# Advanced Channel Measurements and Channel Modeling for Millimeter-Wave Mobile Communication

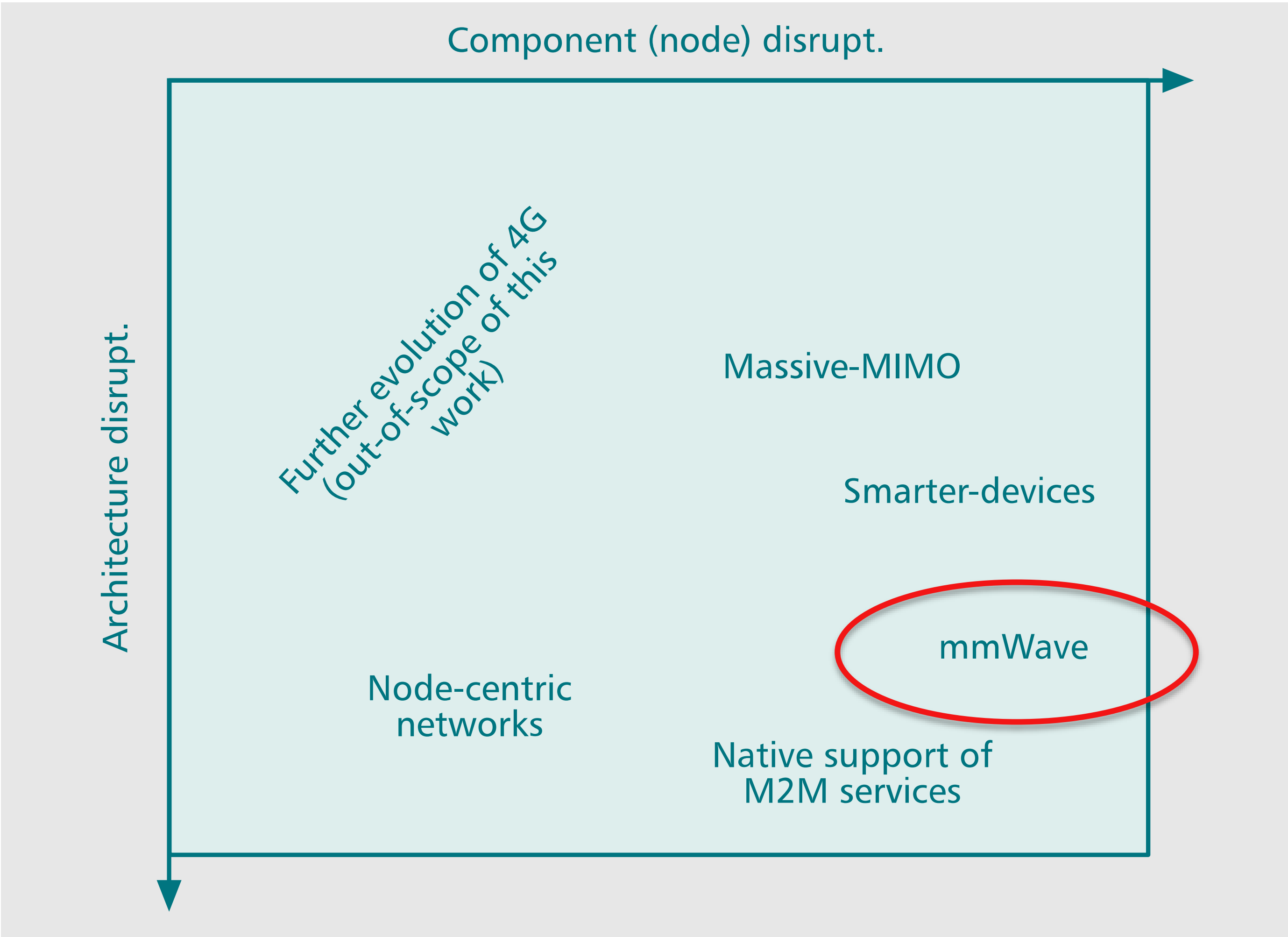
*Wilhelm Keusgen*

International Workshop on Emerging Technologies for 5G Wireless Cellular Networks

December 8th 2014

# Disruptive Technologies for 5G

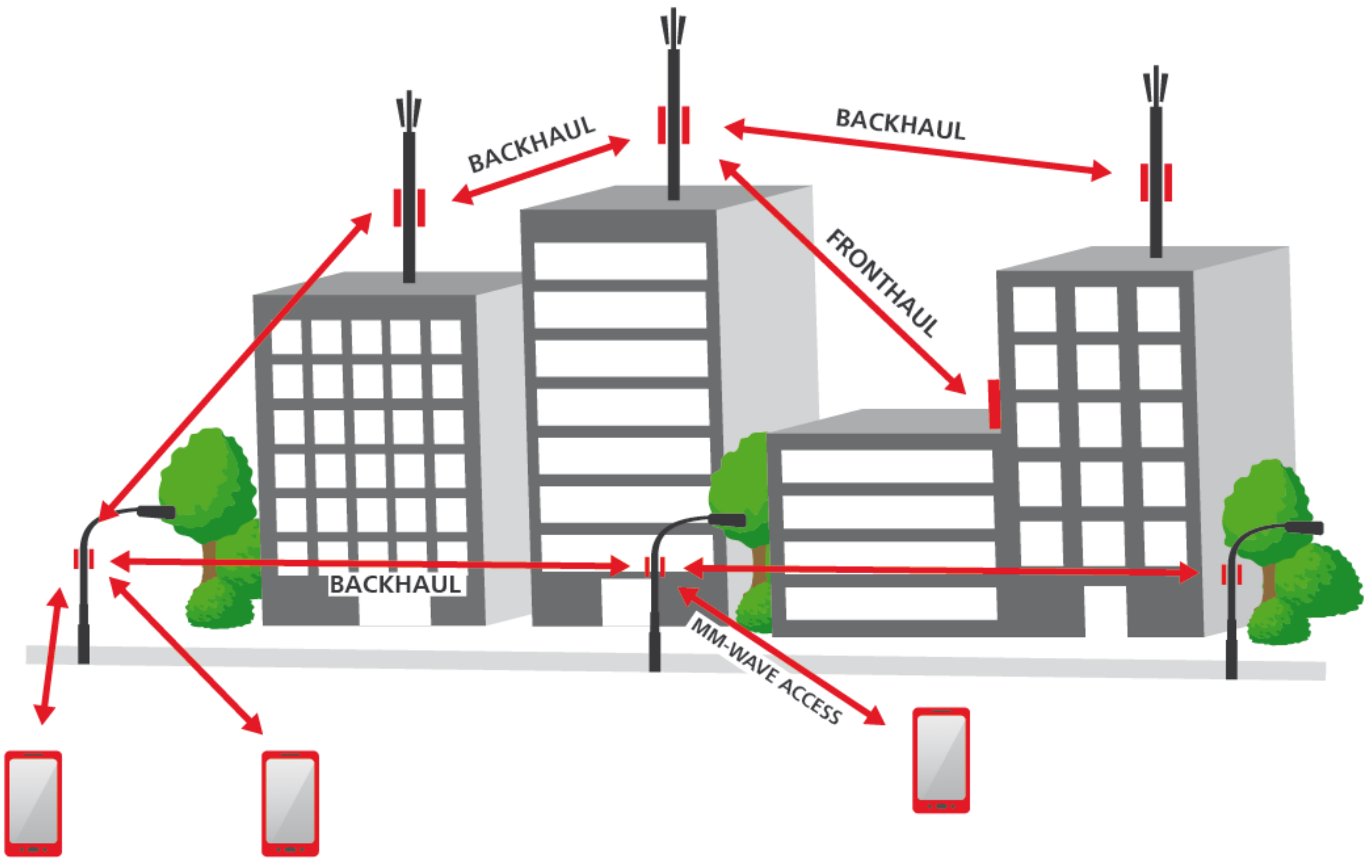





Five Disruptive Technology Directions for 5G, IEEE Communications Magazine • February 2014


Wilhelm Keusgen

# Millimeter-Waves in 5G




## Millimeter-Wave for

- Backhaul
- Fronthaul
- Access
- Offload (WiFi)

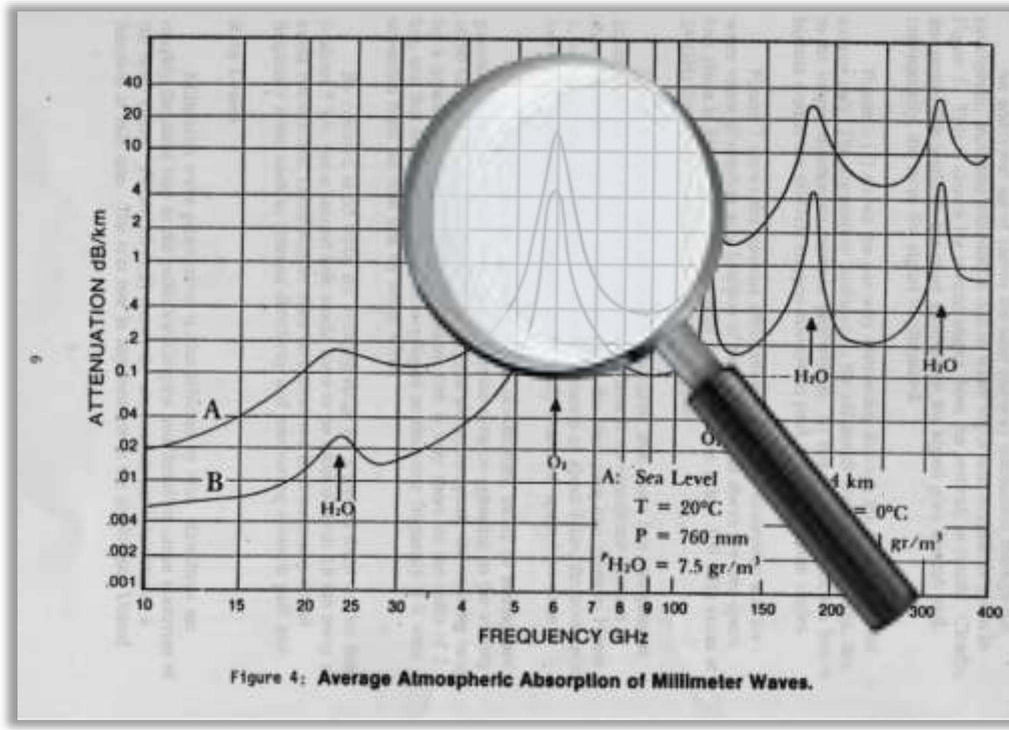
## Enables

- Better user experience
- Dense small cell deployments
- Centralized RAN architecture

# mm-Wave for Mobile Communication

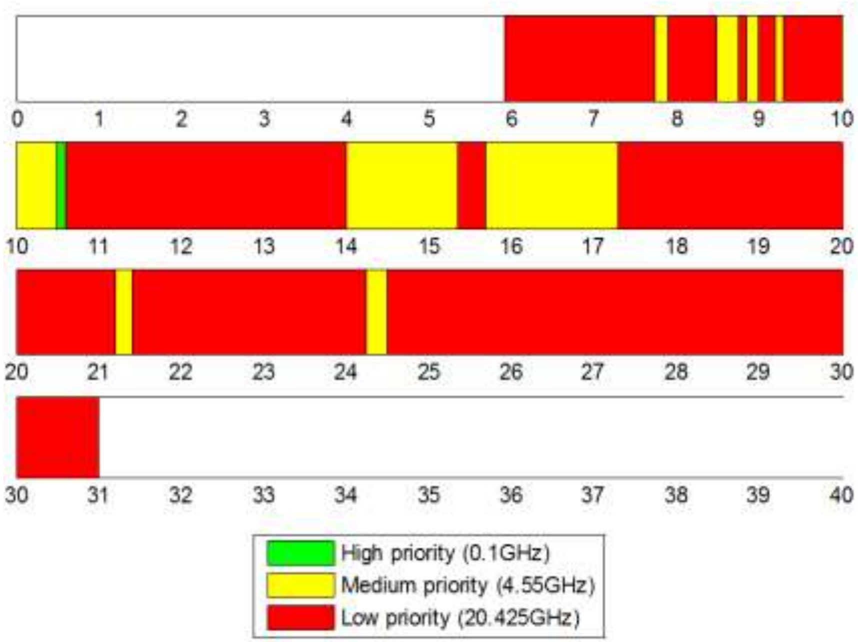
- **Multiple candidate bands**
  - 28 GHz, 39 GHz
  - 60 GHz (unlicensed)
  - 70/80 GHz (unlicensed/ light licensed)

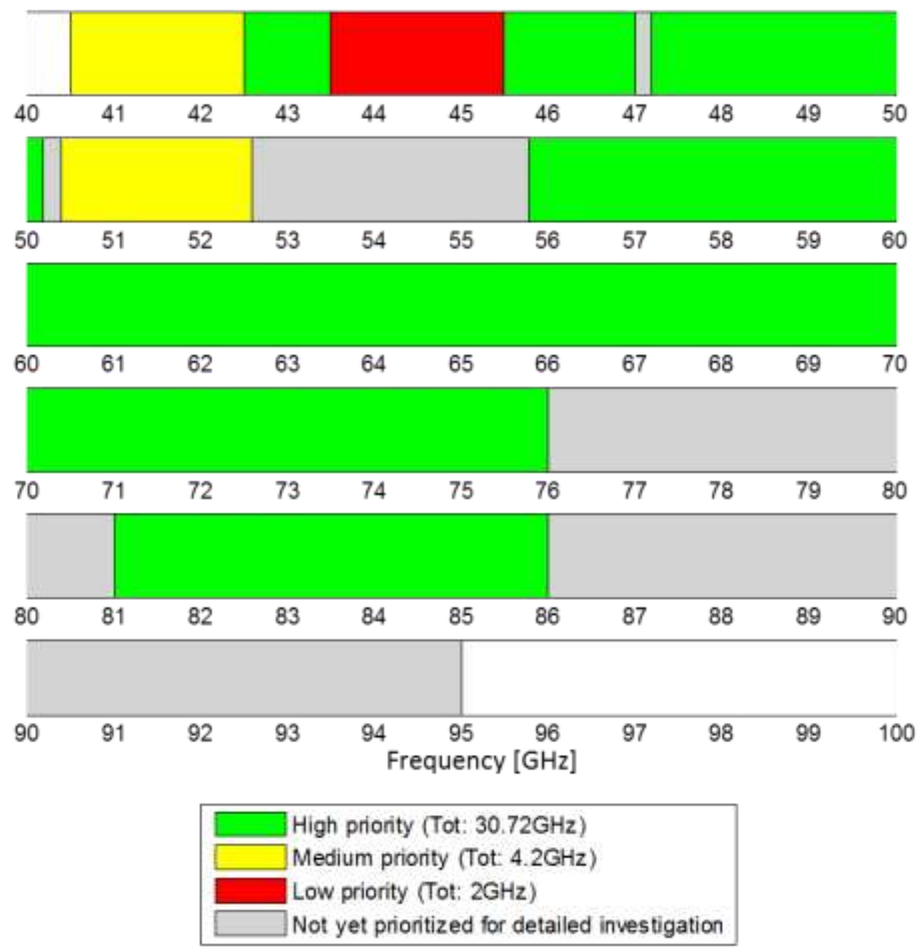
- **Challenging propagation conditions**
  - High pathloss
  - Quasi optical transmission.
  - **No comprehensive channel model yet**



# METIS Spectrum Band Asessments






METIS

# mm-Wave Outdoor Propagation



**We know: Higher path loss**

- Conventional high-gain antennas for fixed links
- Steerable antennas for mobile applications

**We do not know: Temporal, spatial, and angular structure, obstructed LOS**

- Need of comprehensive 3D channel model for link level and system level simulations
- Current mm-Wave channel models neither directly applicable to outdoor nor suited for system-level evaluations in mobile networks
- Channel models for cellular communications (3GPP SCM, WINNER, ITU-R M.2135, COST 2100) do not support higher bands

# HHI Measurement Campaigns in 2014

- Street canyon measurements at 60 GHz in **busy urban access scenario**: temporal characteristics and time variance

- Measurement campaign on former **airport**: impact of ground reflections, distances up to 1000 m (60 GHz)

- **Dual frequency** measurements at 10 and 60 GHz (fully simultaneous) in urban access scenario: frequency dependence of channel characteristics for LOS and NLOS

- Large **adaptive antenna array** measurements for **backhaul** and **access** at 60 GHz: technology demonstration, system trial, and real time spatial resolved channel characteristics

# Omnidirectional, Directional, Adaptive



## Omnidirectional measurements

- Capture all relevant multipaths and time-variance of the channel/environment
- Evaluations based on “real” omnidirectional data without the need for synthetic superposition of directional data
- Directional information can be obtained by processing of virtual array data and accompanying ray tracing simulations

## Directional measurements with fixed beam

- Investigation of directional channels for backhaul applications
- Improvement of link budget for measurements
- Use of application-oriented antennas for measurements to obtain realistic temporal channel characteristics

## Adaptive array measurements

- Quasi instantaneous spatial information (in slowly varying scenarios) for a certain sector
- Evaluation based on “real” antenna data with impairments

# „Light“ Measurement Equipment

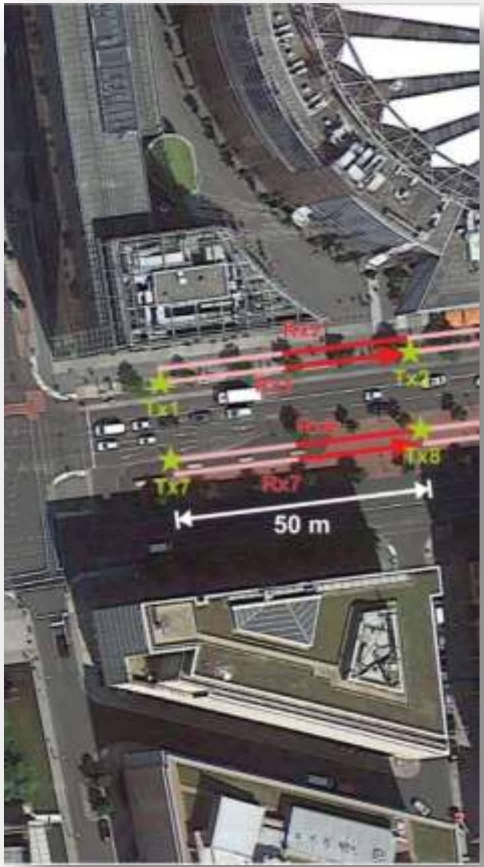
| Channel sounding parameters | |
|---|---|
| Number of Antennas | 2 Tx, 2 Rx |
| Carrier frequency | Variable, e.g. 60 GHz |
| Bandwidth | 250 MHz |
| Output power | 15 dBm |
| Snapshot measurement duration | 65.5 µs |
| Separation of snapshots | Variable, typ. 800 µs (0.4 mm @ .5m/s) |
| Antennas | omni, 2 dBi, vertical pol.,<br>20 dBi horn,<br>Adaptive Antenna Array |
| Max. instantaneous dynamic range | 45 dB |
| Number of snapshots per set | Max. 62,500 |

- Full information on temporal characteristics of the channel available
- Channel impulse response: absolute delay, magnitude and phase of arriving multipath components

# Street Canyon Measurements

## Measurement campaign in Berlin, Germany

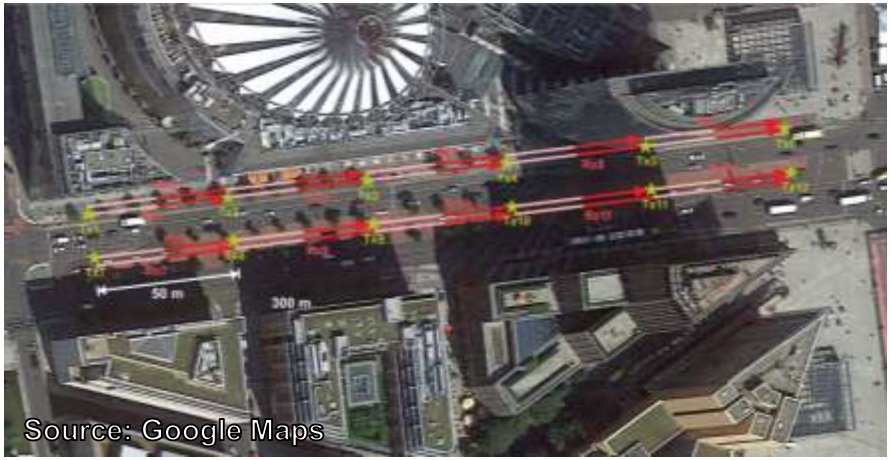
- Small cell urban access channel
- Potsdamer Straße (street canyon) & Leipziger Platz (city square)
- TX: “small cell base station”, RX: “mobile”
- TX-RX distance: 0–50 m
- 12 TX locations for street canyon
- 3.75 million snapshots with mobile RX (0.5 m/s)
- 3.25 million snapshots with static RX



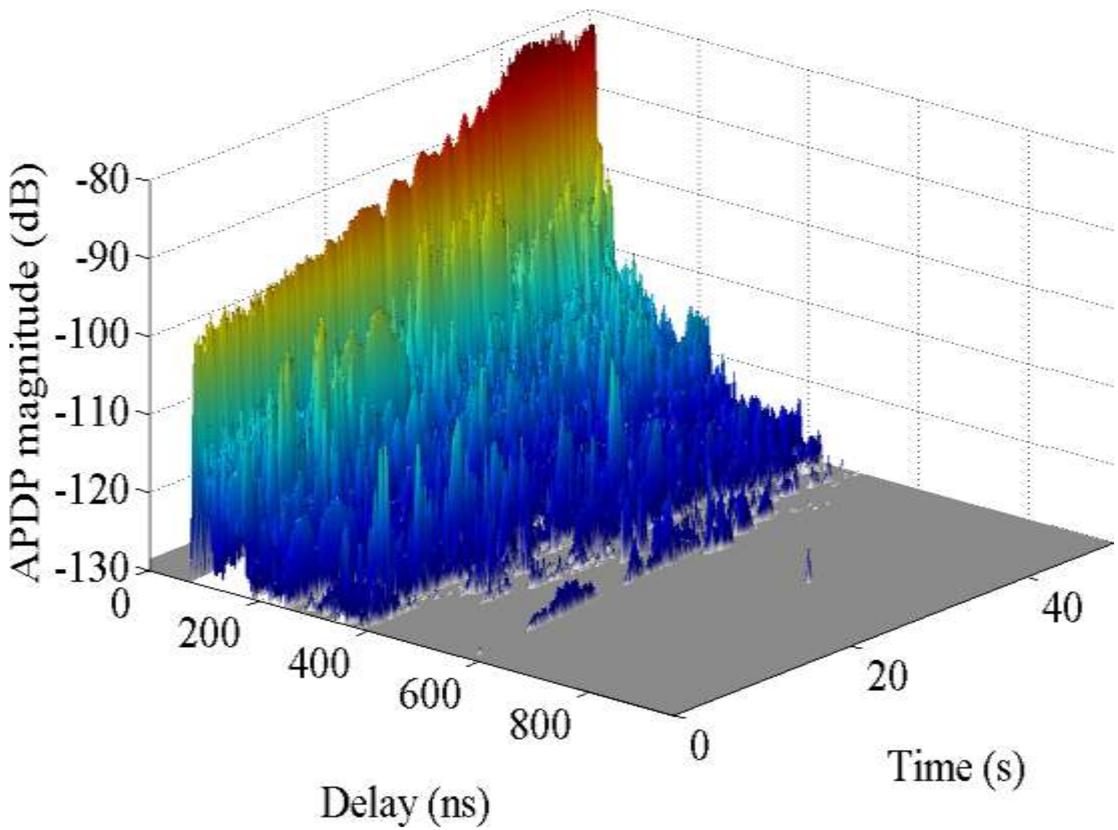
# Street Canyon Scenario

**Potsdamer Str.**

- Modern office buildings
- Significant reflections to be expected from flat surfaces
- Street width: 52 m

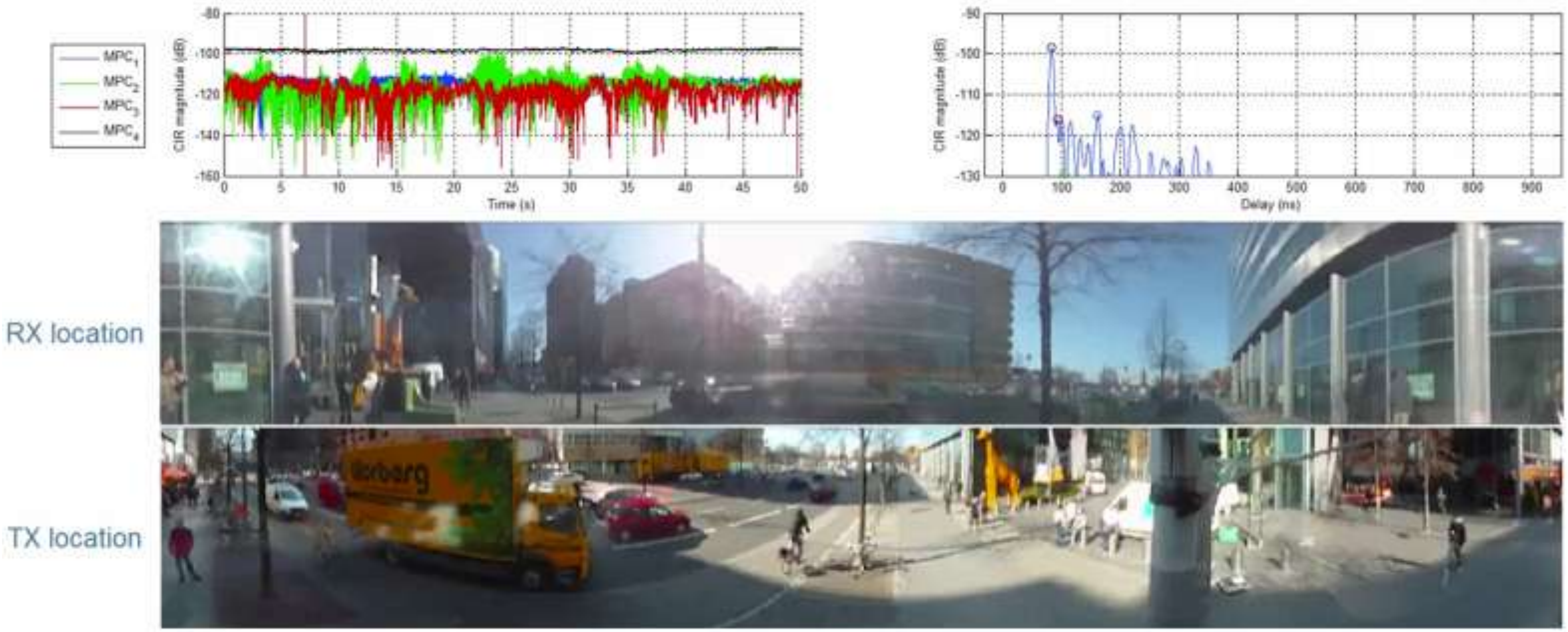

# Typical Result of Mobile Measurement




- TX-RX distance: 25–0 m, full measurement run with 62,500 CIRs
- Averaging over 10 cm segments (250 CIRs) to obtain APDP
- Significant multipath contributions (MPC)
- Channel length: several hundred ns
- Large-scale fading of MPCs due to RX movement and time-variant environment
- Also Fading in first MPC (“LOS component)

# Illustration of Time Variance

- TX & RX at static positions
- TX-RX distance: 25 meter



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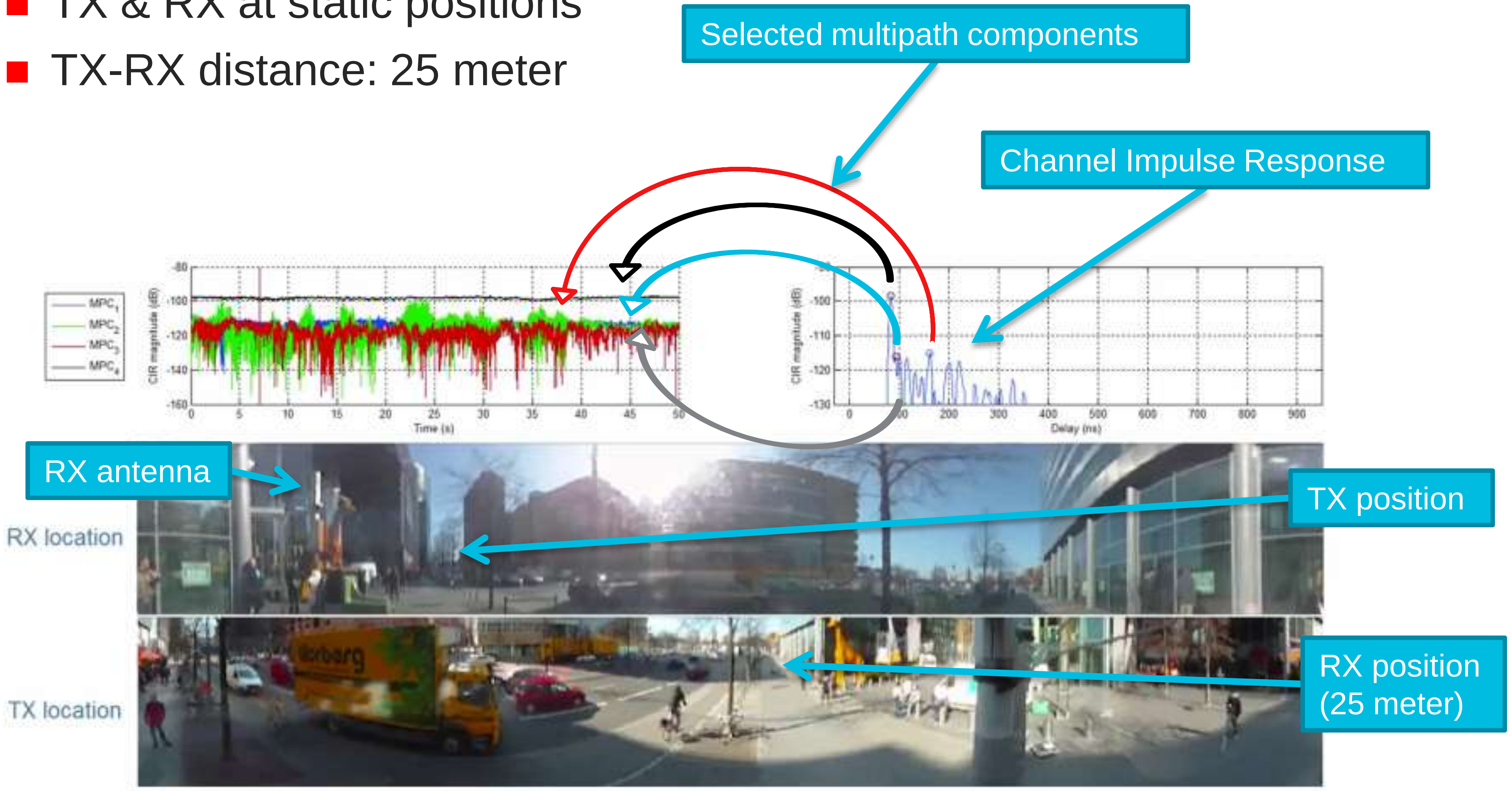

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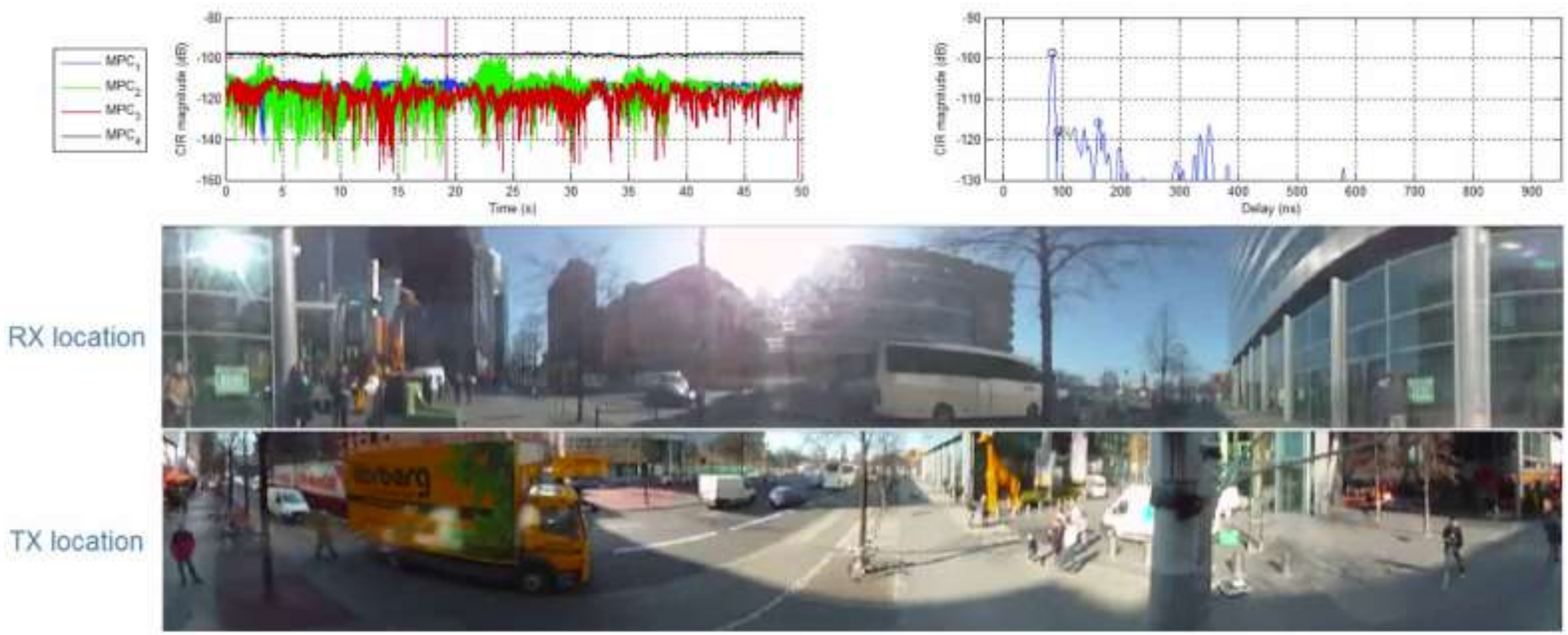

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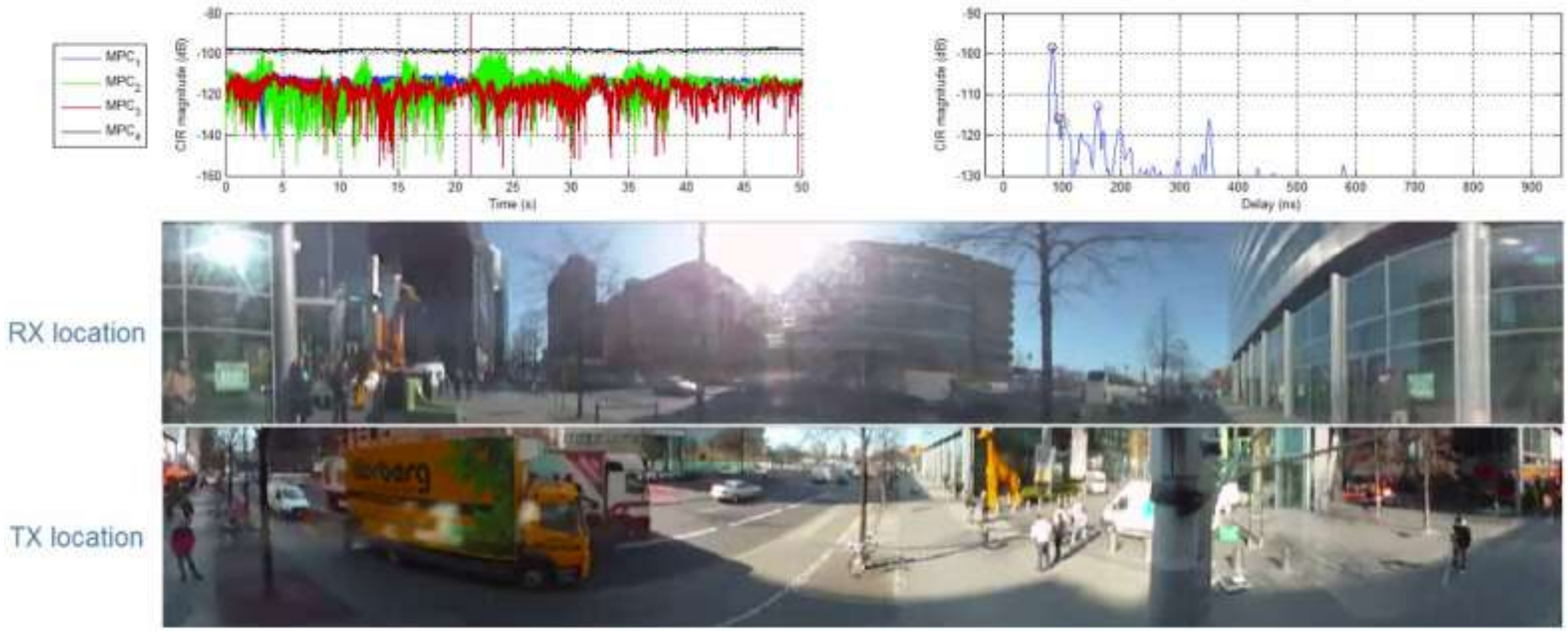

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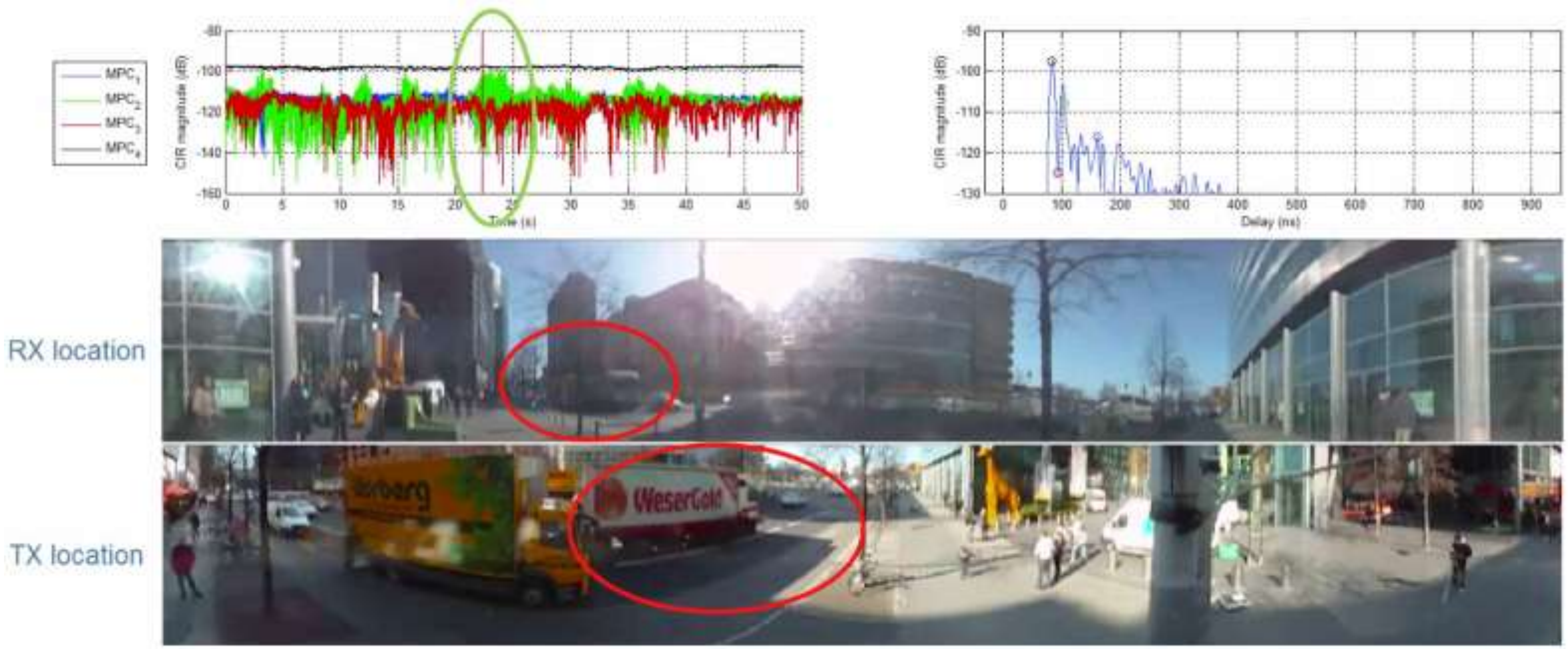

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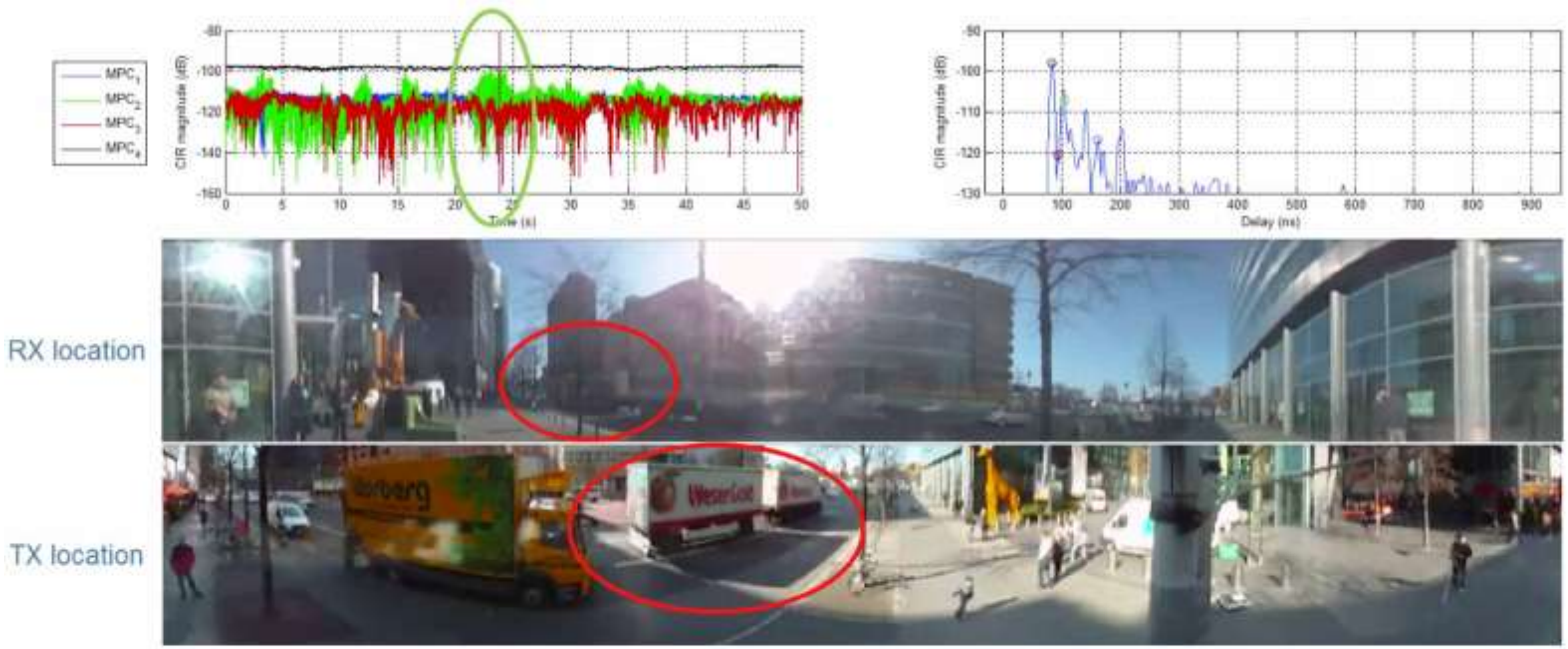

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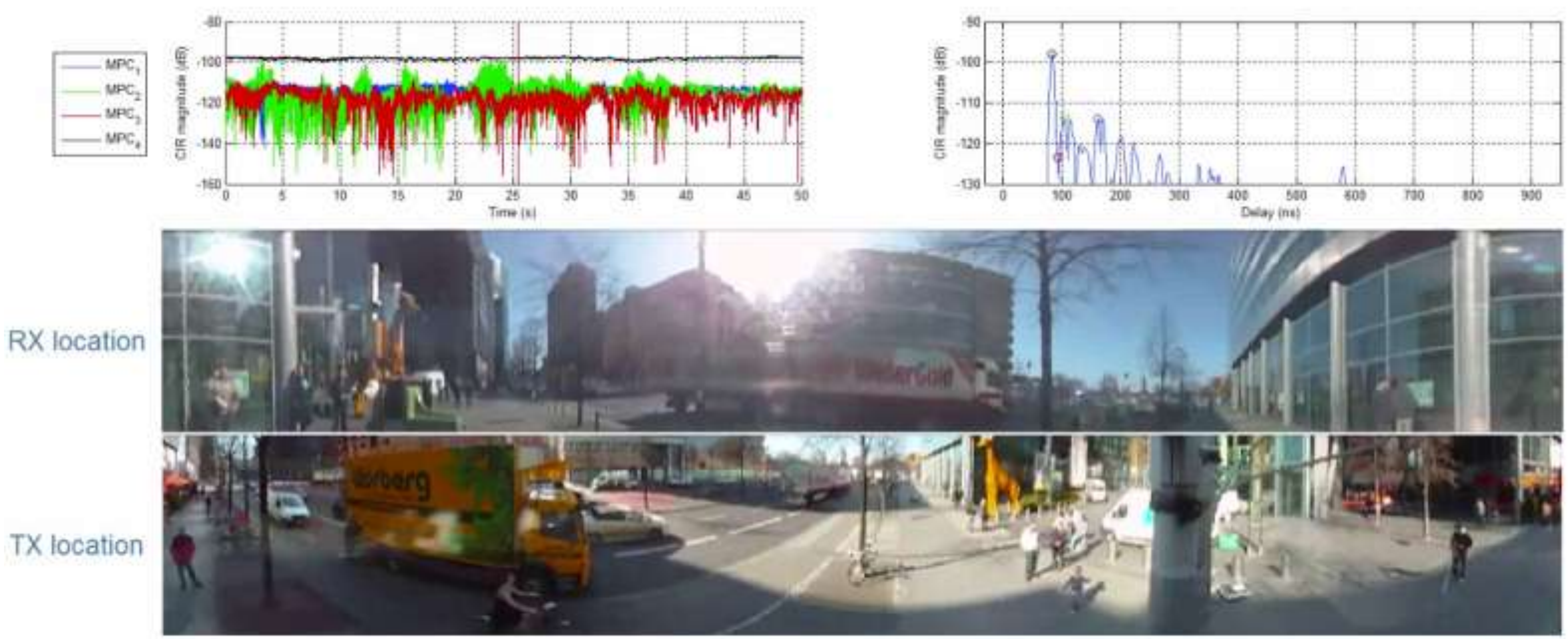
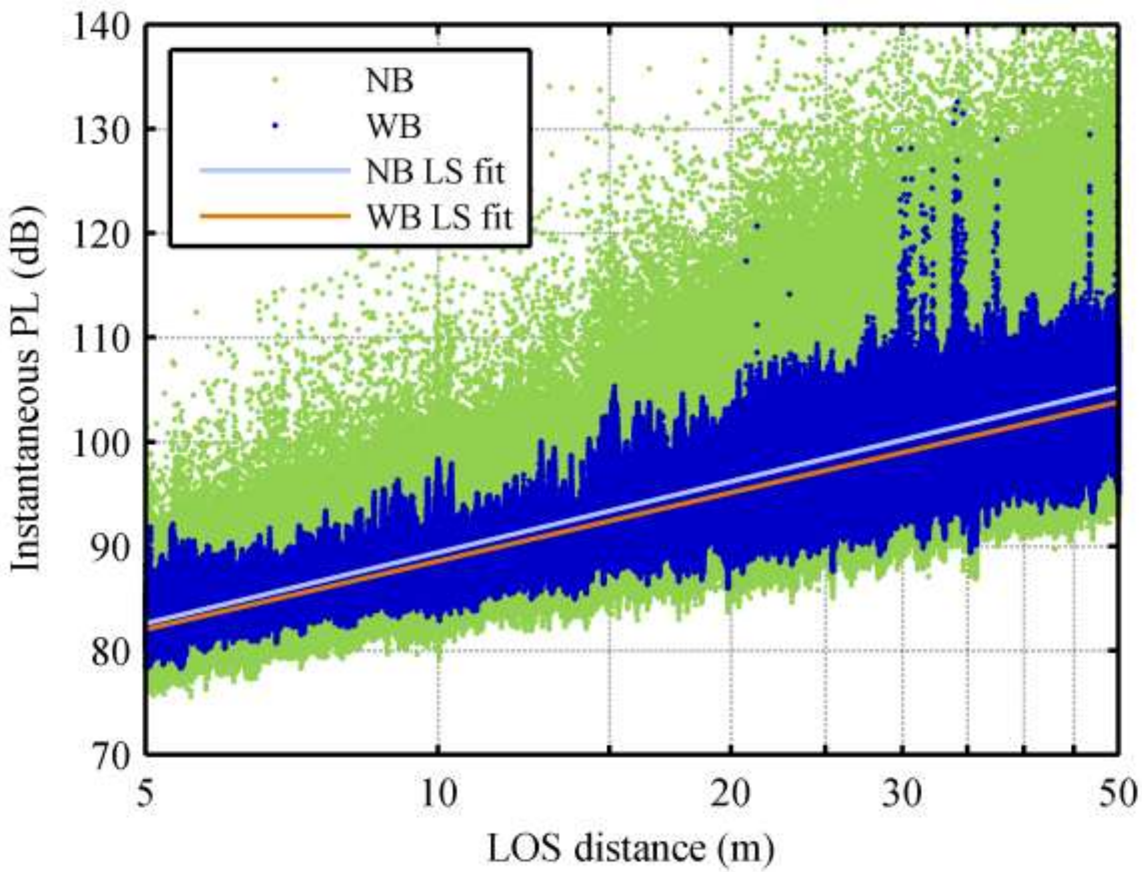


# Path Loss Parameter Extraction (1)



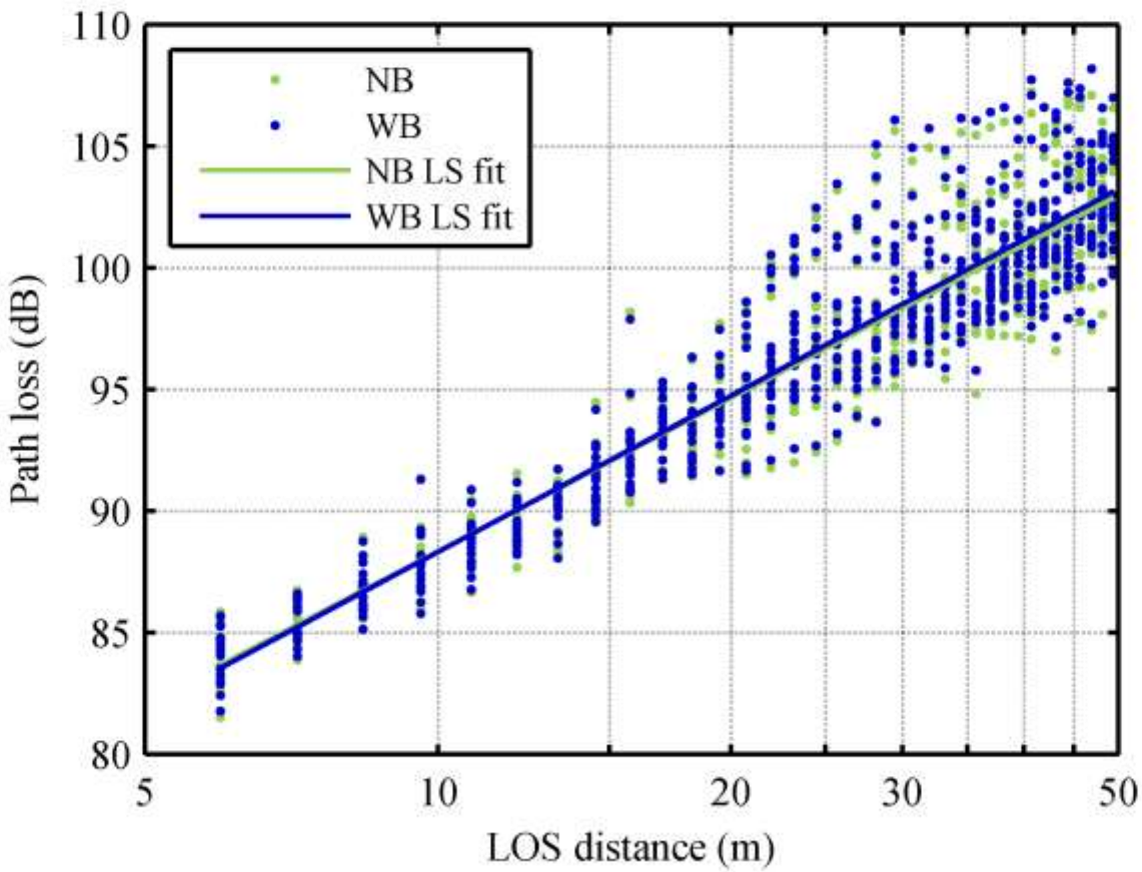



- Least squares fit of LOS-dominant measurement data comprising more than 2 million channel snapshots
- Estimated Parameters:

| | PL (5 m) | n | σ |
|---|---|---|---|
| NB | 82.6 dB | 2.26 | 5.08 |
| WB | 82.0 dB | 2.18 | 2.85 |

- Problem: bandwidth-dependence of results, significant deviation of σ
- σ does not reflect shadow fading term only, but includes small-scale effects
- Averaging (or statistical preprocessing) obligatory prior to extraction of large-scale parameters!

# Path Loss Parameter Extraction (2)

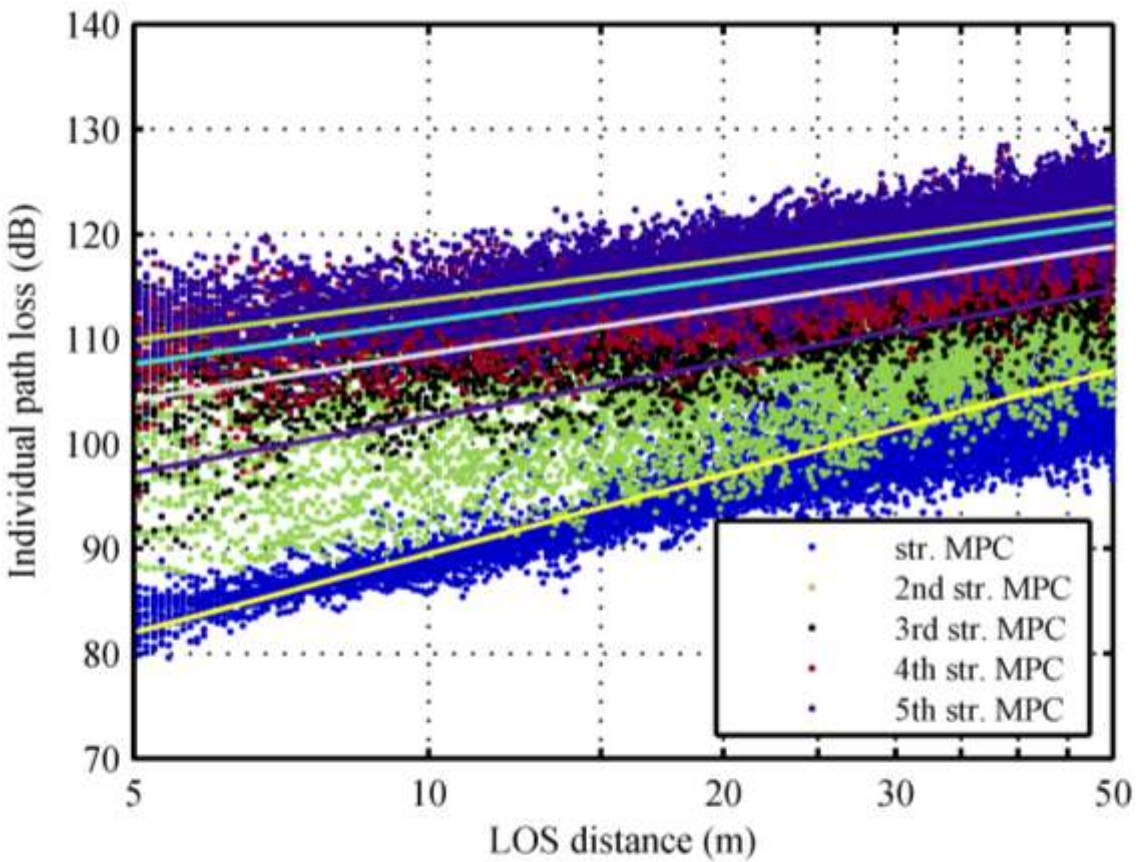



- Equivalent evaluation, but with preceding spatial averaging over 3125 adjacent snapshots (1.25 m segments)
- Estimated parameters become practically independent of bandwidth:

| | PL (5 m) | n | σ |
|---|---|---|---|
| NB | 82.1 dB | 2.09 | 2.05 |
| WB | 81.9 dB | 2.13 | 2.04 |

- Appropriate averaging yields proper and comparable results
- Numerous measurement samples within each averaging bin/window required!

# Individual Path Loss per MPC




- Selection of five strongest multipath components (MPCs) in each APDP
- Calculation of path loss for each MPC individually
- Linear regression according to log-distance law
- Decreasing PL exponent for MPCs: from 2.4 down to 1.2
- Significant exploitable multipath power
- Averaging 10 cm

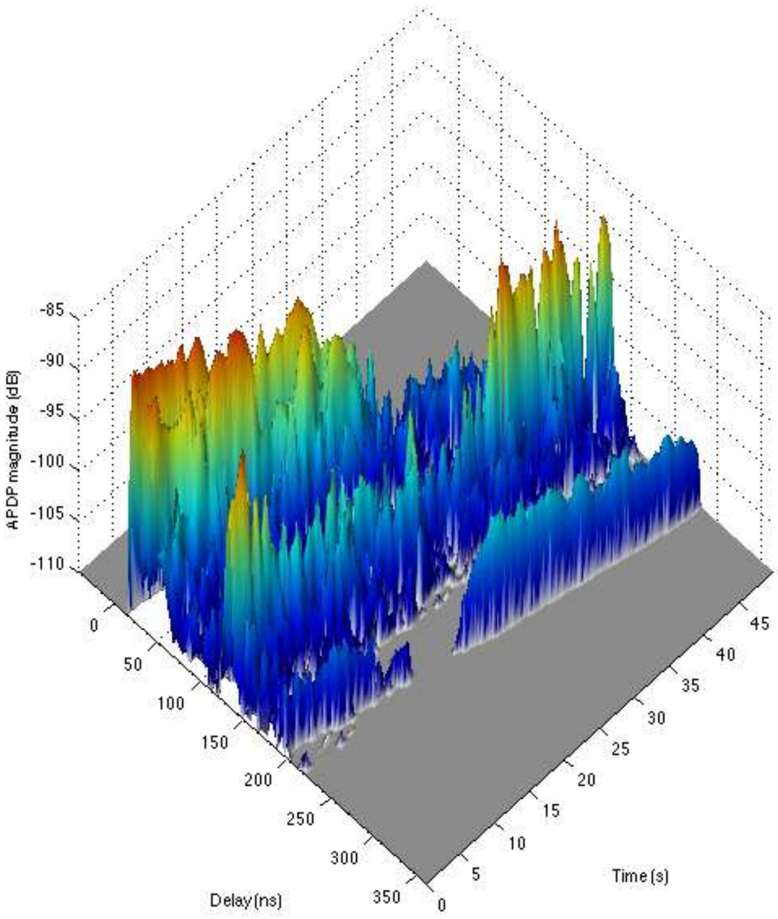
# Multi-Band 10 GHz, 60 GHz, LOS/NLOS



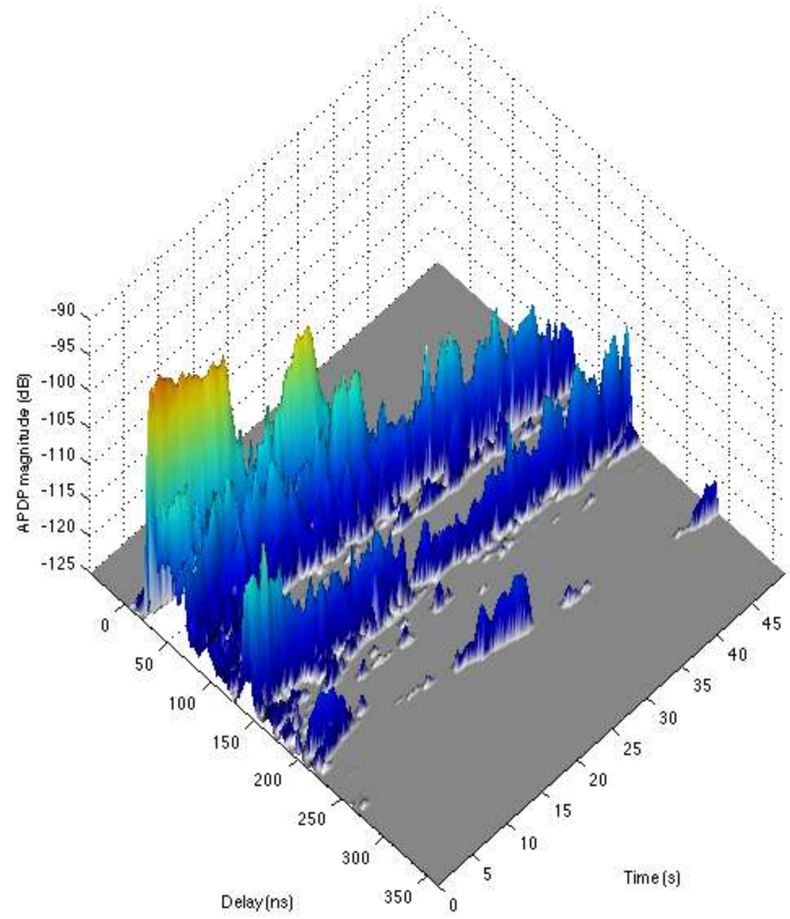

Kreuzberg, Berlin, Germany

# Multi-Band, NLOS Results



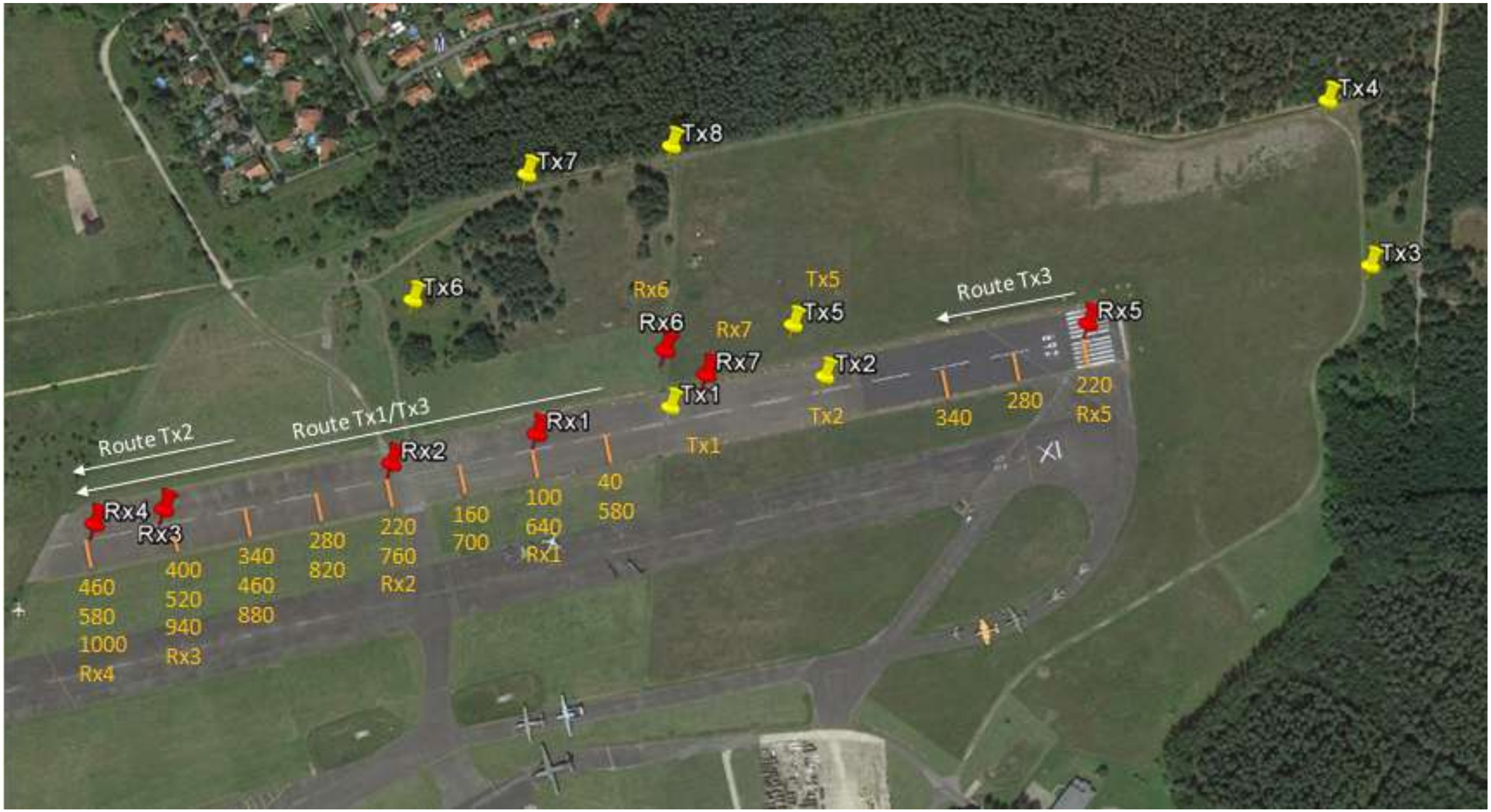



**10 GHz**




**60 GHz**

# Investigation of Two-Way Propagation




Former military airport in Gatow / Berlin

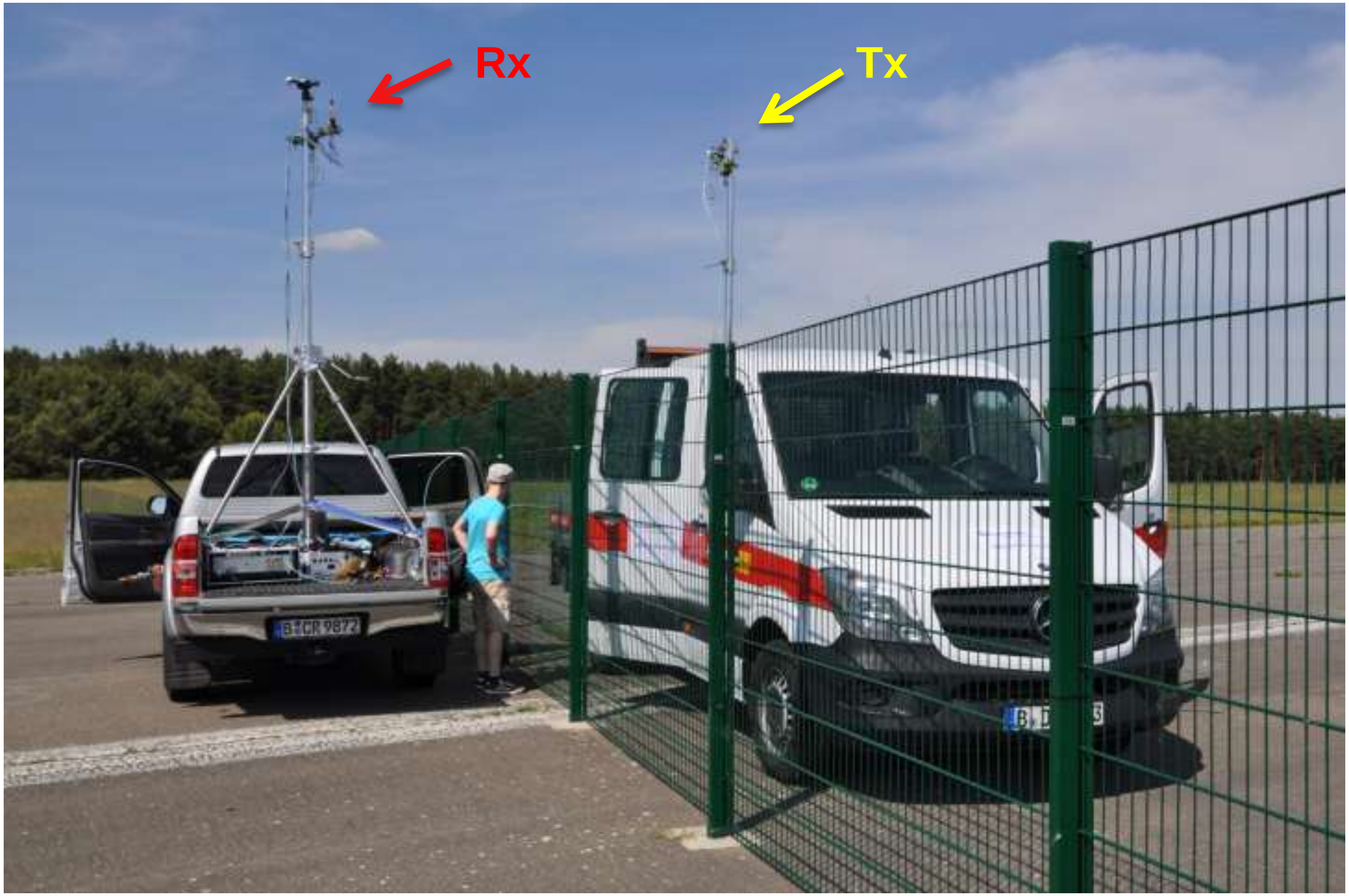
# Objectives, Setup and Procedure



- Objectives: investigate ground reflection for different surfaces, impact of small houses, near LOS conditions
- Setup: HIRATE channel sounder as used for the previous measurements, but reference cable replaced by two rubidium clocks
- Tx and Rx placed on two pickup trucks
- Tx height: 4 m, Rx height: 3–5 m, antennas: standard gain horns with 20 dBi
- Distances: 20 m to 1000 m
- Types of measurements:
  - Two polarizations
  - Moving Rx (1.88 m/s, 6.75 km/h)
  - Height variation of Rx antenna (3–5 m)
- 88 measurement runs for airport (5.3 million CIRs)

# Backhaul Measurement Setup



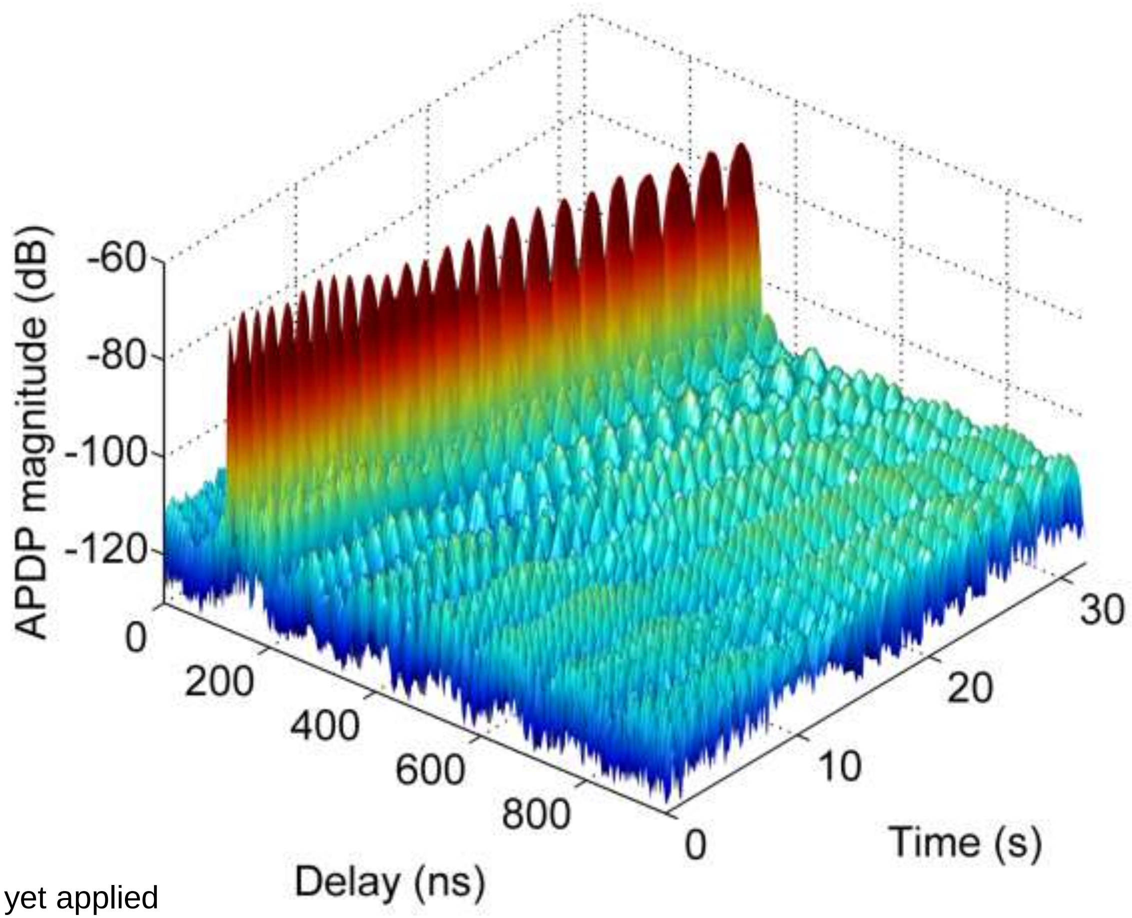


# Measurement on Runway



# Moving Rx (100–160 m) on Runway

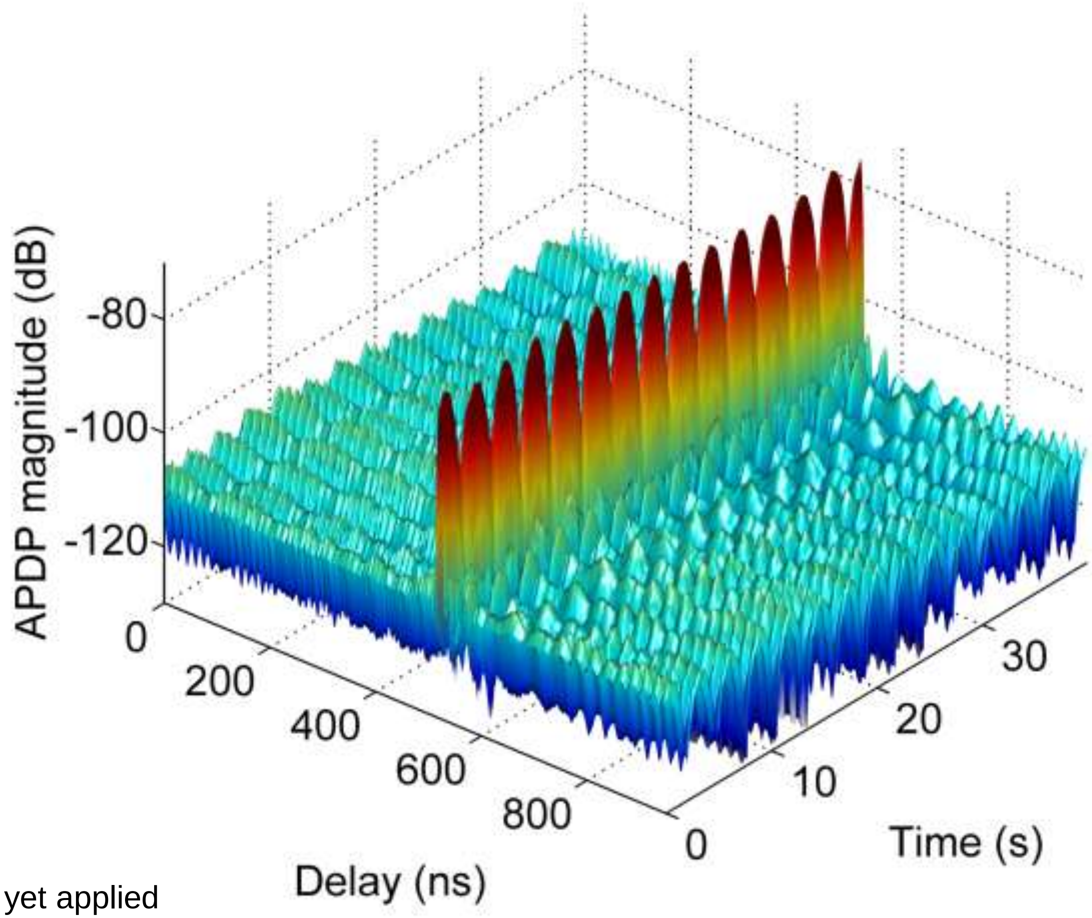





Note: delay calibration not yet applied

# Height Variation Rx (220 m) on Runway

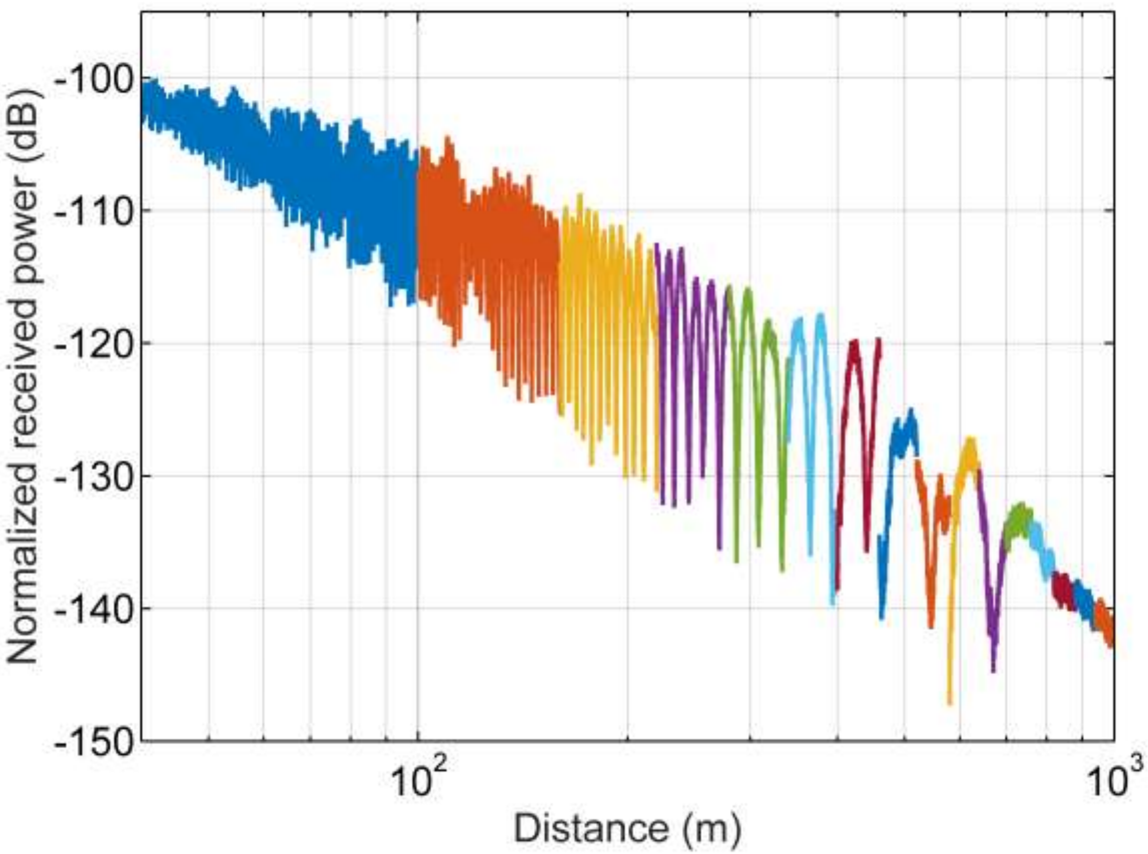





Note: delay calibration not yet applied

# Airport: Received Power vs. Distance

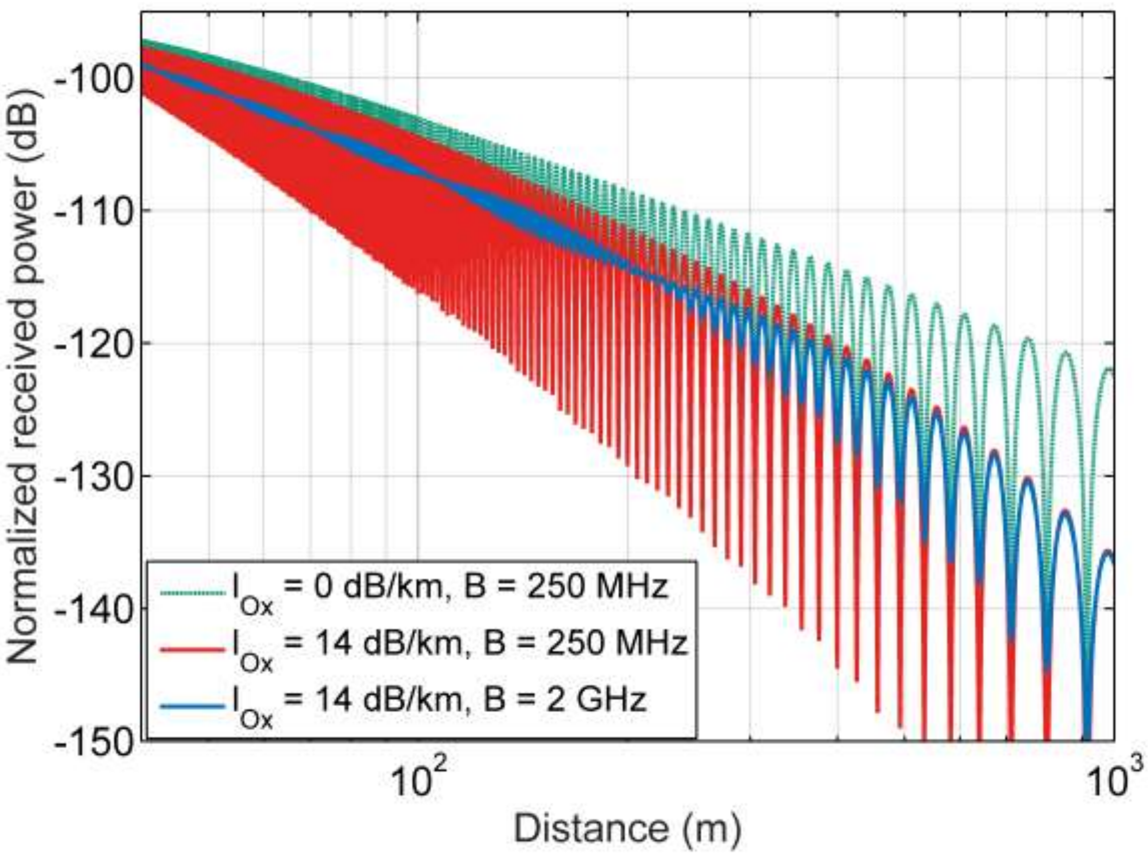





- Normalized received power from 40 to 1000 m on tarmac runway for vertical polarization
- Combination of 16 subsequent measurement runs, 60 m each
- Distinct fading structure can be observed: superposition of direct (LOS) and ground-reflected path
- Some artifacts at the seams due to repositioning of Tx

# Two-ray Propagation Model



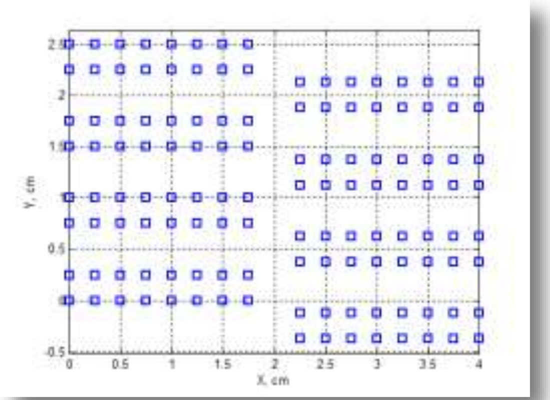



- Two-ray propagation model taking into account Fresnel reflection and oxygen absorption
- Good agreement of fading structure, differences to be investigated in more detail
- Oxygen absorption rate of 14 dB/km estimated: in line with Liebe's MPM model (13.9 dB/km)
- Increase of bandwidth helps to reduce fading effects, however: still significant fading (10 dB) for larger distances despite 2 GHz bandwidth and directional antennas!

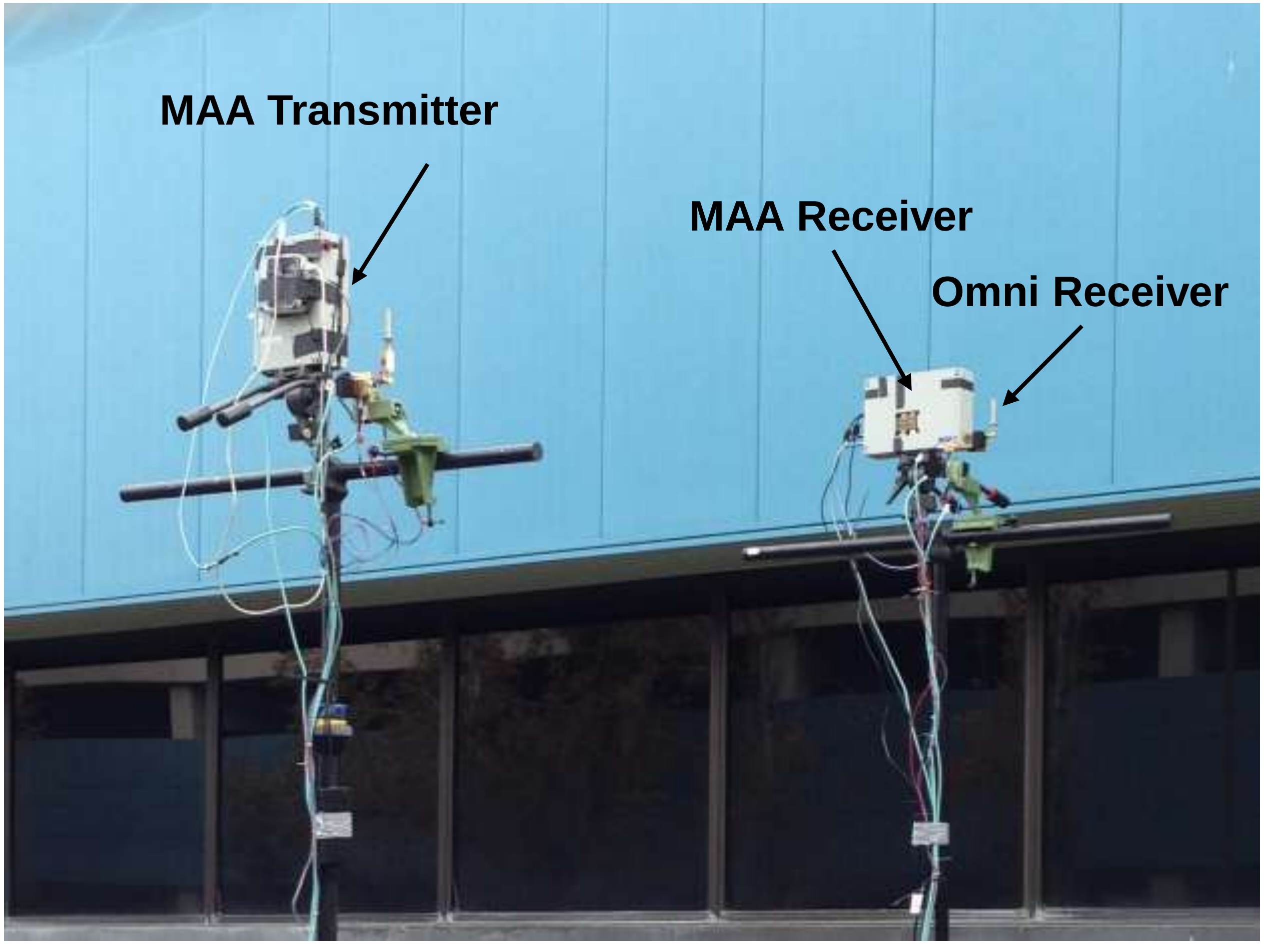
# Adaptive Array Measurements @ Intel

- First use of large adaptive antenna arrays for real-time channel measurements
- Modular Antenna Array (MAA) compromising 8 sub-modules with 2 x 8 antennas each (128 active antenna elements)
- Demonstration of Intel's adaptive antenna technology
- Insight into wireless channels incorporating realistic antenna effects
- Real-time spatial resolved channel measurements including full scans (beam-switching in millisecond range)

(The measurements were also supported by R&S)



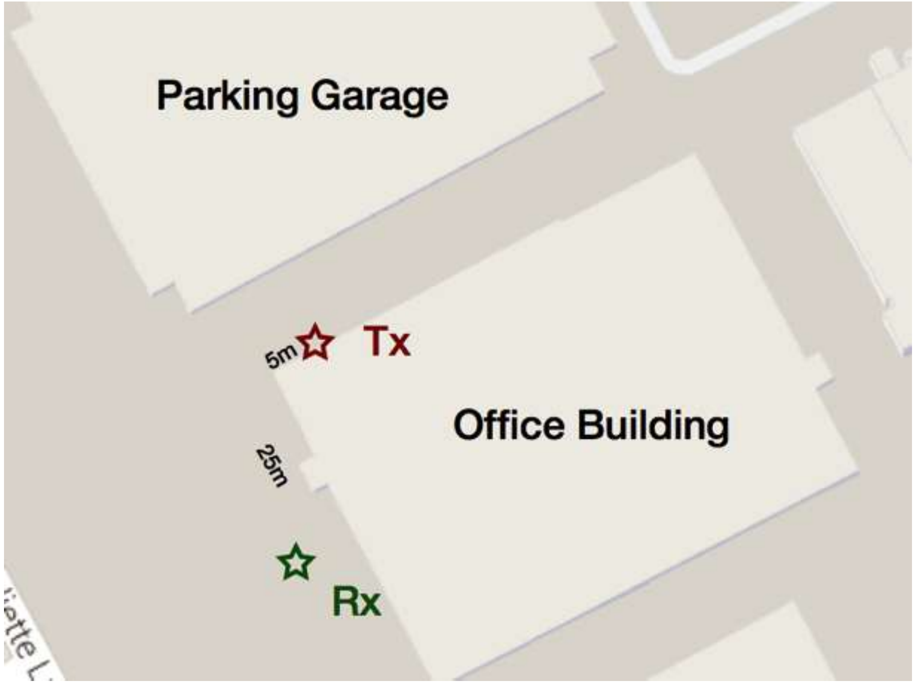
# Measurement Setup

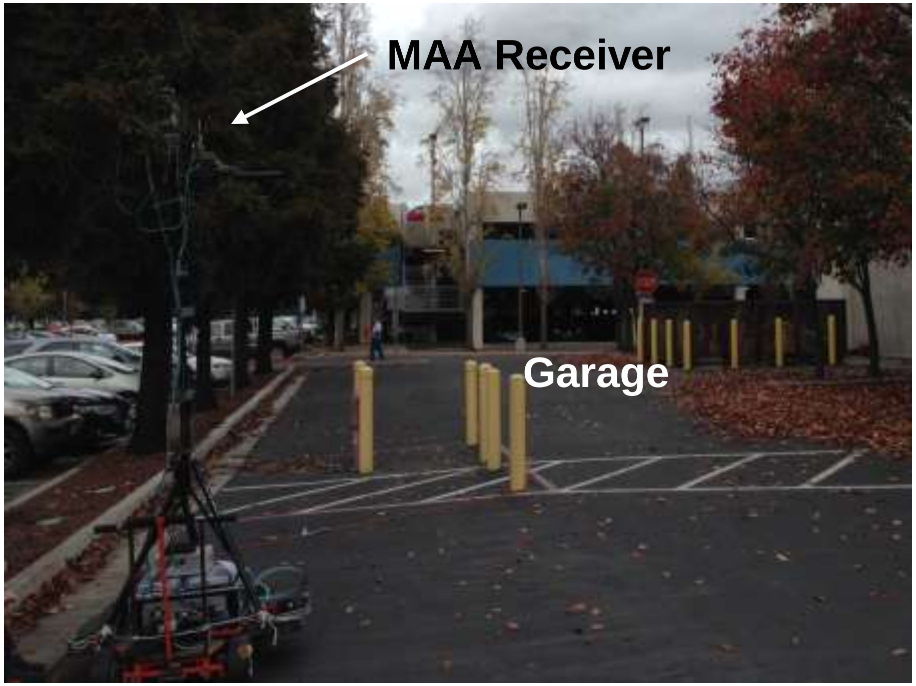



- MAA at both sides
- Simultaneous measurement with omni-antenna at receiver side (SIMO)
- 90° scan angle in azimuth and 30° scan angle in elevation
- 5° resolution, 17 x 9 beams
- 140 measurements sets each with 62,500 impulse responses: approx. 8.8M in total

# NLOS Backhaul

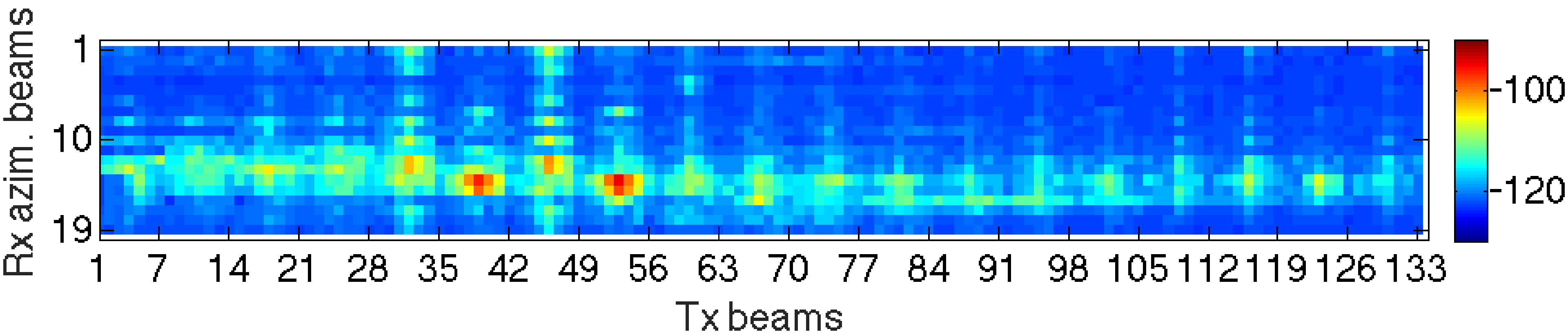





- Street level backhaul in street canyon: 3 m antenna height, distances up to 125 m, LOS and NLOS measurements
- Exhaustive beam search with full scan at the transmitter and azimuth scan at the receiver (2257 beam combinations)

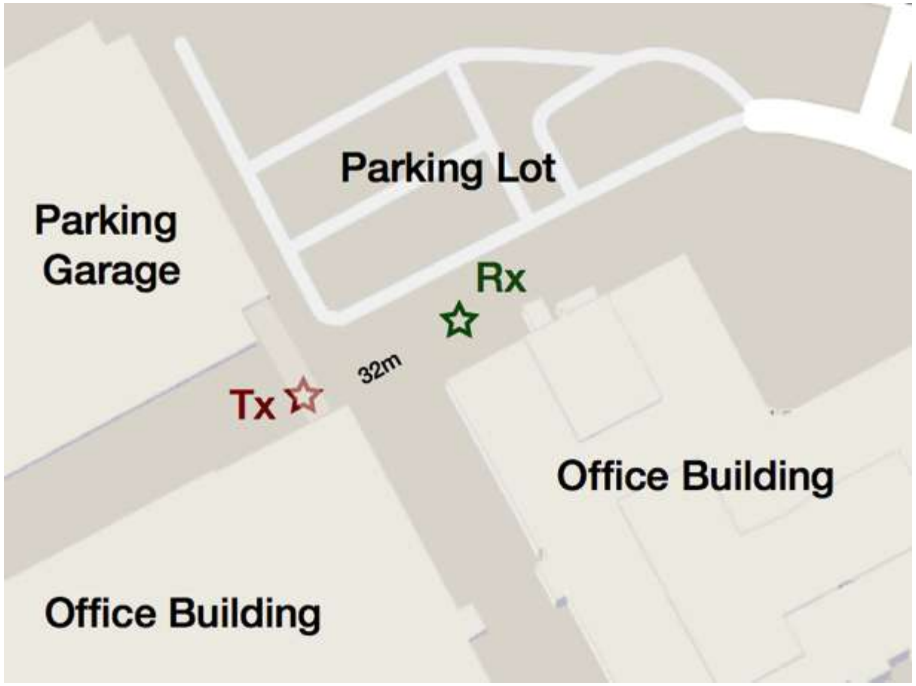
# Preliminary Results




**Map of total received power per beam**

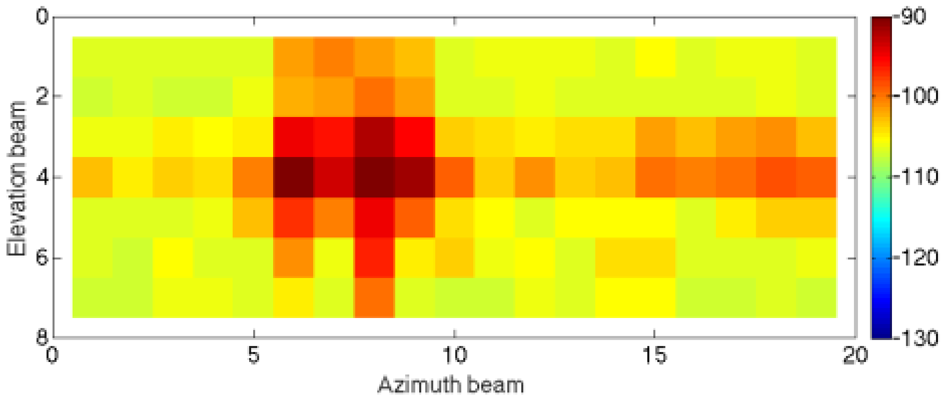
- Several useful beam combinations could be found
- Influence of multiple reflections and antenna side-lobes
- NLOS backhaul with MAA is feasible
- Further investigations on temporal characteristics needed

# User Access

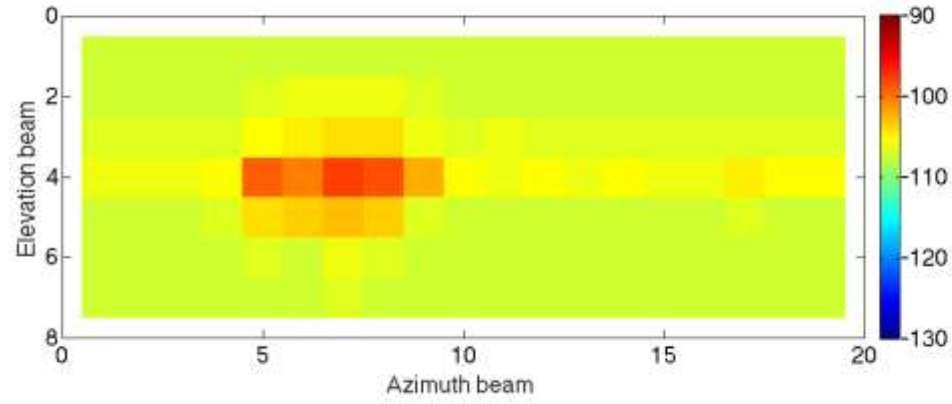



- User Access on plaza: 3 m antenna height at base station, 1.2 m antenna height at terminal, measured distances up to 60 m on continuous grid
- Full scan at the transmitter and omni-receiver (133 beam combinations)

# Preliminary results



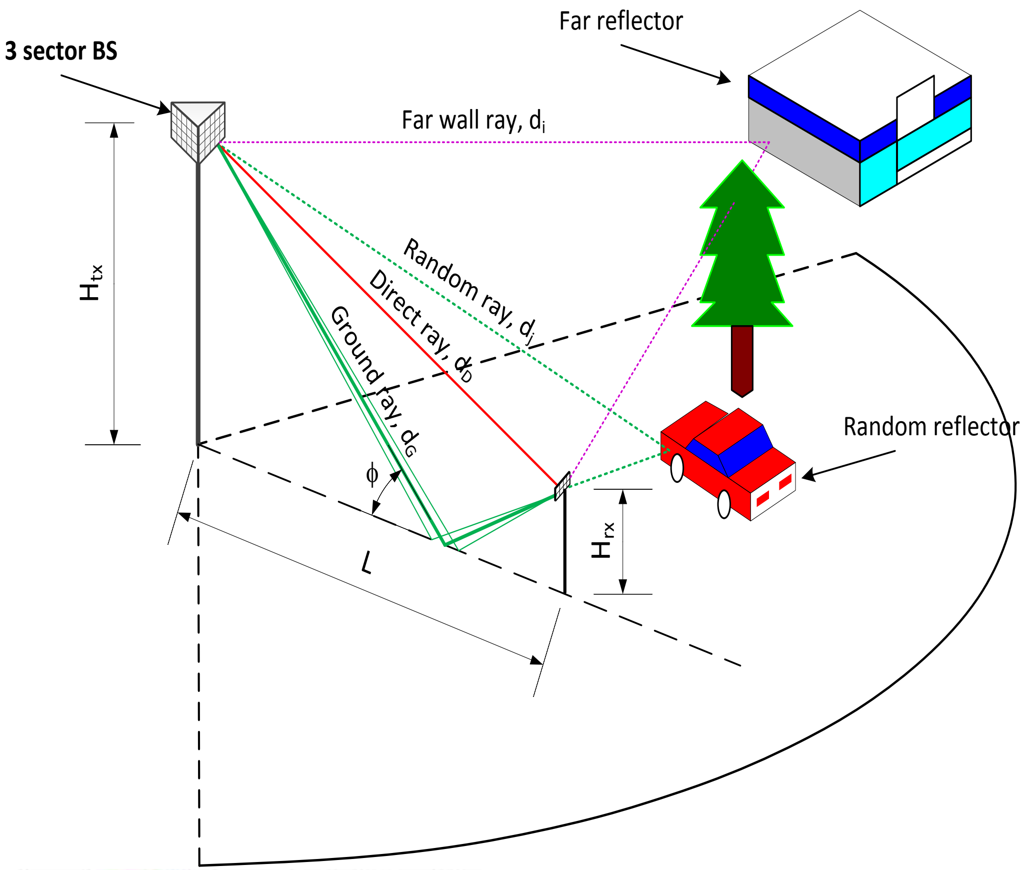

**Total received power per Tx beam (LOS)**




**Total received power per Tx beam (OLOS)**

- Multipath propagation could be spatially resolved
- Obstruction (OLOS, human body shadowing) has some impact
- In OLOS communication still feasible (appr. 15 dB loss)

# Quasi Deterministic Channel Model




MiWEBA Intel, Fraunhofer HHI

## Methodology

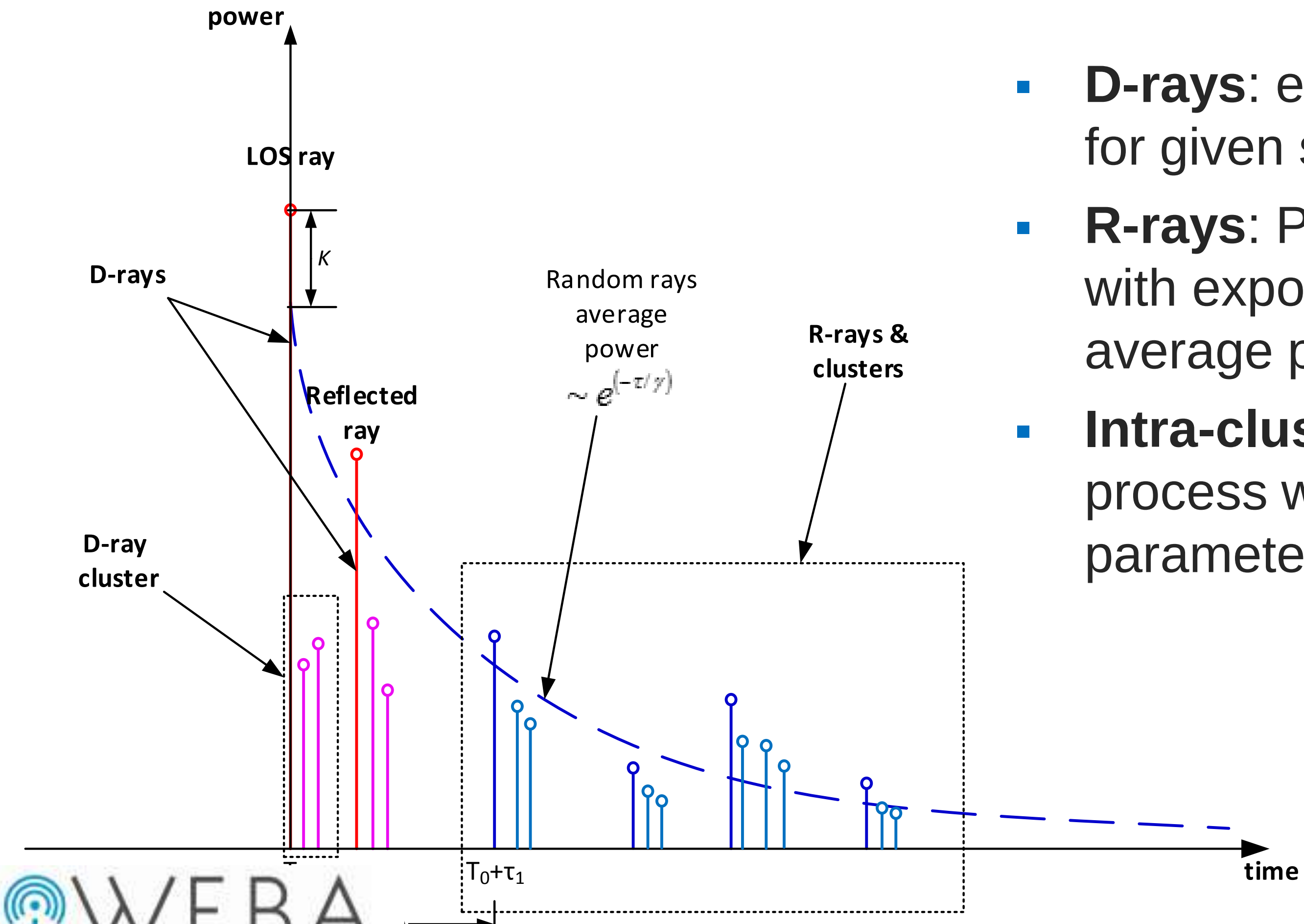
### D-rays:

- Direct ray and strong reflections (e.g. ground reflection)
- Given by free space loss, reflection coefficient, polarization, and mobility effects (Doppler shift and user displacement)

### R-rays:

- Far-away reflections
- Defined by PDP, angular and polarization characteristics according to scenario-specific probability distributions

# Channel Impulse Response Structure




- **D-rays**: explicitly calculated for given scenario
- **R-rays**: Poisson process with exponentially decaying average power
- **Intra-cluster rays**: Poisson process with appropriate parameters

Intel, Fraunhofer HHI

# Conclusions

- Measurement campaigns on mm-Wave outdoor channels for access and backhaul scenarios, for 5G system evaluation
- Omnidirectional, directional and adaptive array antennas
- Full information on temporal characteristics through real-time measurements
- Spatial information through array antenna measurements