Exposure of the general public due to wireless LAN-applications in urban environments

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Background:

- Rapidly growing number of Wireless LAN (WLAN) applications in recent years

  ⇒ Public concern about the increasing number of Access Points in public areas

  ⇒ Only a few publications based on measurements available so far

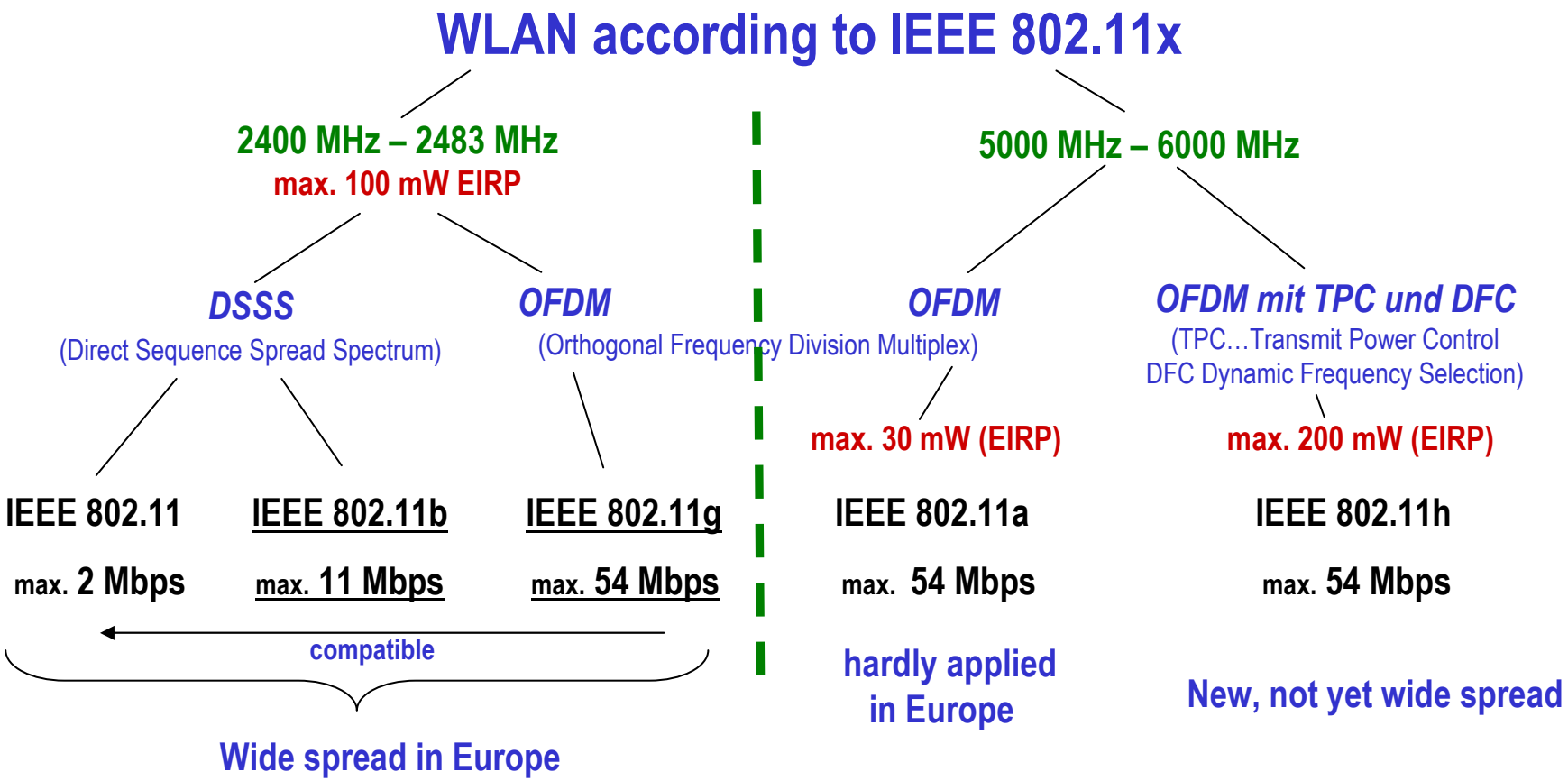
  ⇒ Hardly comparable measurement techniques applied

- Question of “typical” and worst case exposures due to WLAN applications

Project Outline:

- Characterization of WLAN parameters relevant for exposure assessment
- Definition of optimized measurement methods
- Selection of 6 real scenarios in Germany: 2 indoor
  2 outdoor in public places in the city center
  2 outdoor in residential areas
- Numerical computations of field distributions in these scenarios based on GTD/UTD-software (optical propagation)
- Measurement campaigns in the real scenarios

1. Characterisation of WLAN Systems (as far as relevant for exposure assessment):



WLAN according to IEEE 802.11b,g (2,4 GHz-ISM-Band)

Datenrate [Mbps]	Träger Modulation	Übertragungs-verfahren	Faltungs-Kodierrate	Standard
1	DBPSK	DSSS (11 chip Barker Sequ.)	-	IEEE 802.11
2	DQPSK			
5,5	DQPSK	DSSS (4 8-chip CCK)	-	IEEE 802.11b
11	DQPSK	DSSS (64 8-chip CCK)	-	
6	BPSK	OFDM (48 Datenträger +4 Pilot-Träger)	1/2	IEEE 802.11g
9	BPSK		3/4	
12	QPSK		1/2	
18	QPSK		3/4	
24	16QAM		1/2	
36	16QAM		3/4	
48	64QAM		1/2	
54	64QAM		3/4	

WLAN according to IEEE 802.11b,g

- Operating Frequency Range: 2400 MHz – 2483 MHz
- Transmission Mode: **IEEE 802.11b**: *Direct Sequence Spread Spectrum (DSSS),*
  occupied bandwidth per WLAN channel ≈ 22 MHz

  IEEE 802.11g: *Orthogonal Frequency Division Multiplex (OFDM)*
  (52 Carrier + 4 Pilot Carrier)
  occupied bandwidth per WLAN channel ≈ 17 MHz
- Medium Access : CSMA/CA (*Carrier Sense Medium Access/Collision Avoidence*)

⇒ in every channel only one station can transmit at a given time

⇒ sychronization of stations by Beacon Signal (approx. 2.5 ms long RF-Burst transmitted every 100 ms by Access Point)

- Transmit Power (EIRP): max. 100 mW EIRP

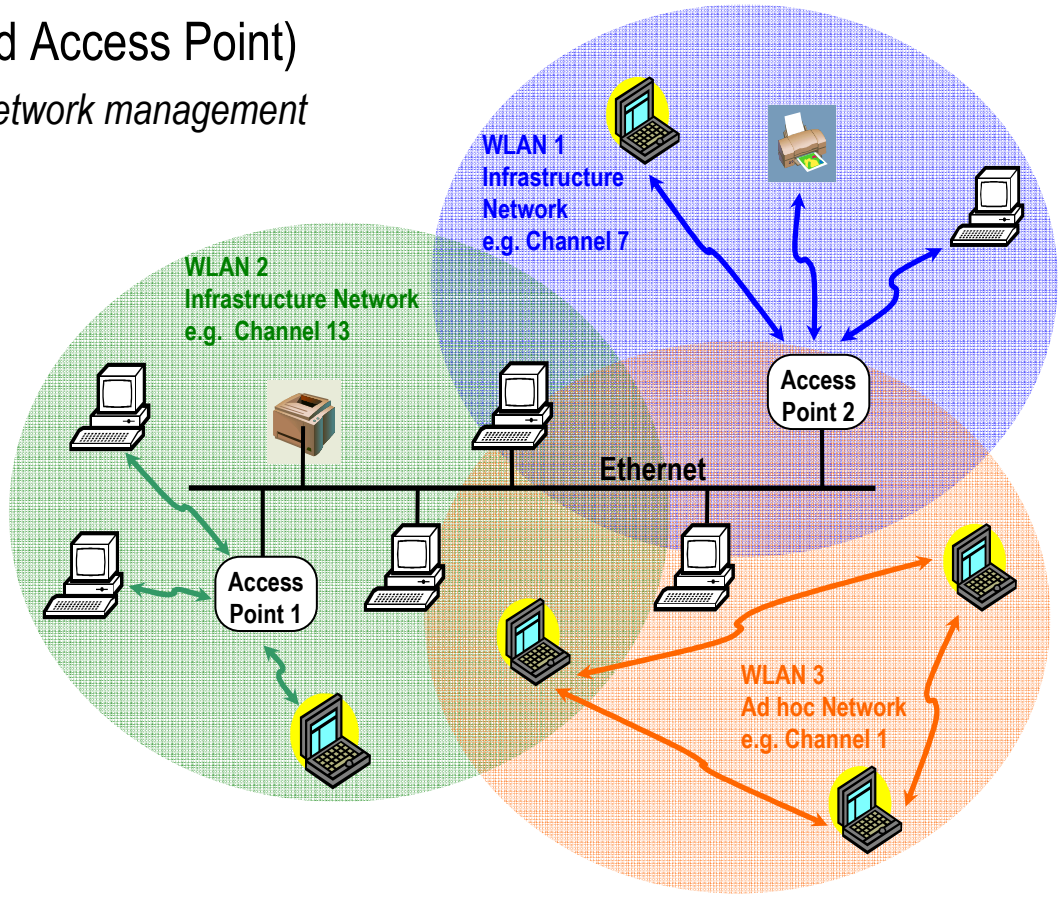
Possible Network Configurations

- Infrastructure network (with dedicated Access Point)
- Ad hoc network (without dedicated Access Point)

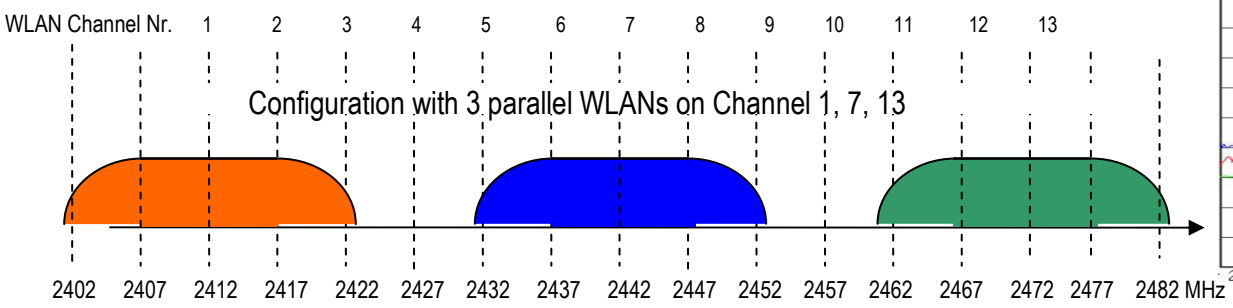
  one of the client stations takes over the network management

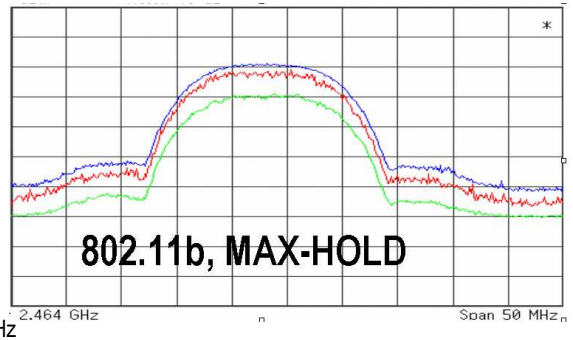
Spectral allocation

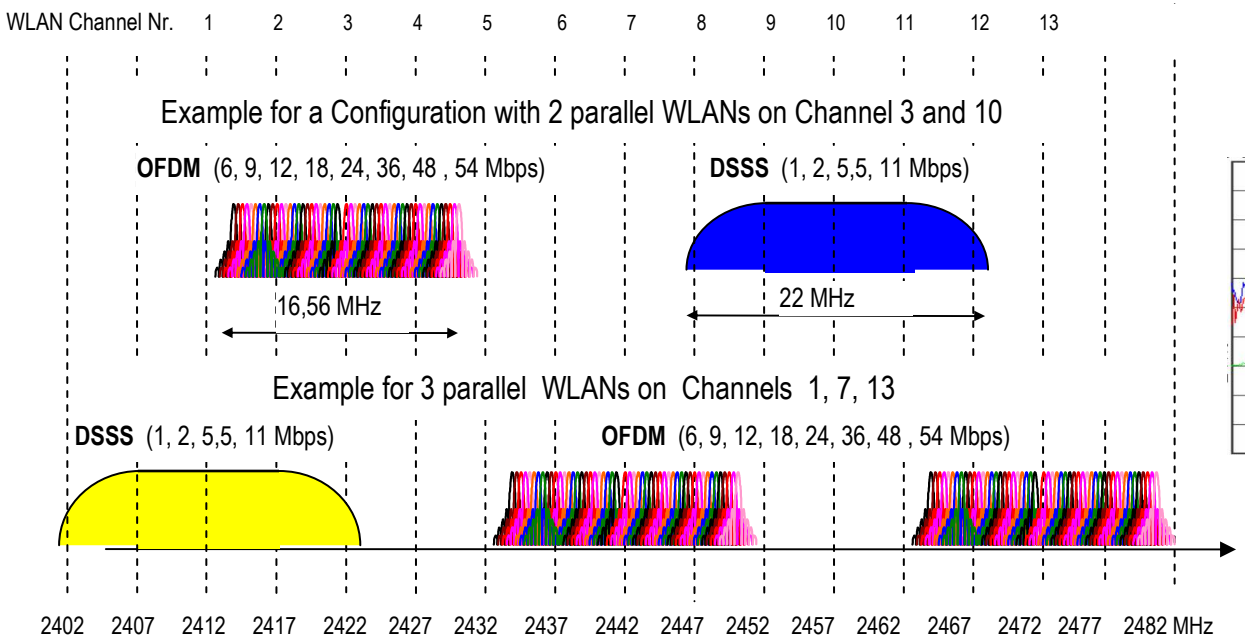
- 13 Channels (5 MHz wide) allocated between 2400 and 2483 MHz
- Maximum of 3 parallel WLAN Channels in a certain area

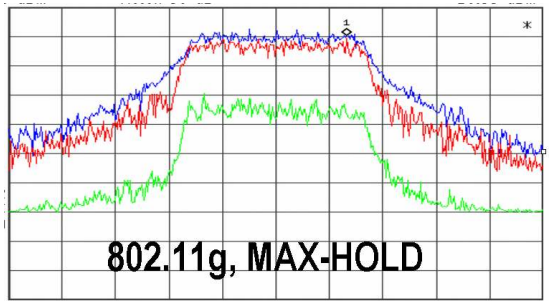


Examples for spectral allocations of WLANs









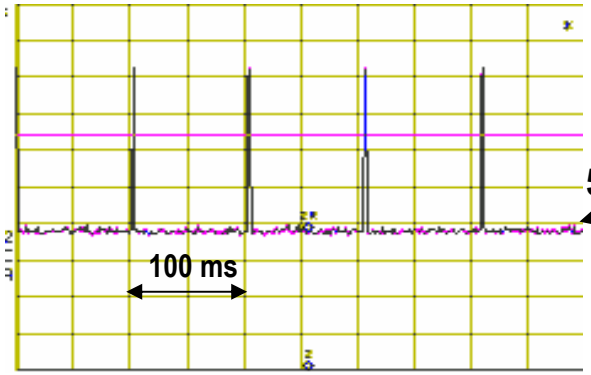
Time course of emitted WLAN Signals (1)

- Due to CSMA/CA medium access scheme WLAN stations are emitting RF-bursts. Burst duration and Burst repetition depend on the actual Data traffic (Data rate and structure of data) ⇒ statistical appearence of RF-bursts
- Stochastic signal characteristics within the RF-bursts due to DSSS and OFDM transmission
- Without data traffic in the network, the Access Points transmits only the Beacon Signal (approx. 2,5 ms Burst length, every 100 ms)
- At full (highest possible) data traffic only about 80% of the time can be occupied by RF transmission due to the medium access policy.

→ time averaged transmit power (EIRP) of a WLAN station (Access Point) can dynamicly vary between approx. 100mW*2,5/100= 2,5 mW (no traffic, Beacon only) and approx. 80% of the maximum Burst Power (i.e. 80mW), depending on the data traffic, network configuration, data structure (packet length).

Time course of emitted WLAN Signals (2)

- Beacon transmission of an Access Point

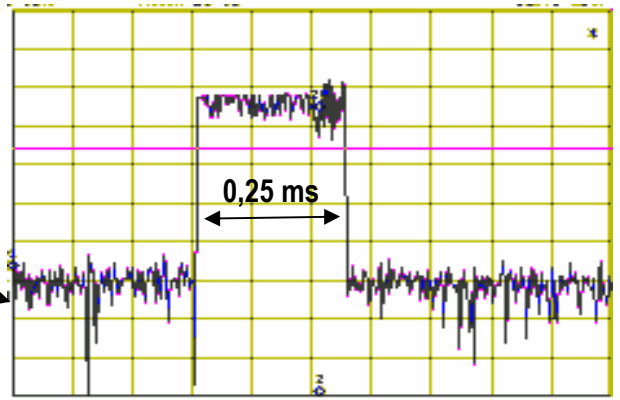


ZERO-SPAN Mode

500 ms Sweep time

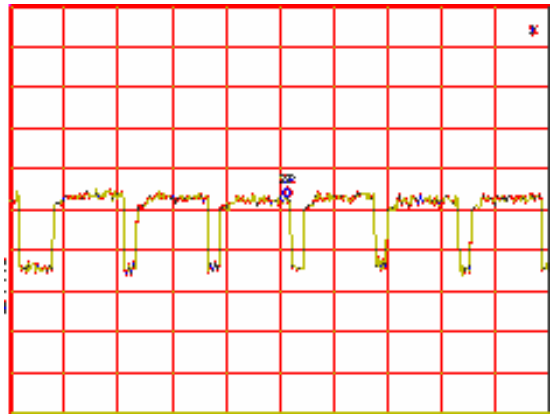
1 ms Sweep time

t/T_{eff} = 2.5%



- Access Point transmission for the case of a file transfer (one big file):

  Client A –(Ethernet)- AP–(Wireless)-Client B

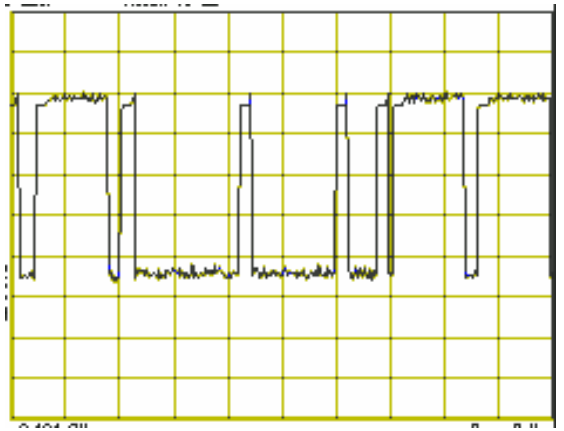


t/T_{eff} = 80%

Time course of emitted WLAN Signals (3)

- Access Point transmission for the case of a file transfer (one big file):

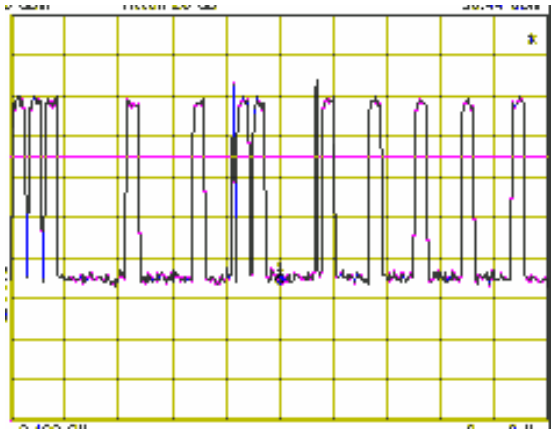
  Client A –(Wireless)- AP–(Wireless)-Client B



t/T_{eff} = 48%

- Access Point transmission for the case of a file transfer (multiple small files):

  Client A –(Wireless)- AP–(Wireless)-Client B



t/T_{eff} = 40%

⇒ in practice the maximum average (6 minute) t/T_{eff} is hardly higher than 20-30%

2. Implications for the applied measurement techniques

- Frequency selective measurements (antenna + spectrum analyzer)
- **RMS-Detector** necessary
  (peak detector would overestimate exposure due to stochastic signal characteristic of DSSS and OFDM)
- Resolution bandwidth (RBW) ≤ signal bandwidth
  ⇒ correction of measured amplitude necessary
- Problem of dynamic changes of emissions
  due to statistical characteristic of data traffic

Possible measurement modes:

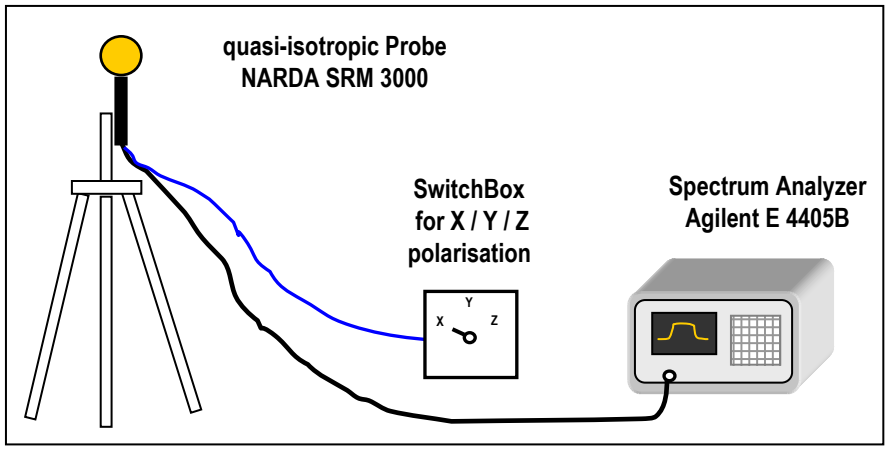
LIVE with averaging: remaining variations under heavy network load up to approx. 4 -6dB (1 sec. avg), depending on variation on the network load; peak values not assessed,

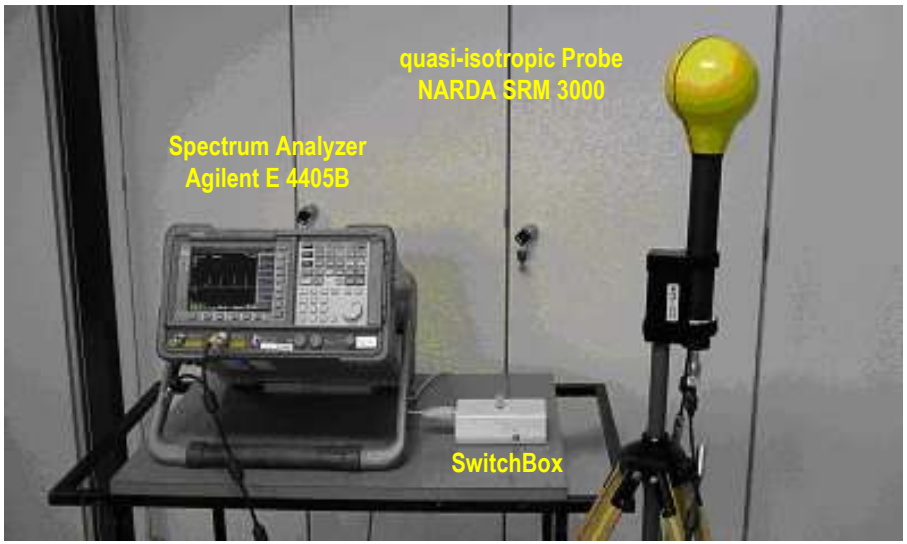
CHANNEL POWER with averaging: same as LIVE

MAX-HOLD: measure for peak value, significant overestimation (up to 30 dB, depending on actual data traffic) of time averaged exposure

⇒ approach: MAX-HOLD measurements and scaling according to expected data traffic

3. Measurement system used

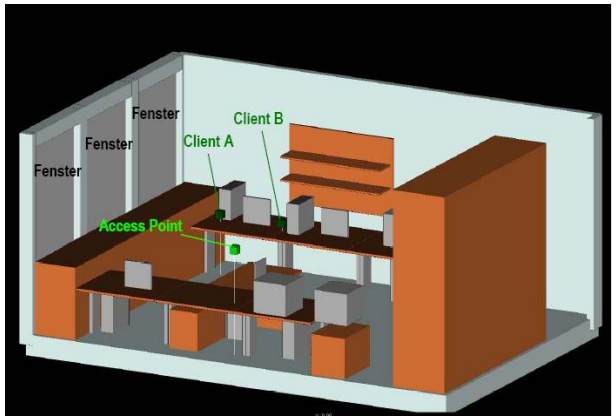


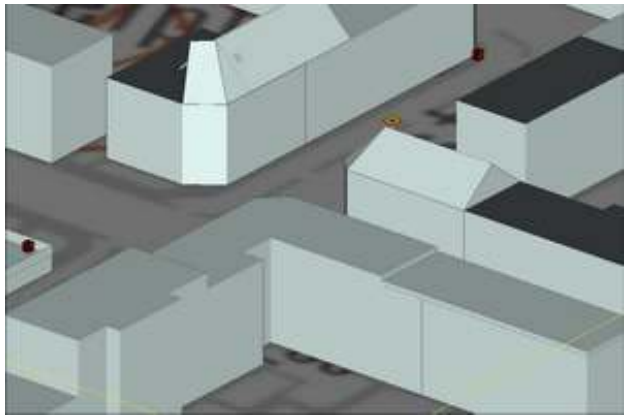


4. Numerical computation tool used

Wireless Insite 2.0.5 (Remcom Inc., USA)

- based on optical propagation
- amplitude **and** phase are considered
- transmissions, reflections and diffractions are considered
- possibilities of detailed (small scaled) indoor- as well as large scaled outdoor modelling

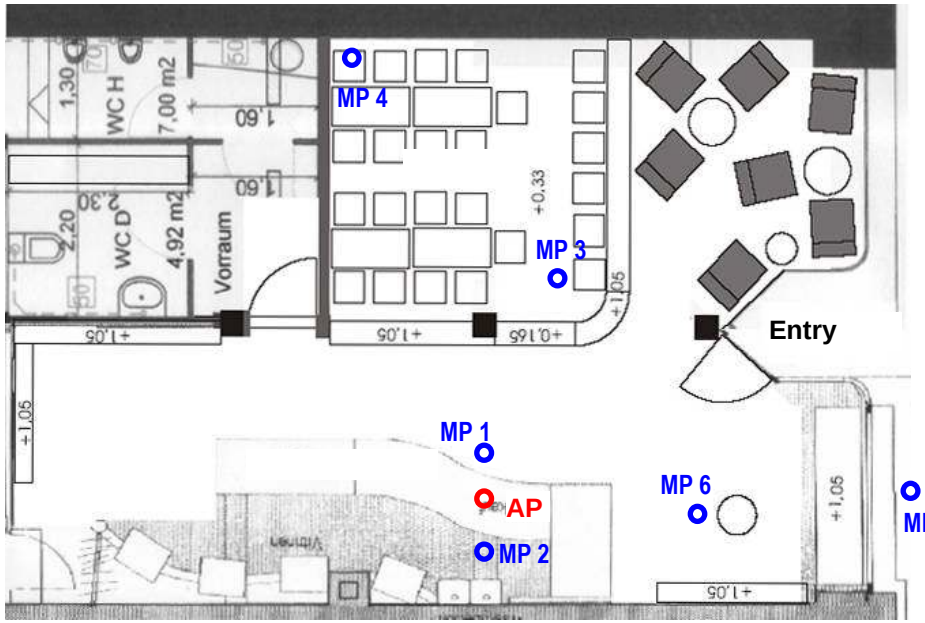




5. Results

Indoor Scenario: *Star Coffee, Heidelberg*

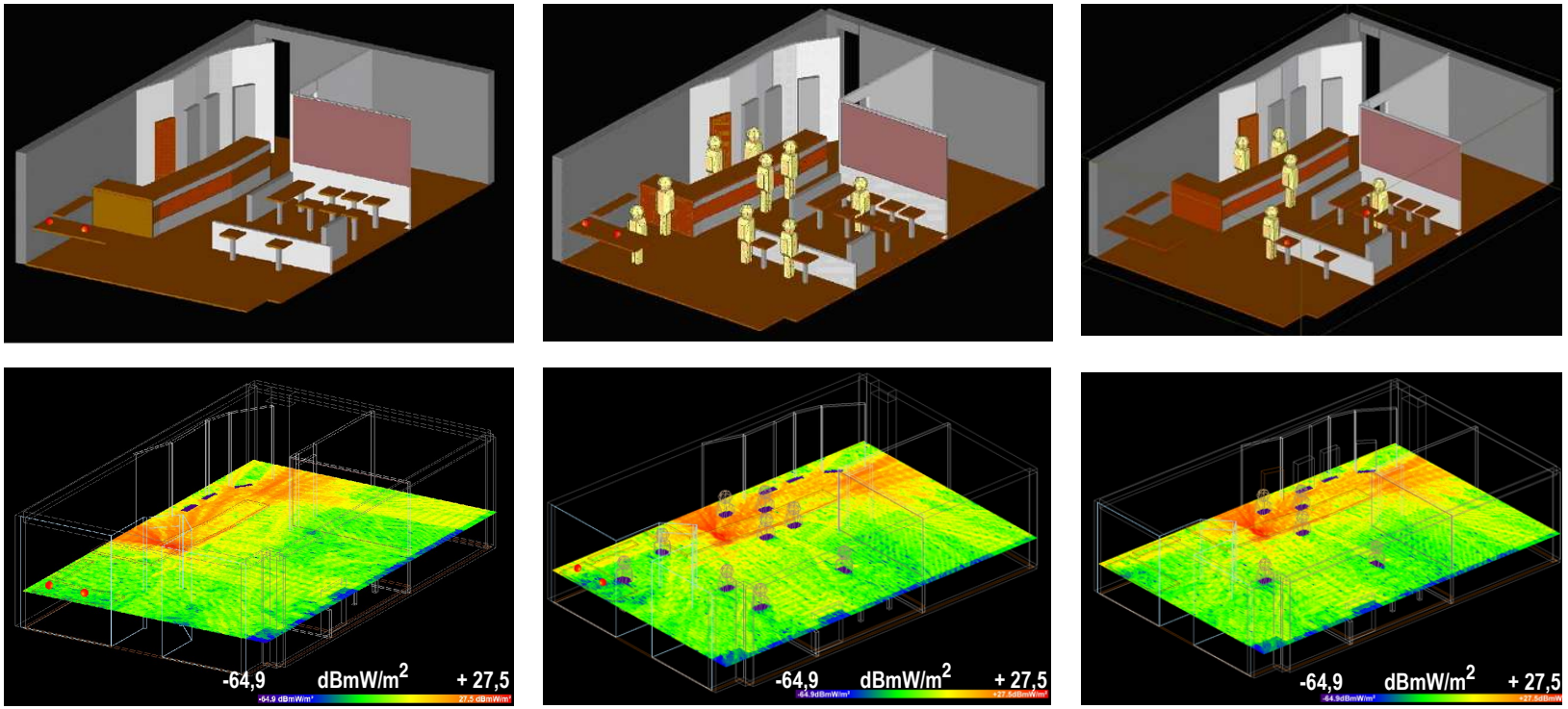
- 1 Access Point for providing internet connectivity for the customers



SOPHIENSTRASSE

Indoor Scenario: *Star Coffee, Heidelberg*

- Model in Wireless Insite (Access Point and different Clients at different locations)



Burst peak values (power flux density) of Access Point 1m above the floor

Indoor Scenario: *Star Coffee, Heidelberg*

- Numerical exposure assessment in selected areas (measurement positions MP):
  spatial average over 50 cm x by 50 cm area between 75 cm and 175 cm above floor

	effective Duty Cycle			Power flux density in mW/m²					
				MP1	MP2	MP3	MP4	MP5	MP6
Burst peak contribution	AP:	1.0	Spatial average	2.7692	12.5249	0.1308	0.0382	0.0041	0.0337
			Spatial Maximum	32.2903	123.445	0.9504	0.2740	0.0271	0.2013
	NB1:	1.0	Spatial average	0.0712	0.0352	0.2796	0.1268	2.4350	0.4458
			Spatial Maximum	0.4296	0.1669	1.7789	0.6147	13.7455	2.5420
	NB2:	1.0	Spatial average	0.6216	0.3667	0.2394	0.1628	4.3766	1.8139
			Spatial Maximum	2.5633	1.4595	2.7725	0.6185	17.8970	8.3095
Situation 1 combined, spatially avgeraged exposure	AP: NB1: NB2:	0.3 0.1 0.1	Spatial average	0.9000	3.7977	0.0911	0.0404	0.6824	0.2361
			Spatial Maximum	9.8056	37.0602	0.3975	0.1195	2.4118	0.8583
Situation 2 combined, spatially averaged exposure	AP: NB1: NB2:	0.6 0.1 0.1	Spatial average	1.8001	7.5953	0.1823	0.0808	1.3648	0.4722
			Spatial Maximum	19.6112	74.1203	0.7949	0.2391	4.8236	1.7167
Situation 3 combined, spatially averaged exposure	AP: NB1: NB2:	0.1 0.0 0.7	Spatial average	0.7120	1.5092	0.1806	0.1178	3.0640	1.2731
			Spatial Maximum	4.0877	12.5296	1.9715	0.4397	12.5288	5.8206
Situation 4 combined, spatially averaged exposure	AP: NB1: NB2:	0.003 0.0 0.0	Spatial average	0.01385	0.06262	0.00065	0.00019	0.00002	0.00017
			Spatial Maximum	0.16145	0.61723	0.00475	0.00137	0.00014	0.00101

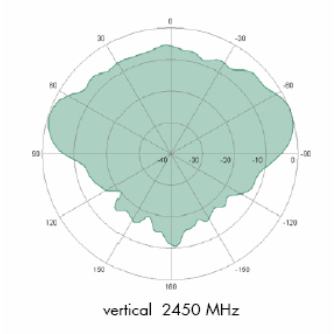
Indoor Scenario: *Star Coffee, Heidelberg*

- Measurements in the same measurement positions at 5 different heights between 75 cm and 175 cm above floor
- Deviations between measurements and computations with respect to spatial average of burst peak values in the considered measurement positions: approx. 4 dB
- Variations due to considered different locations of persons approx. 5 dB

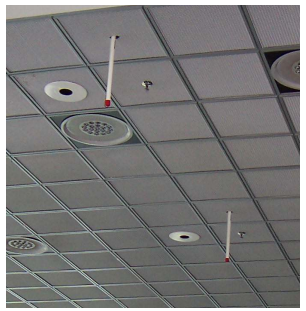
Indoor Scenario: *Airport, Frankfurt*

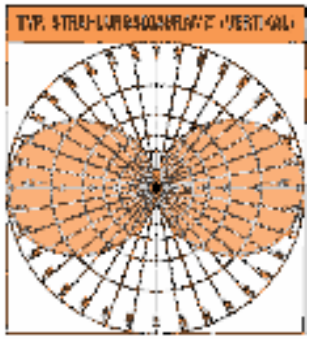
- 2 areas with 2 APs each for providing internet connectivity for waiting passengers

Area between Gates A1 to A5



Area between Gates A28 to A30

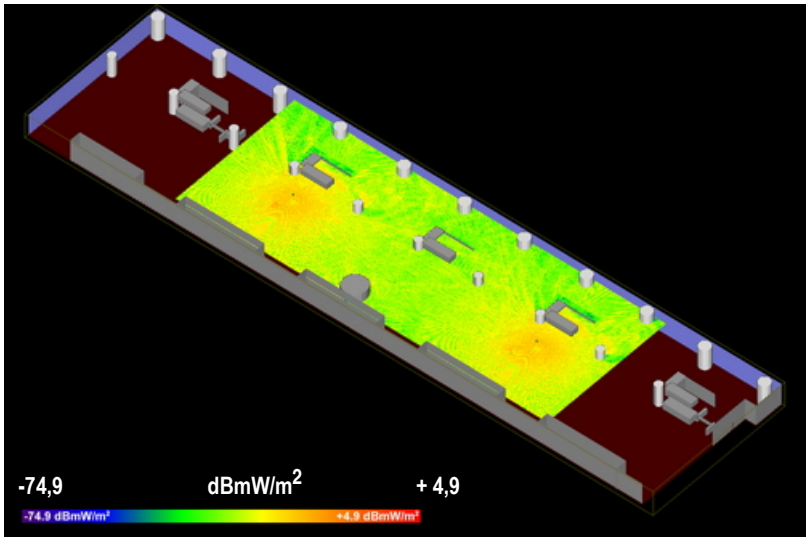




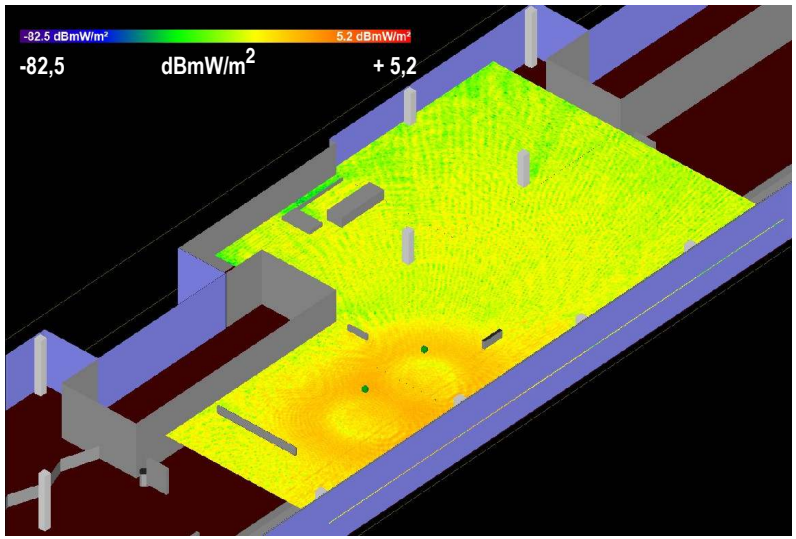
Indoor Scenario: *Airport, Frankfurt*

- 2 areas with 2 APs each for providing internet connectivity for waiting passengers

Area between Gates A1 to A5



Area between Gates A28 to A30



Time averaged combined exposure from Access Points without data traffic (beacon transmission only)
175 cm above floor

Indoor Scenario: *Airport Frankfurt*

- Numerical exposure assessment and comparative measurements in selected areas (measurement positions) of 50 cm x by 50 cm in heights between 75 cm and 175 cm above floor:

Summary of exposure assessment in the considered measurement positions:

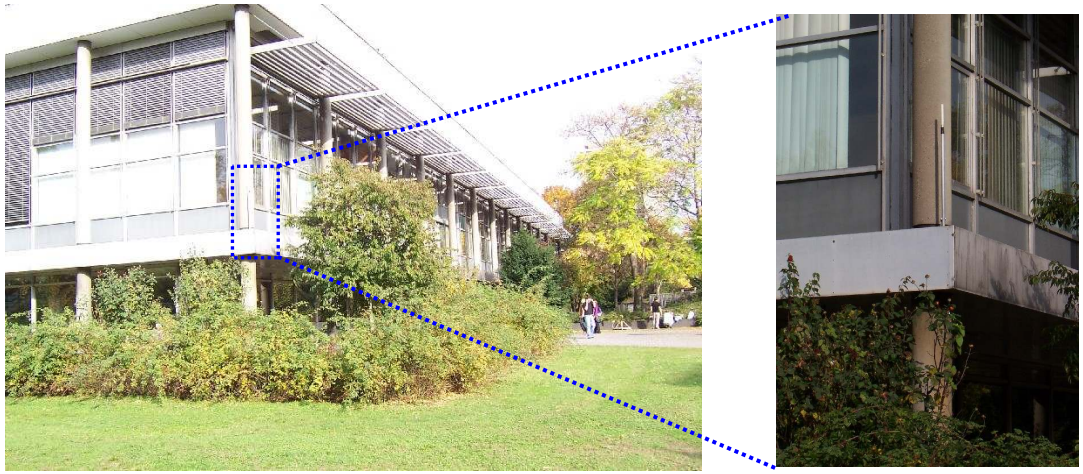
Spatial maximum Burst Peak values of APs: 0.03 – 1.6 mW/m^2
Spatial average Burst Peak values of APs: 0.006 – 0.48 mW/m^2

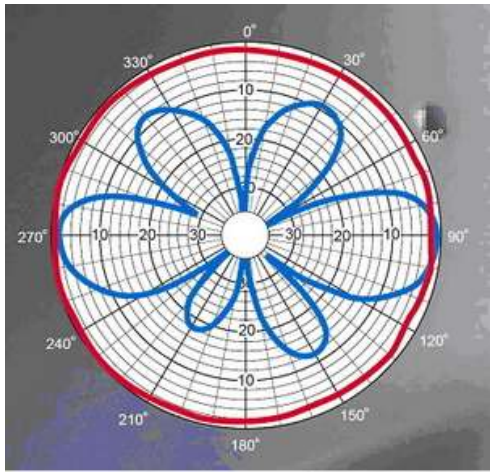
Time averaged spatial maximum values due to APs (beacon only): 0.0004 – 0.18 mW/m2
Time averaged spatial average values due to APs (beacon only): 0.00007 – 0.005 mW/m2

Time averaged spatial maximum values for typical traffic situations (incl. clients): 0.008 – 11.4 mW/m2
Time averaged spatial average values for typical traffic situations (incl. clients) : 0.001 – 3.6 mW/m2

Outdoor Scenario: *Place in front of Library of University of Stuttgart*

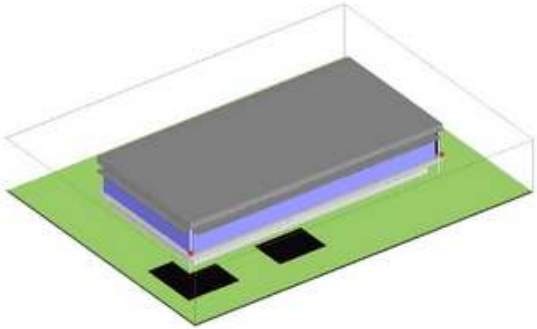
- 1 active Access Point for providing internet connectivity for students

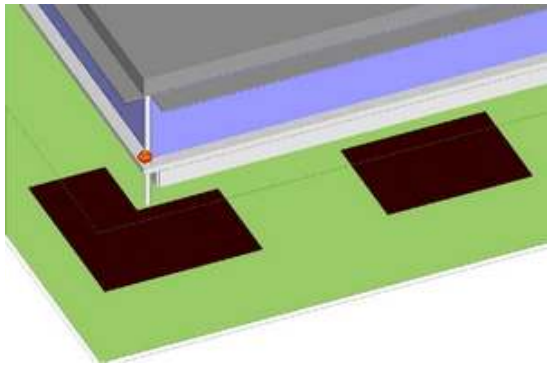


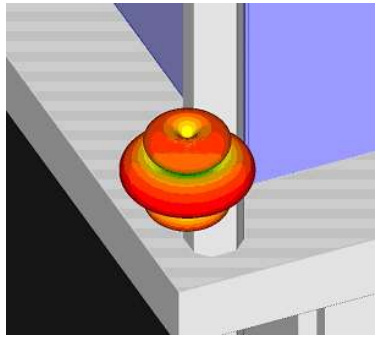


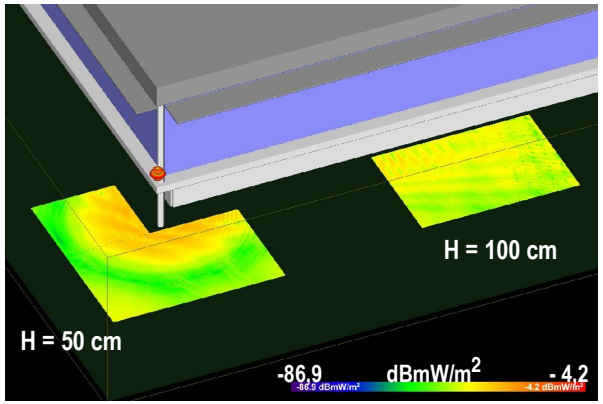
Outdoor Scenario: *Place in front of Library of University of Stuttgart*

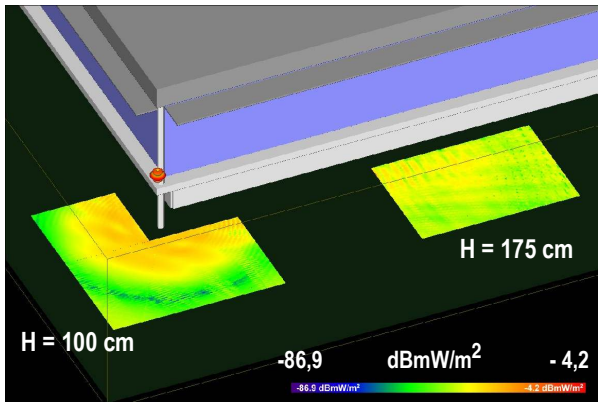
- Wireless Insite model











Time averaged exposure from Access Points without data traffic (beacon transmission only)

Outdoor Scenario: *Place in front of Library of University of Stuttgart*

- Numerical exposure assessment and comparative measurements in selected areas (measurement positions) of 50 cm x by 50 cm in heights between 75 cm and 175 cm above floor:

Summary of exposure assessment in the considered measurement positions:

Spatial maximum Burst Peak values of APs: 0.005 – 0.36 mW/m^2
Spatial average Burst Peak values of APs: 0.0002 – 0.21 mW/m^2

Time averaged spatial maximum values due to APs (beacon only): 0.0001 – 0.002 mW/m^2
Time averaged spatial average values due to APs (beacon only): 0.0001 – 0.001 mW/m^2

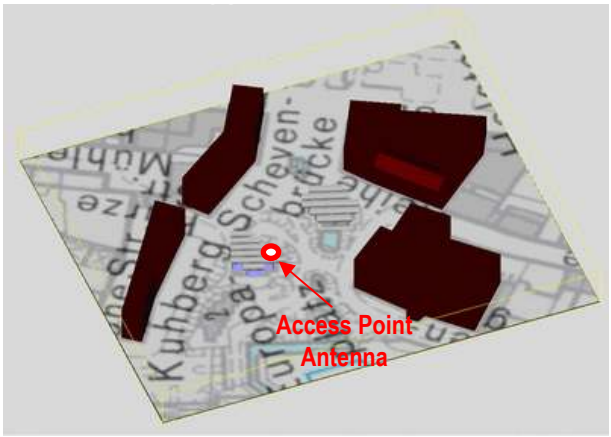
Time averaged spatial maximum values for typical traffic situations: 0.002 – 0.25 mW/m^2
Time averaged spatial average values for typical traffic situations: 0.0004 – 0.15 mW/m^2

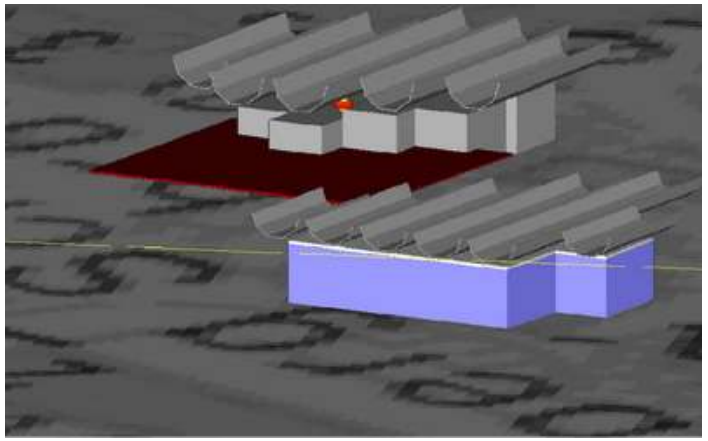
Outdoor Scenario: *Europaplatz, Kiel*

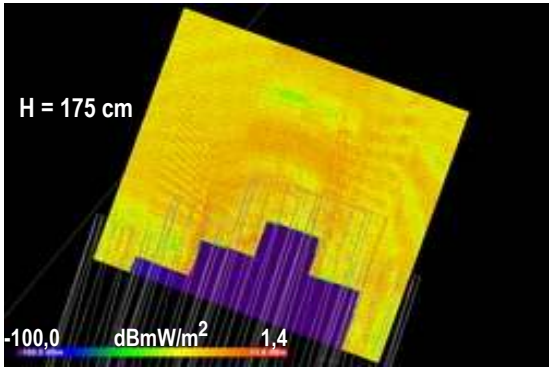
- 1 Access Point for providing internet connectivity in surrounding cafes, pubs, ..

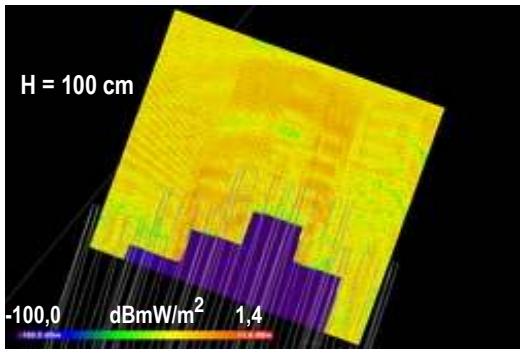
Outdoor Scenario: *Europaplatz, Kiel*

- Wireless Insite model









Time averaged exposure from Access Point without data traffic (beacon transmission only)

Outdoor Scenario: *Europaplatz, Kiel*

- Numerical exposure assessment and comparative measurements in selected areas (measurement positions) of 50 cm x by 50 cm in heights between 75 cm and 175 cm above floor:

Summary of exposure assessment in the considered measurement positions:

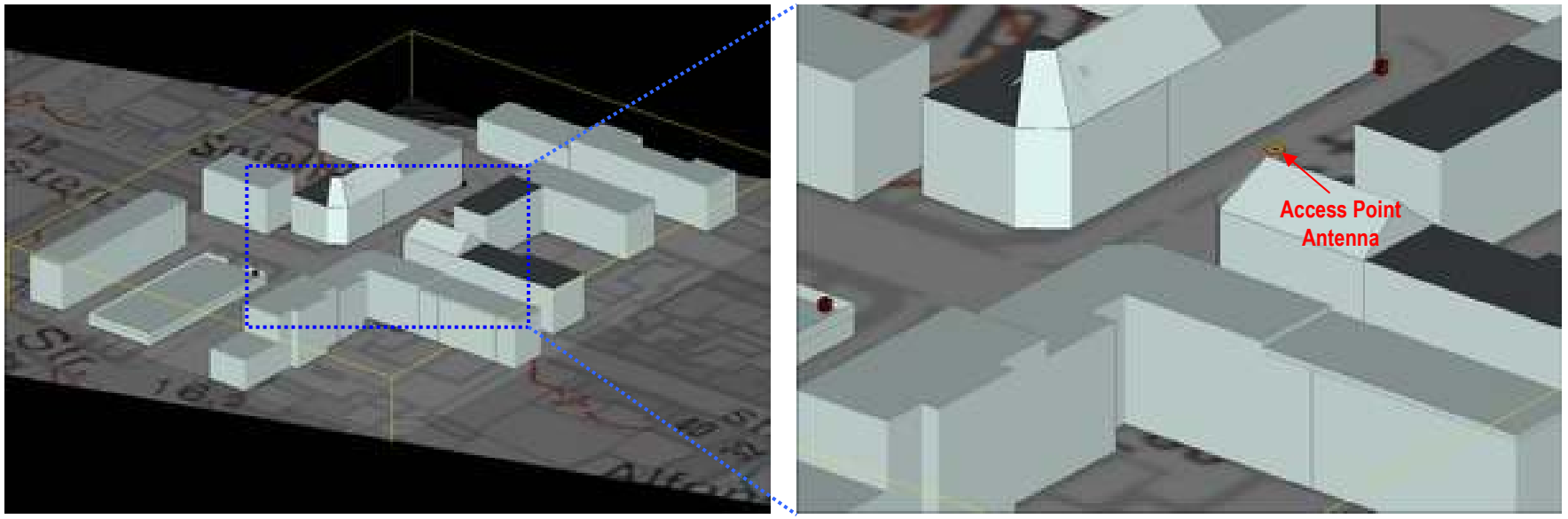
Spatial maximum Burst Peak values of AP: 0.02 – 0.34 mW/m^2
Spatial average Burst Peak values of AP: 0.005 – 0.10 mW/m^2

Time averaged spatial maximum values due to APs (beacon only): 0.0001 – 0.0012 mW/m^2
Time averaged spatial average values due to APs (beacon only): 0.00002 – 0.0005 mW/m^2

Time averaged spatial maximum values for typical traffic situations: 0.002 – 0.24 mW/m^2
Time averaged spatial average values for typical traffic situations: 0.0005 – 0.07mW/m^2

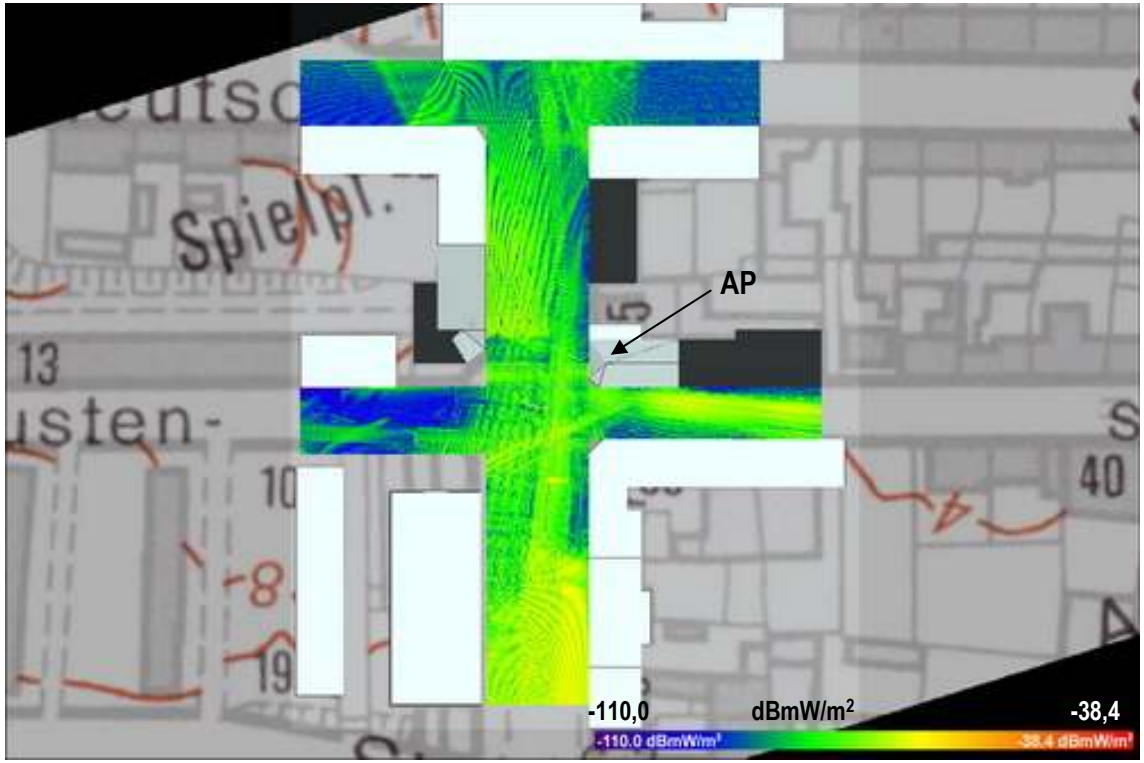
Outdoor Scenario: *Schulstraße, Kiel*

- 1 Access Point for providing internet connectivity in surrounding flats



Outdoor Scenario: *Schulstraße, Kiel*

- Field distribution at 175 cm above street level



Time averaged exposure from Access Point without data traffic (beacon transmission only)

Outdoor Scenario: *Schulstraße, Kiel*

- Numerical exposure assessment and comparative measurements
  in selected areas (measurement positions, indoor as well as outdoor) of 50 cm x by 50 cm
  in heights between 75 cm and 175 cm above floor:

Summary of exposure assessment in the considered measurement positions:

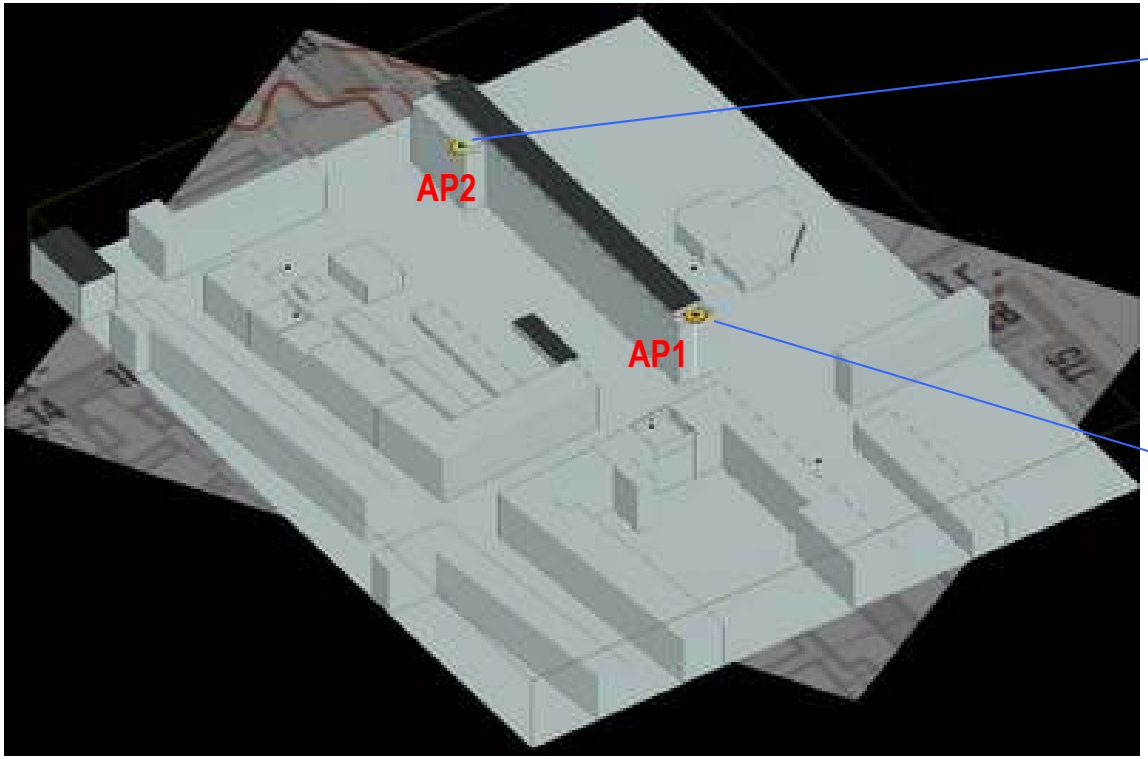
Spatial maximum Burst Peak values of AP: 0.003 – 0.5 μW/m^2
Spatial average Burst Peak values of AP: 0.002 – 0.2 μW/m2

Time averaged spatial maximum values due to APs (beacon only): 0.00002 – 0.0024 μW/m2
Time averaged spatial average values due to APs (beacon only): 0.00001 – 0.0009 μW/m2

Time averaged spatial maximum values for typical traffic situations: 0.0003 – 0.05 μW/m2
Time averaged spatial average values for typical traffic situations: 0.0002 – 0.02 μW/m2

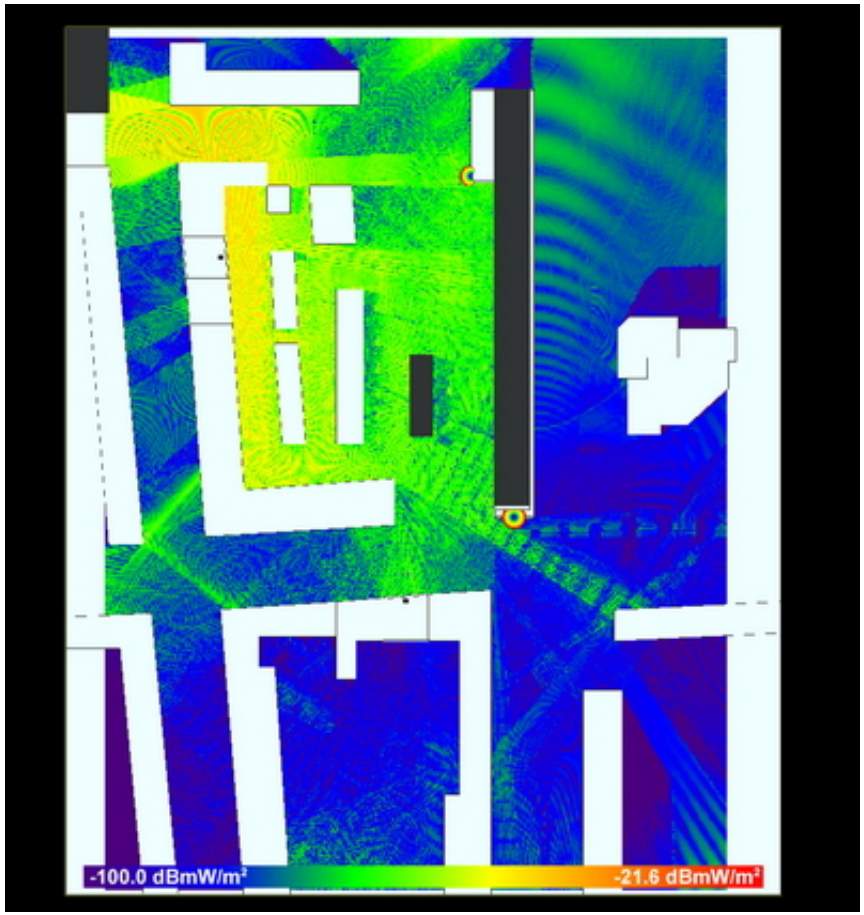
Outdoor Scenario: *Medusastraße, Kiel*

- 2 Access Points for providing internet connectivity in surrounding flats



Outdoor Scenario: *Medusastraße, Kiel*

- Field distribution at 175 cm above street level



Combined time averaged exposure from Access Points without data traffic (beacon transmission only)

Outdoor Scenario: *Medusastraße, Kiel*

- Numerical exposure assessment and comparative measurements
  in selected areas (measurement positions, indoor as well as outdoor) of 50 cm x by 50 cm
  in heights between 75 cm and 175 cm above floor:

Summary of exposure assessment in the considered measurement positions:

Spatial maximum Burst Peak values of AP: 0.002 – 0.4 μW/m^2
Spatial average Burst Peak values of AP: <0.002 – 0.15 μW/m2

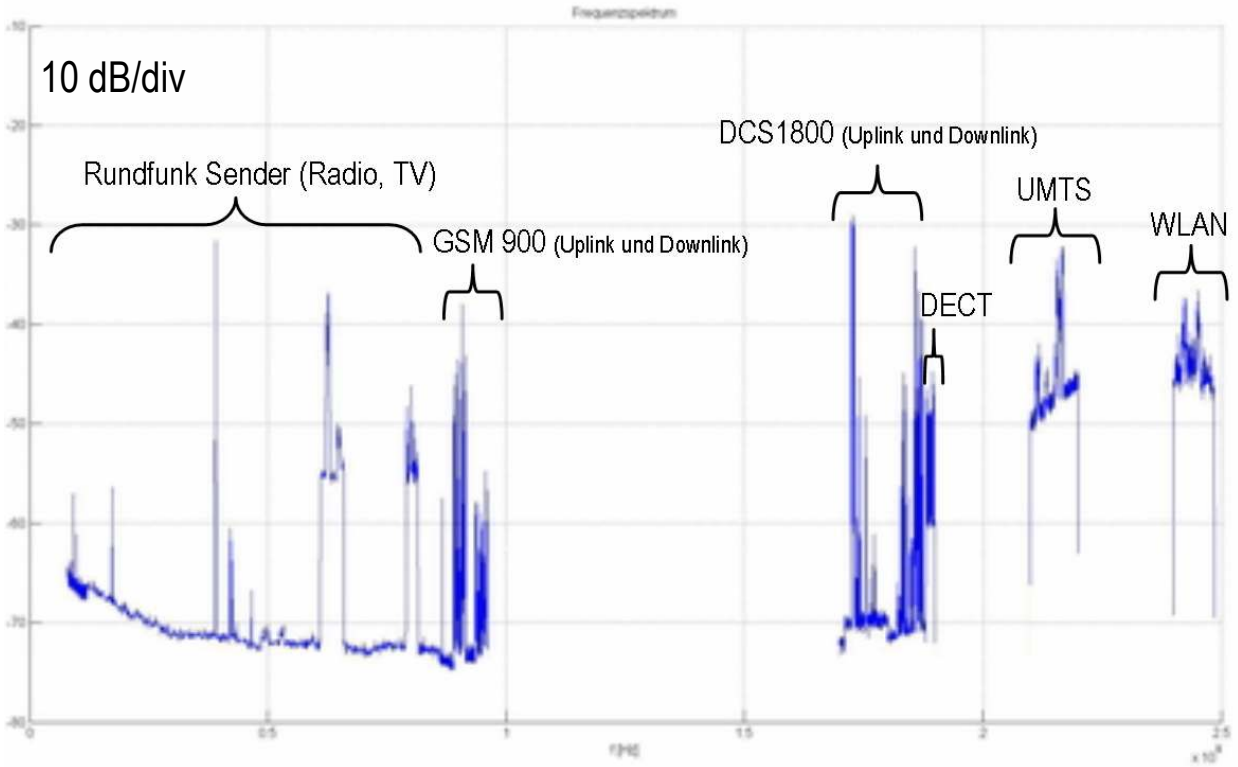
Time averaged spatial maximum values due to APs (beacon only): 0.00001 – 0.002 μW/m2
Time averaged spatial average values due to APs (beacon only): <0.00002 – 0.0008 μW/m2

Time averaged spatial maximum values for typical traffic situations: 0.0002 – 0.04 μW/m2
Time averaged spatial average values for typical traffic situations: <0.0001 – 0.015 μW/m2

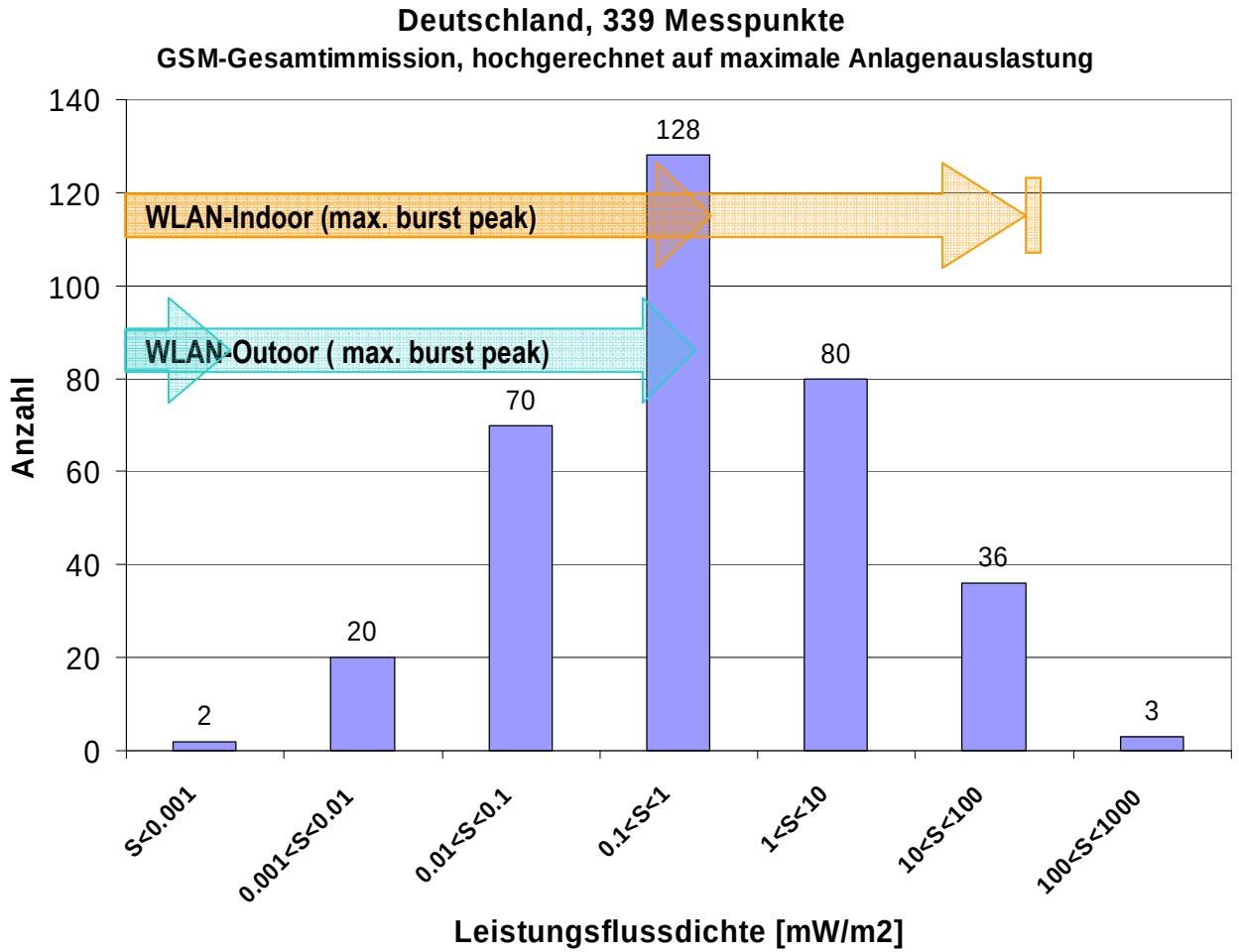
6. Comparison with other sources (1)

Measurements at the CeBit 2006 exhibition, Hannover

(RMS detector, MAX-HOLD ⇒ Burst peak values)



6. Comparison with other sources (2)



Conclusions:

- Public exposure from WLAN application is clearly far below current limits (10000 mW/m^2)
- In indoor scenarios, where the distance to the antennas is usually small, spatial and temporal peak exposures can be up to approx. 100 – 200 mW/m^2. Maximum spatially averaged (over body dimensions and time averaged (over 6 minutes) exposure, are usually at least 1-2 orders of magnitude lower, i.e. approx. $\leq$ 0.1% of the current limits
- In outdoor scenarios, where the distance to the antennas is usually big, spatial and temporal peak exposures are usually lower than 1 mW/m^2. Maximum spatially averaged (over body dimensions and time averaged (over 6 minutes) exposure, are usually at least 1-2 orders of magnitude lower, i.e. approx. $\leq$ 0.001% of the current limits
- Compared to other RF sources (Radio and TV broadcast, GSM, UMTS, DECT) public exposure from WLAN applications seems to be comparably small

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