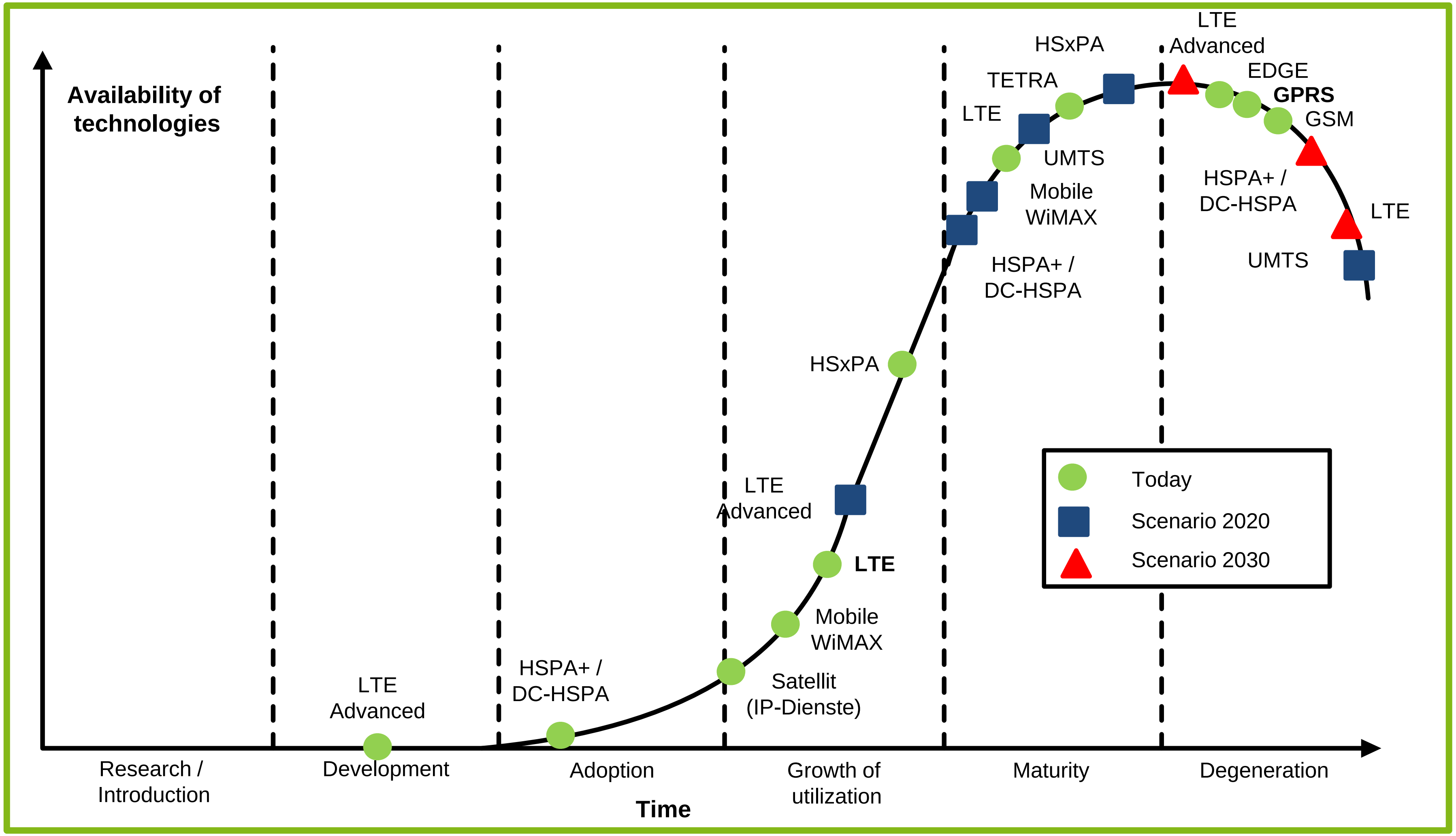
2007: iPhone
2008: 3G
2009: 3GS
2010: 4G
2011: 4GS
2012: 5
2013: 5S

Power Systems: Decades

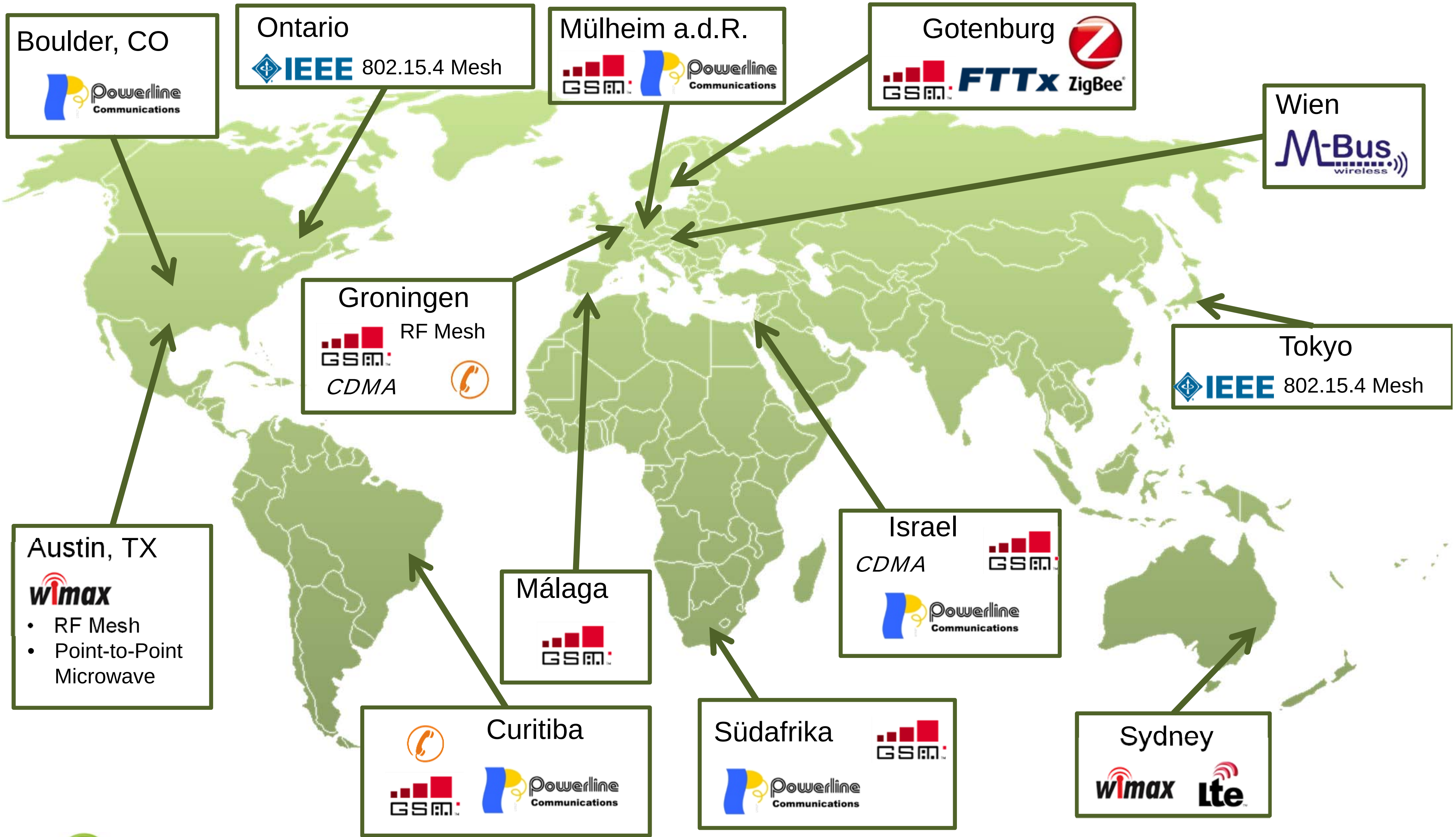


Quellen: Apple.com, Google.de

Technology Life-Cycles of Wireless Access Technologies



Reference Smart Grid Projects and Access Technologies



Wireless Access Technologies for Smart Grids

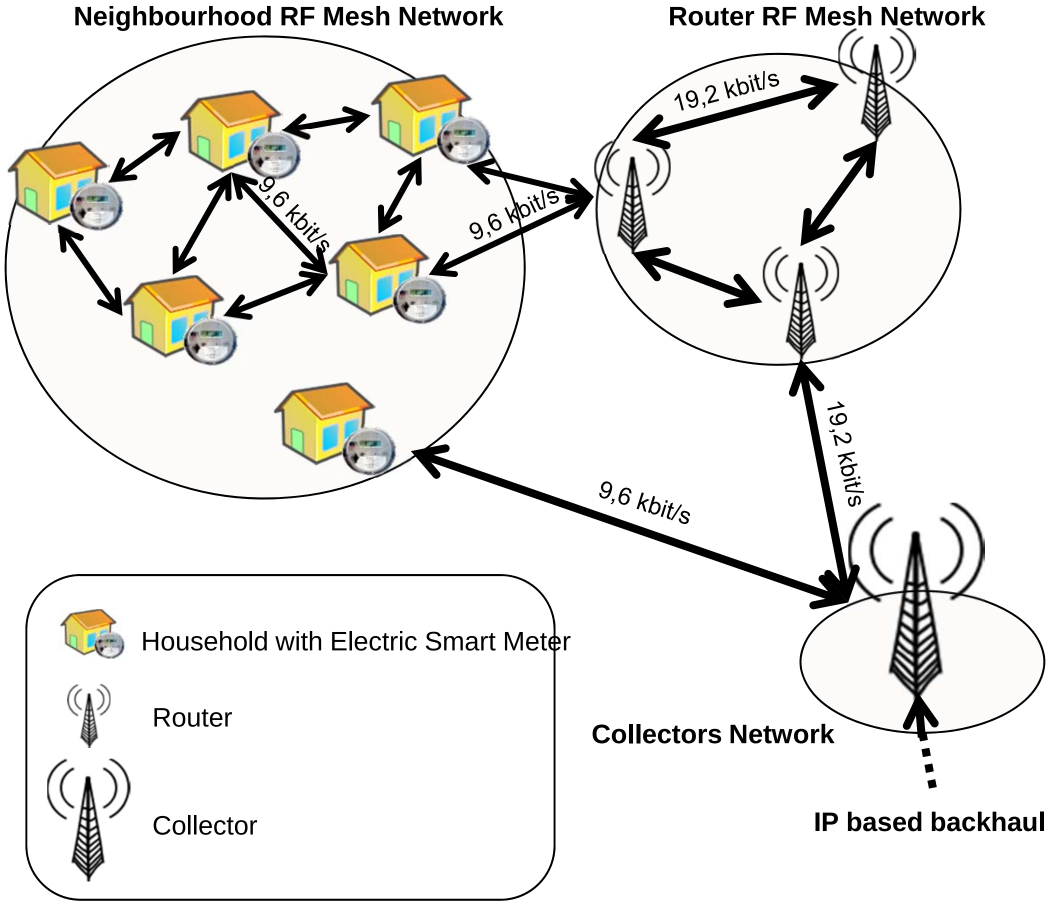
Technology	GSM	UMTS	TETRA	CDMA450	WiMAX	LTE
Modulation	GMSK (EDGE: 8-PSK)	QPSK (HSPA(+): 16-/64-QAM)	π/4 DQPSK	QPSK, 8-PSK, 16-QAM	BPSK, QPSK, 16-QAM, 64-QAM	QPSK, 16QAM, 64-QAM
Frequency	900 MHz 1,8 GHz	1,9 GHz, 2,1 GHz	BOS: 380-395 MHz Private: 400 MHz	450 MHz	2,6 GHz, 3,5 GHz	800 MHz, 1,8, 2,0, 2,6 GHz
Datarate	9,6 kbit/s (GPRS: 171,2 kbit/s, EDGE: 384 kbit/s)	2 Mbit/s (HSPA: 14 Mbit/s, HSPA+: 168 Mbit/s)	28,8 kbit/s	144 kbit/s (EV-DO & EV-DV): DL: 3,1 Mbit/s UL: 1,8 Mbit/s)	70 Mbit/s (up to 1Gbit/s for low mobility users)	DL: 350 Mbit/s UL: 75 Mbit/s
Coverage	up to 35 km	up to 20 km	up to 22 km	up to 45 km	up to 5 km	up to 10 km
Licence	First allocation: 1989 (D-Net), 1993 (E-Net) Until end of 2016	First allocation: Mid 2000 Until end of 2021	Reallocation of C-Band: Start of 2004 Until end of 2020		Allocation (3,5 GHz): End of 2006 Until end of 2021	First allocation: Mid 2010 („Digital Dividend“) Until end of 2025
Remarks	Experts: 10 additional years needed	First allocation revenue: approx. 50 bn. €	Bands cleared for general trunked radio systems (“Technology-neutral“)		Frequency range for general broadband usage, revenue: 56 M. €	First allocation revenue: 4,4 bn. €

Wireless Inhouse Technologies for Smart Grids

Technology	Bluetooth	EnOcean	KNX-RF	Wireless M-Bus	WLAN	ZigBee	Z-Wave
Frequency	2,4 GHz	868 MHz	868 MHz	868 MHz	2,4 GHz	2,4 GHz / 868 MHz (Europa)	868 MHz
Bandwidth	1 MHz	280 kHz	200 kHz	50 kHz	20 MHz	2 MHz (2,4 GHz) /600 KHz (868 MHz)	20 kHz
TX power	max. 20 dBm	max. 10 dBm	max. 13,98 dBm	max. 10 dBm	max. 20 dBm	0 dBm (class 3)/ max. 20 dBm (class 1)	0 dBm /max. 13,98 dBm
Modulation	GFSK	ASK	FSK	2-FSK	BPSK /DQPSK	BPSK (868 MHz) / OQPSK (2,4 GHz)	GFSK
Data rate	732 kBit/s	125 kBit/s	16 kBit/s	66,67 kBit/s	11 MBit/s / 54 MBit/s	250 kBit/s (2,4 GHz) / 20 kBit/s (868 MHz)	9,6 kBit/s
Coverage indoor	5 m - 10 m	30 m	30 m	30 m	25 m - 40 m	14 m	30 m
Coverage outdoor	100 m	300 m	100 m	500 m	>100 m	175 m	>200 m

RF Mesh Systems for Automated Meter Reading

Smart Meter (US)



System Parameter:

- 900 MHz RF Mesh
- 9,6 kbit/s per channel
- Slotted Aloha channel access
- Geo-based routing algorithm (Greedy Forwarding)
- Max. number of hops: 40
- Scenario 1: Small-scale scenario
- Scenario 2: Full-scale scenario (17.181 meters)

B. Lichtensteiger, B. Bjelajac, C. Müller and C. Wietfeld, "RF Mesh Systems for Smart Metering: System Architecture and Performance", Proceedings of the 1st IEEE International Conference on Smart Grid Communications (SmartGridComm 2010), Gaithersburg, Maryland, USA, Oct 2010, pp. 379-384.

RF Mesh Systems for Automated Meter Reading

- Geo-based small-scale evaluation scenario
- Comparison of frequency options for SRD at 2,4 GHz, 868 MHz, 450 MHz and 169 MHz

3d Simulation Model

RF Mesh Systems for Automated Meter Reading

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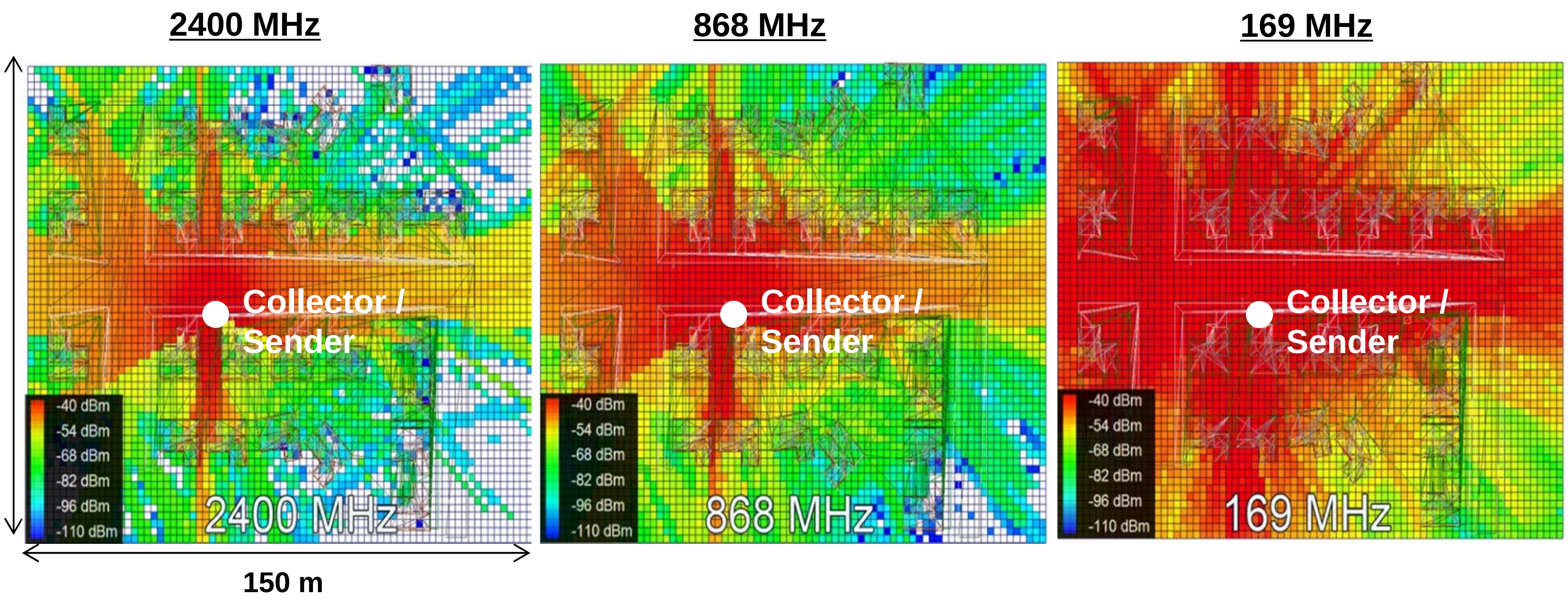
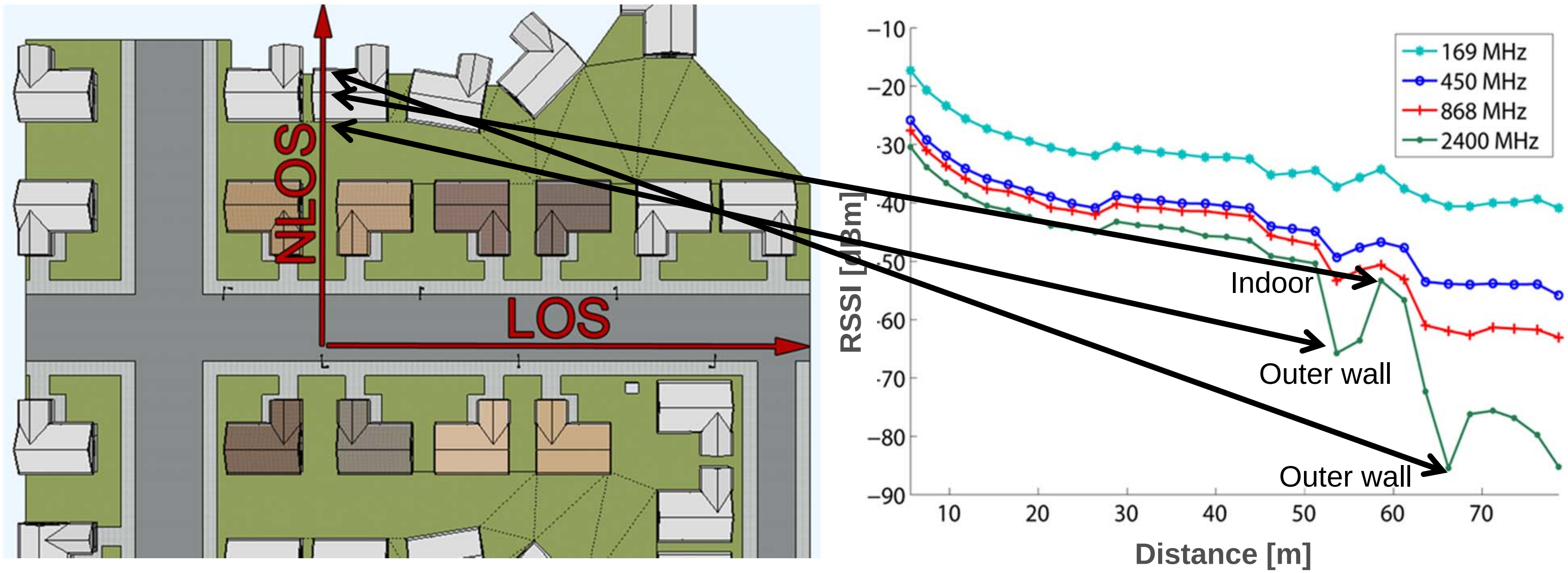


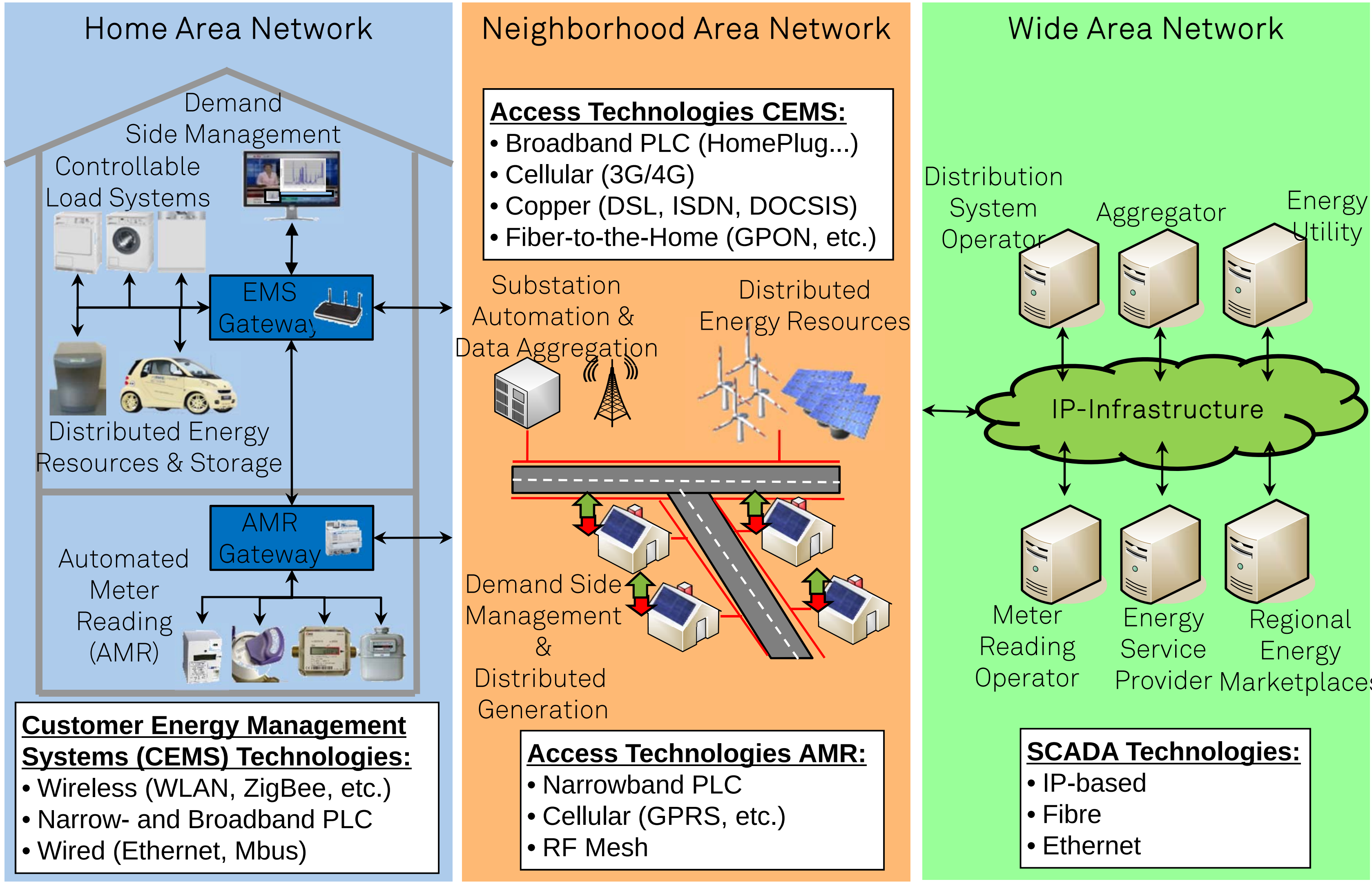
RF Mesh Systems for Automated Meter Reading


3d Simulation Model

- Geo-based small-scale evaluation scenario
- Comparison of frequency options for SRD at 2,4 GHz, 868 MHz, 450 MHz and 169 MHz
- Sub-GHz frequencies show better performance on building penetration



Customer Energy Management Systems in Smart Grids



Deployment Scenarios of AMR and CEMS Components

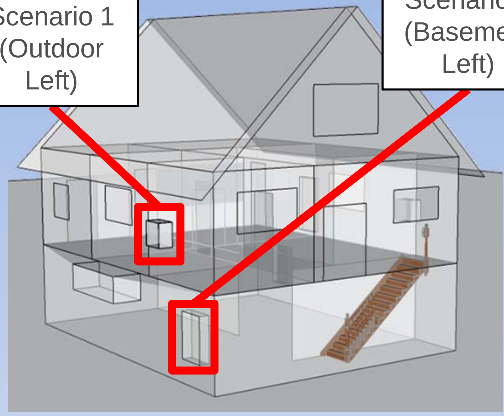
Real Life Scenarios

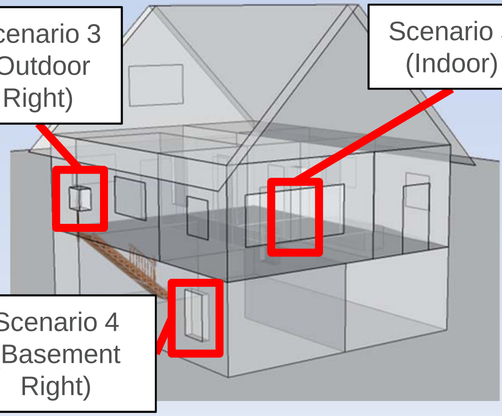
Outdoor Installation

Indoor Installation

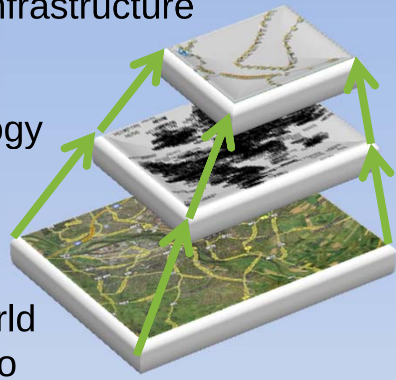
Basement Installation

Simulation Scenarios





Topology Scenarios



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

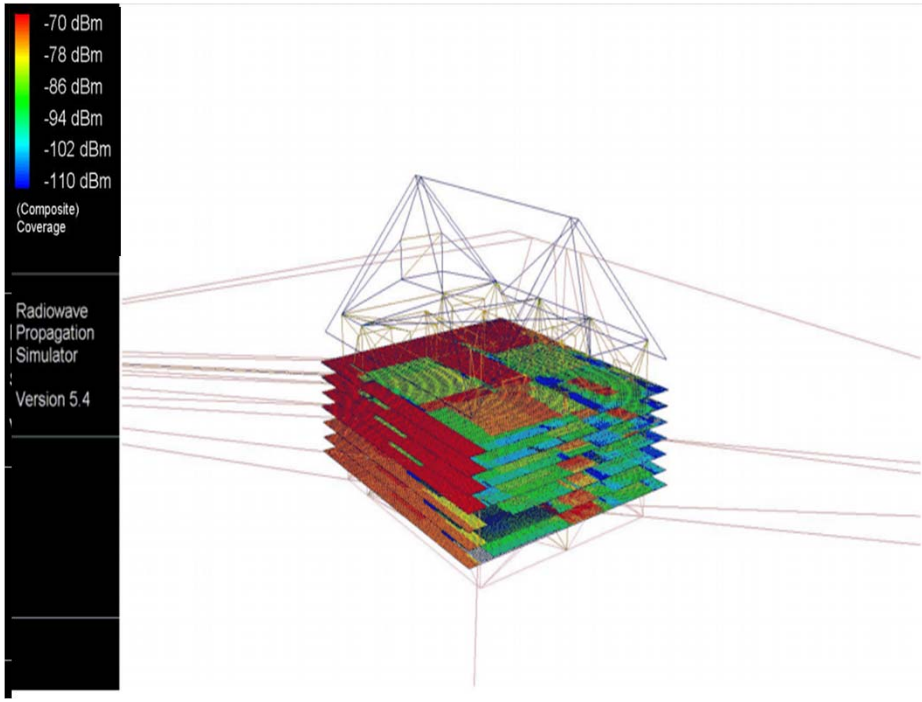
C. Müller, H. Georg, M. Putzke and C. Wietfeld, "Performance Analysis of Radio Propagation Models for Smart Grid Applications", 2nd IEEE International Conference on Smart Grid Communications (SmartGridComm 2011), Brussels, Belgium, Oct 2011, pp. 96-101.

Performance Analysis of Radio Propagation Models for Building Penetration

Small Scale Ray Tracing Analysis:

- 3D House Model
- Stepwise base station positioning (1 degree steps)
- Calculating signal strength on previously specified Inhouse positions
- Parameterization and Enhancements (lower Frequency range, basement) for Radio Propagation Models

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



Parameters for Cost 231 WI Building Penetration Channel Model:

$$L_{dB} = L_{fsp}(S+d)_{dB} + W_e + (1-\sin(\Theta))^2 \cdot W_{Ge} + Max(\Gamma_1, \Gamma_2)$$

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

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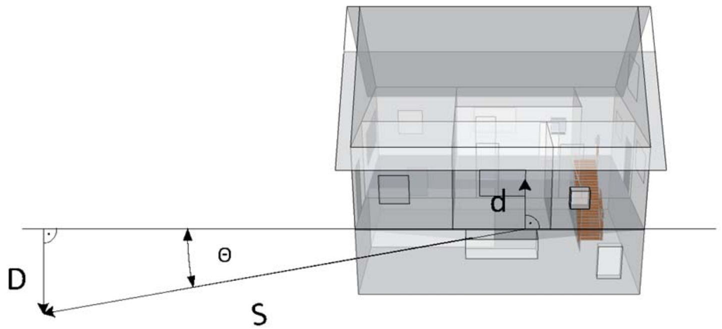
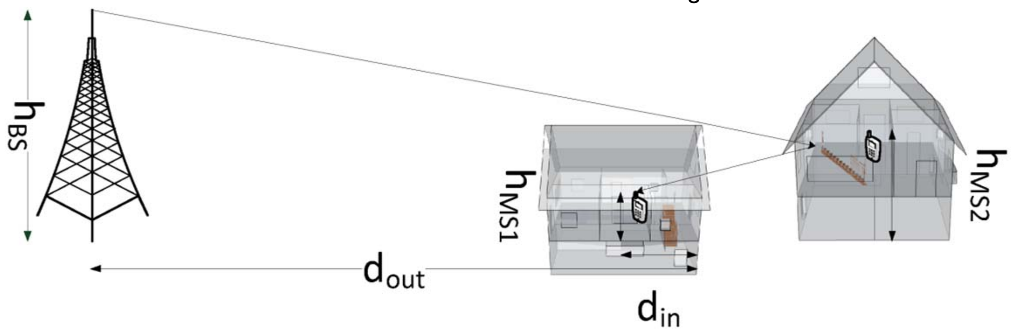


Parameters for Cost 231 Building Penetration



Parameters for Winner II C4

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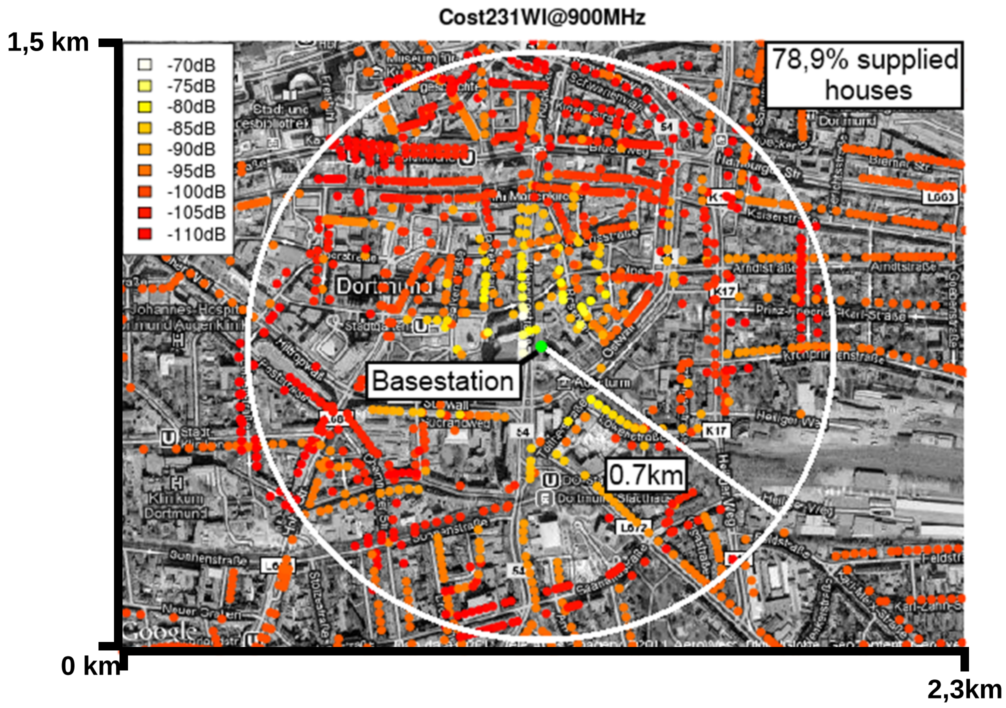
Performance Analysis of Radio Propagation Models for Building Penetration

Large Scale Analysis (real topology):

- Radio propagation models for outdoor-to-indoor transition
- 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 of Real-World Scenario using Cost 231 WI Building Penentration Channel Model at 900 MHz

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 2011), Brussels, Belgium, Oct 2011, pp. 96-101.

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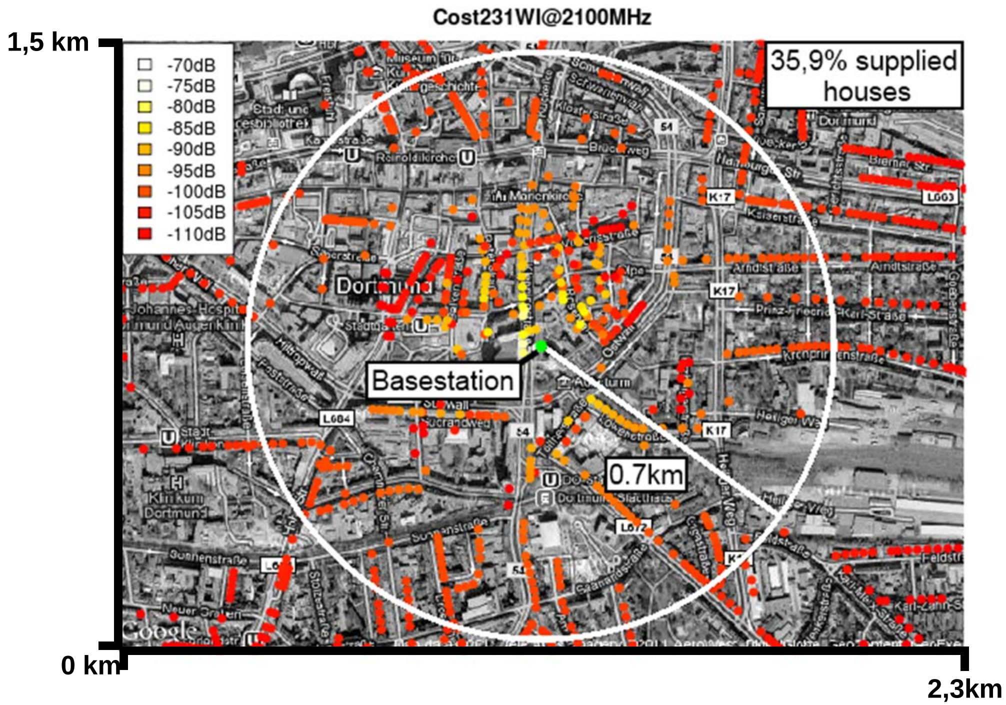
    - Threshold -110 dB



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

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 2011), Brussels, Belgium, Oct 2011, pp. 96-101.

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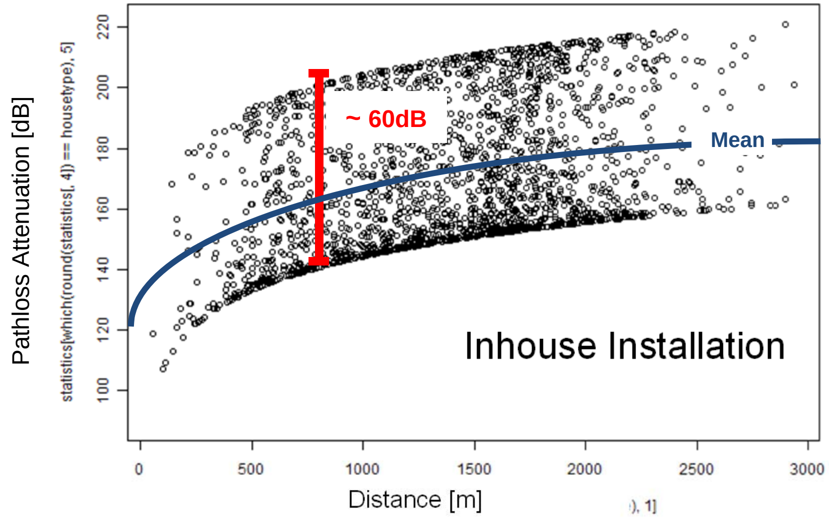

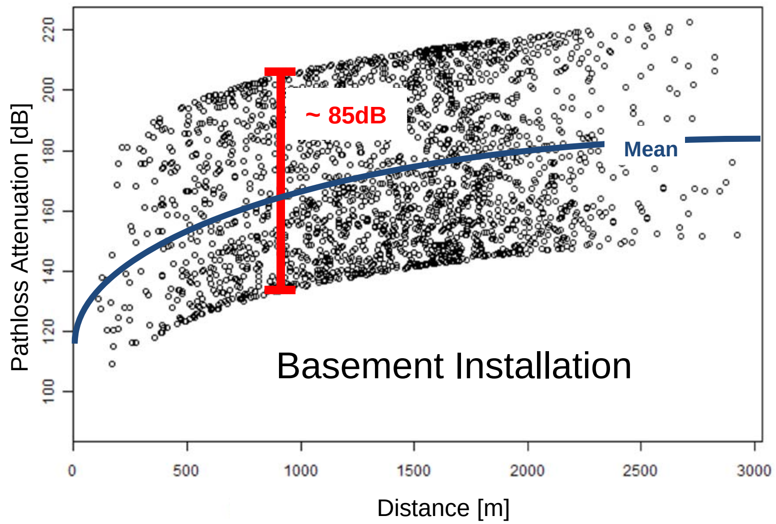

C. Müller, H. Georg, M. Putzke and C. Wietfeld, "Performance Analysis of Radio Propagation Models for Smart Grid Applications", 2nd IEEE International Conference on Smart Grid Communications (SmartGridComm 2011), Brussels, Belgium, Oct 2011, pp. 96-101.

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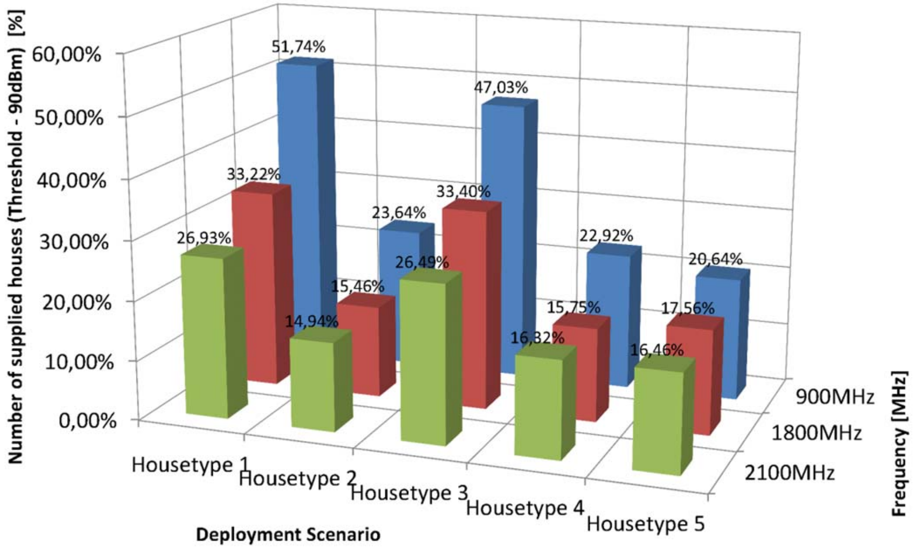
  - Within a radius of 0,7 km 35,9% of Houses supplied
  - Threshold -110 dB
- **Comparison 900 MHz / 2,1 GHz**
  - Outdoor: ~ 50 % vs. 27 % supplied
  - Indoor: ~ 24 % vs. 15 % supplied
  - Basement: ~ 20 % vs. 16 % supplied



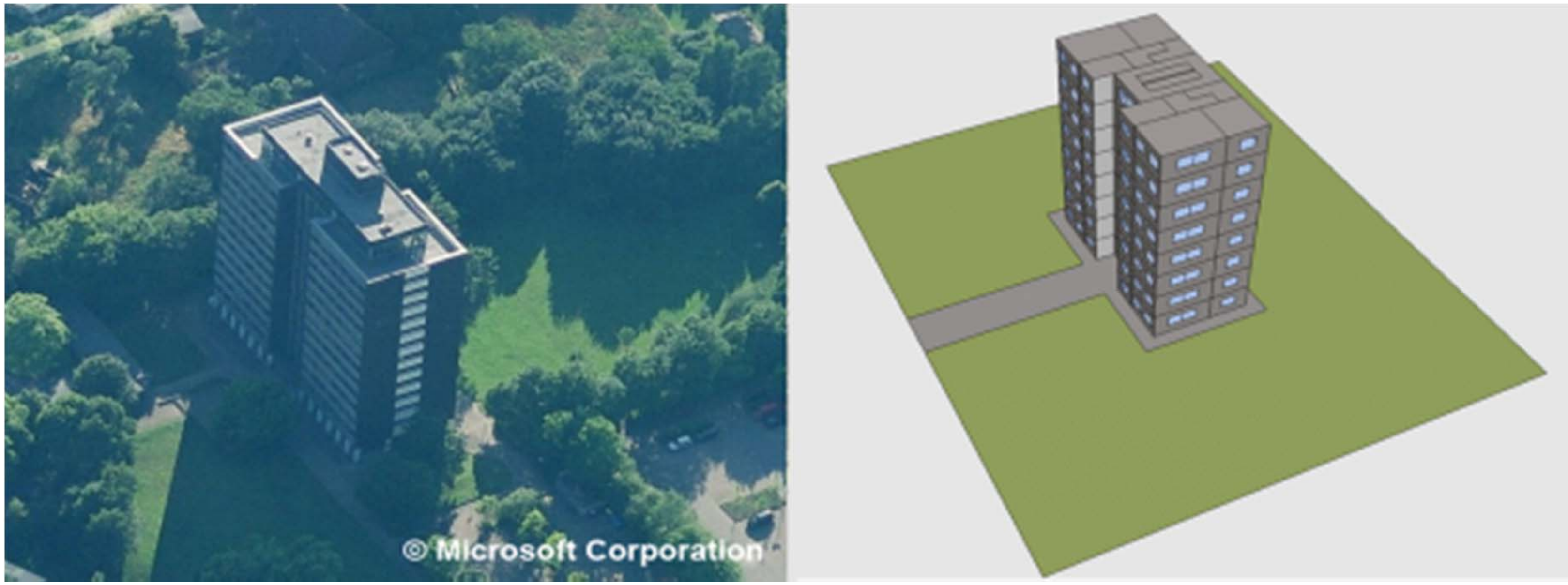
Coverage Analysis for Large-Scale Scenario using Cost 231 WI Building Penentration Channel Model (threshold -90dB)

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 2011), Brussels, Belgium, Oct 2011, pp. 96-101.

Performance Analysis of Frequency Options for Indoor Multi-Wall Penetration

- Typically apartment house installation scenario
- Comparison of frequency options for SRD at
  2,4 GHz, 868 MHz, 450 MHz and 169 MHz

3d Simulation Model



Performance Analysis of Frequency Options for Indoor Multi-Wall Penetration

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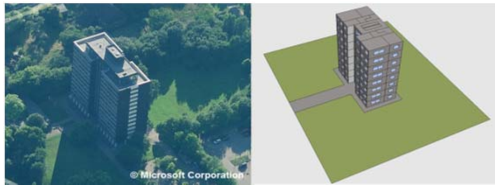

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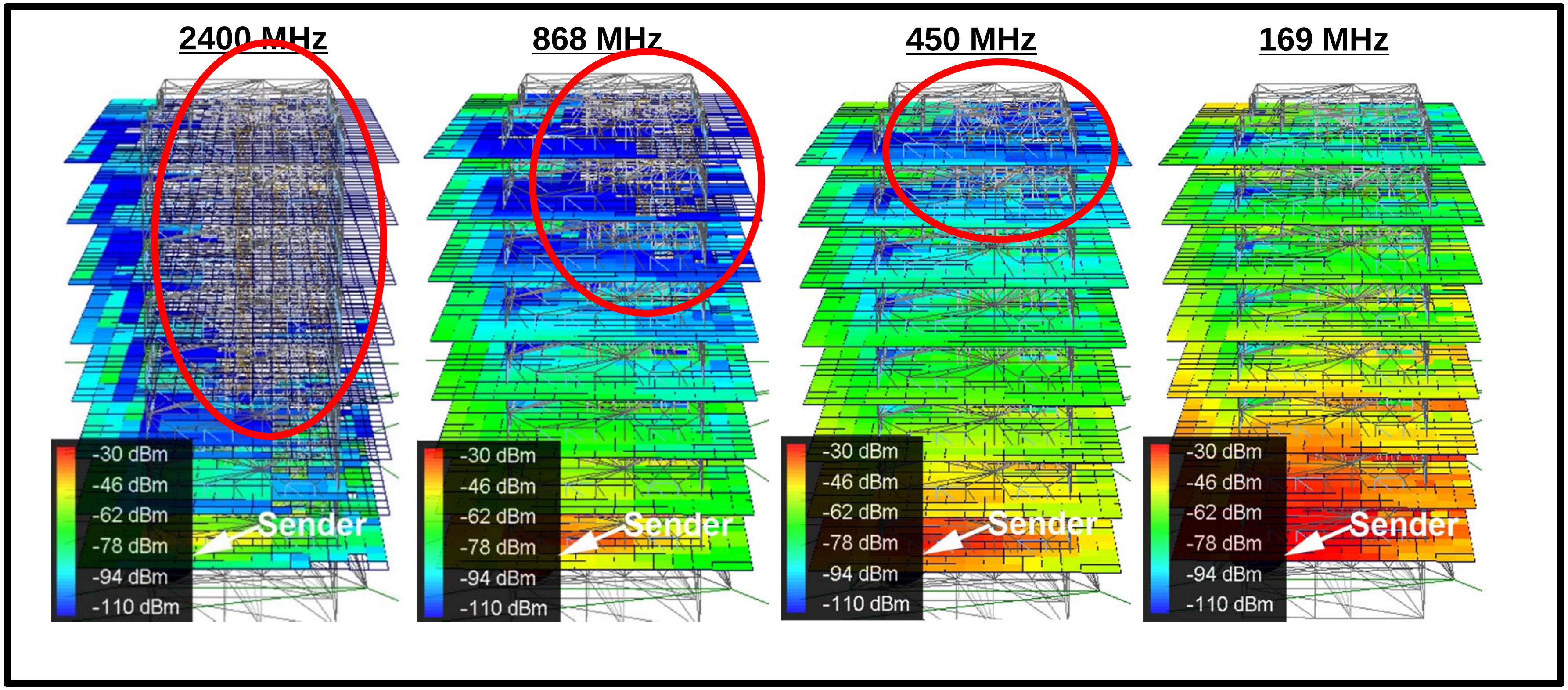

Performance Analysis of Frequency Options for Indoor Multi-Wall Penetration

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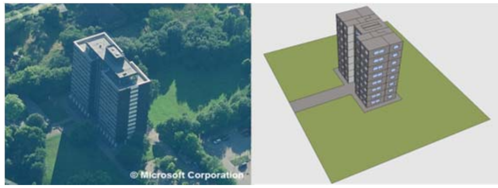
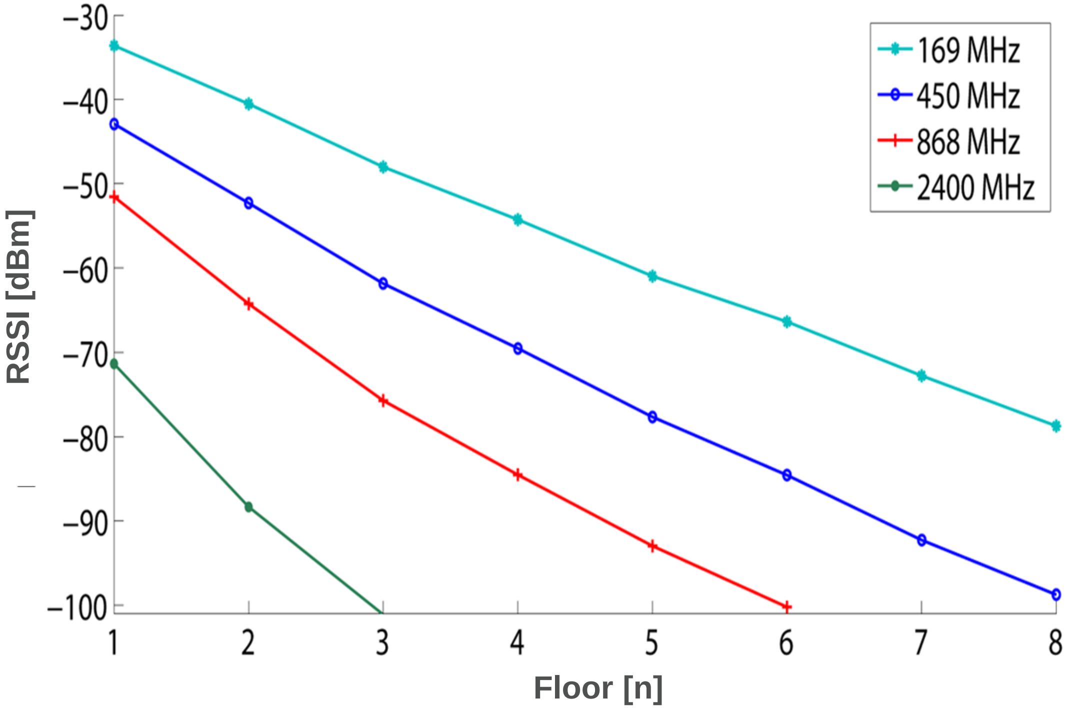


- Typically apartment house installation scenario
- Comparison of frequency options for SRD at 2,4 GHz, 868 MHz, 450 MHz and 169 MHz

- **Sub-GHz frequencies:**
  4 and more floors with average RSSI of -90 dBm, full coverage of example scenario with 169 MHz

- **2,4 GHz:**
  up to 2 floors with an average RSSI of -90dBm, usage for basement floor limited due to higher attenuation



Conclusion

- **General:** Wireless Technologies attractive options for Smart Distribution Grid Applications due to lower deployment costs for existing systems
    - **AMR Services:** Dedicated technologies (RF-Mesh, sub-GHz cellular)
    - **CEMS Services:** Dedicated technologies / value-added services
    - **LV mgmt. & ctrl.:** exclusive usage of dedicated frequency spectrums
- **Access Networks:** Strong impact on installation scenarios
    - Up to 25dB additional pathloss for basement installations (Accurate antenna alignment for indoor installations required)
    - Sub-GHz frequency ranges show better performance than usual mobile frequencies (up to 50 % coverage), e.g. LTE (i.e. MTC) / Mobile WiMAX at 800 MHz, TETRA, CDMA 450, RF-Mesh
- **Inhouse Networks:** Heterogeneous approaches
    - Usage of existing Inhouse systems possible (where applicable)
    - Solution for low-benefit or multi-party customers required

Acknowledgment

The presented results are based on the following CNI publications:

- *C. Wietfeld, H. Georg, S. Gröning, C. Lewandowski, C. Müller and J. Schmutzler, "Wireless M2M Communication Networks for Smart Grid Applications", Proceedings of the 17th European Wireless 2011 (EW 2011), Vienna, Austria, Apr 2011, pp. 275-281.*
- C. Müller, H. Georg, M. Putzke and C. Wietfeld, "Performance Analysis of Radio Propagation Models for Smart Grid Applications", Proceedings of the 2nd IEEE International Conference on Smart Grid Communications (SmartGridComm 2011), Brussels, Belgium, Oct 2011, pp. 96-101.
- B. Lichtensteiger, B. Bjelajac, C. Müller and C. Wietfeld, "RF Mesh Systems for Smart Metering: System Architecture and Performance", Proceedings of the 1st IEEE International Conference on Smart Grid Communications (SmartGridComm 2010), Gaithersburg, Maryland, USA, Oct 2010, pp. 379-384.
- C. Wietfeld, C. Müller, J. Schmutzler, S. Fries, A. Heidenreich and H. -. Hof, "ICT Reference Architecture Design based on Requirements for Future Energy Marketplaces", Proceedings of the 1st IEEE International Conference on Smart Grid Communications (SmartGridComm 2010), Gaithersburg, Maryland, USA, Oct 2010, pp. 315-320.
- L. Grunwald, „Analyse drahtloser Kommunikationslösungen zur Realisierung von Smart Home Anwendungen", BA 2012, CNI, TU Dortmund

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- *BMWi E-Energy Project E-DeMa „Development and Demonstration of Decentralized Integrated Energy Systems on the Way Towards the E-Energy Marketplace of the Future" - 01/2008 - 03/2013*

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