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

Wilhelm Keusgen

International Workshop on Emerging Technologies for 5G Wireless Cellular Networks
December 8\textsuperscript{th} 2014
Disruptive Technologies for 5G

Component (node) disrupt.

Architecture disrupt.

Further evolution of 4G (out-of-scope of this work)

Node-centric networks

Massive-MIMO

Smarter-devices

mmWave

Native support of M2M services

Five Disruptive Technology Directions for 5G, IEEE Communications Magazine • February 2014
Millimeter-Waves in 5G

Millimeter-Wave for
- Backhaul
- Fronthaul
- Access
- Offload (WiFi)

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

Wireless Communications and Networks

METIS Public 14...

Target bandwidth increases the opportunities significantly, but outdoor deployments and wider coverage implies more

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31.01.2015
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 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
### Channel sounding parameters

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

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

Sources: Google Maps
Wireless Communications and Networks

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
Illustration of Time Variance

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

Selected multipath components
Channel Impulse Response
RX antenna
TX position
RX position (25 meter)
RX location
TX location
Illustration of Time Variance

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- TX-RX distance: 25 meter
Path Loss Parameter Extraction (1)

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

- Estimated Parameters:

<table>
<thead>
<tr>
<th>PL (5 m)</th>
<th>n</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>82.6 dB</td>
<td>2.26</td>
</tr>
<tr>
<td>WB</td>
<td>82.0 dB</td>
<td>2.18</td>
</tr>
</tbody>
</table>

- 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!
Equivalent evaluation, but with preceding spatial averaging over 3125 adjacent snapshots (1.25 m segments)

Estimated parameters become practically independent of bandwidth:

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<tr>
<th>PL (5 m)</th>
<th>n</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>82.1 dB</td>
<td>2.09</td>
</tr>
<tr>
<td>WB</td>
<td>81.9 dB</td>
<td>2.13</td>
</tr>
</tbody>
</table>

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