Fraunhofer Heinrich Hertz Institute

Mobile Millimeter-Wave Access: Opportunities, Challenges, Concepts

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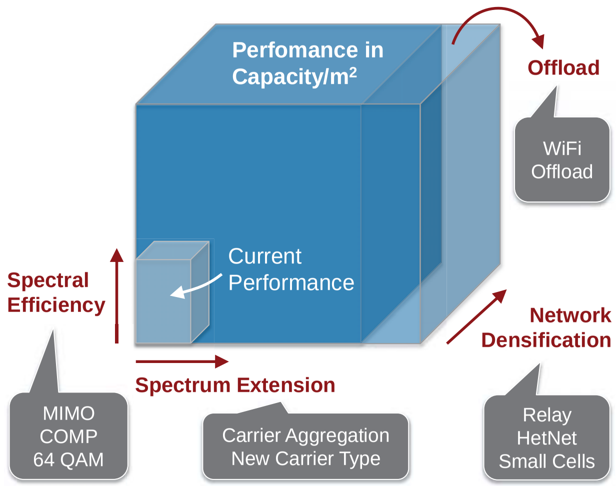
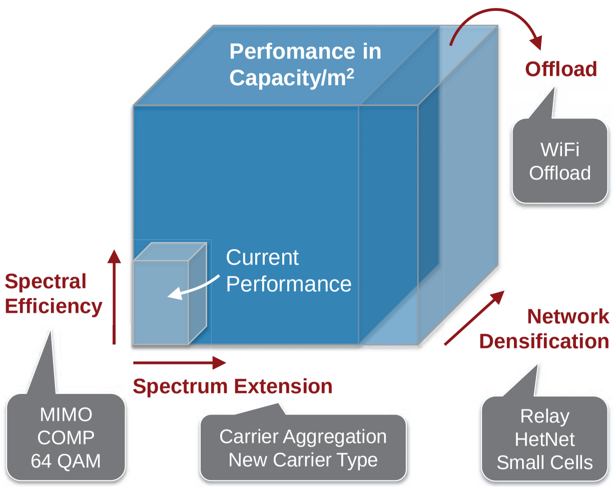
How to increase Capacity?



- Spectral Efficiency: Factor 5
- Spectrum Extension: Factor 2
- Network Densification: Factor 10
- Offload: Factor 2
- Sum Gain: 200

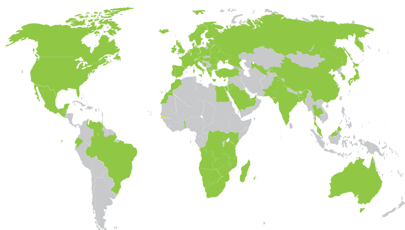
Achieving 10.000x?



- Spectral Efficiency: Factor 5
- Spectrum Extension: Factor **20**
- Network Densification: Factor **50**
- Offload: Factor 2
- Sum Gain: **10.000**

mm-Waves in Mobile Communication

- mm-wave opportunities for broadband mobile networks
  - Indoor / short range (WLAN, IEEE 802.11ad)
  - Backhaul / fronthaul (Point to Point, Point to multipoint)
- Key benefits
  - License free or light licensed in many countries
  - Large available bandwidth (up to 9 GHz)
  - Low interference probability
- **60 GHz as huge opportunity for mobile access links: spectrum x 20**



Scenario

- Cellular network densification and spectrum extension by means of mm-wave cellular overlay
- Multi-Gbps cell capacity and Gbps user data rates
- Seamless integration into existing network
- Street level (lamp post) deployment, height: 1–4 m
- Adaptive antenna gains at BS and terminal (approx. 15 dBi at each side)

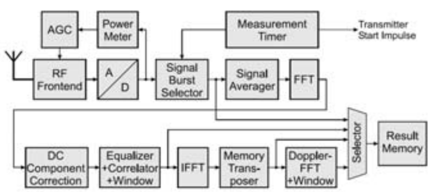
Crucial issues

- mm-wave outdoor channel
- PHY design & beamforming

60 GHz Outdoor Channel Measurements

Measurement Equipment

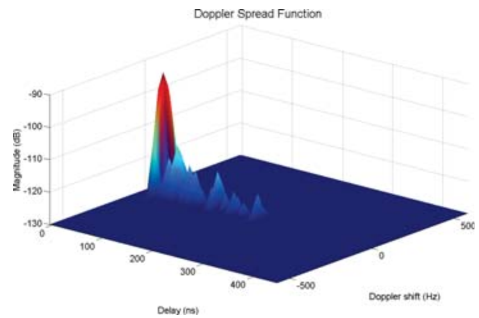
- HIRATE: Modular testbed comprising digital baseband platform, plug-on modules and external 60 GHz transceivers
- Channel sounding implementations for two different modes: real-time mode, high-precision mode
- Transmission of periodic wideband correlation signal
- Computation of Doppler-resolved CIR
- Measurement bandwidth: 250 MHz, delay resolution approx. 7 ns
- Antennas used for outdoor measurements: 25° beamwidth

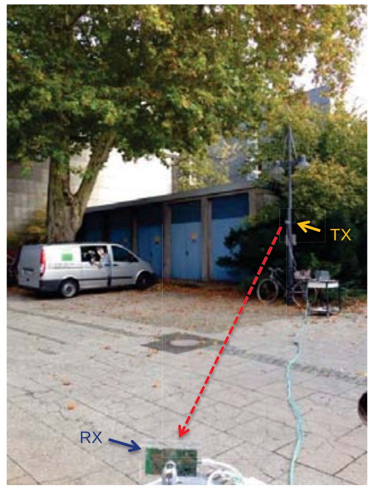


Channel sounder Rx implementation

LOS – Direct Path

- LOS transmission with 10 m distance
- High receive power: easy to establish high-rate data link
- Significant multipath components despite directional transmission (antenna alignment)

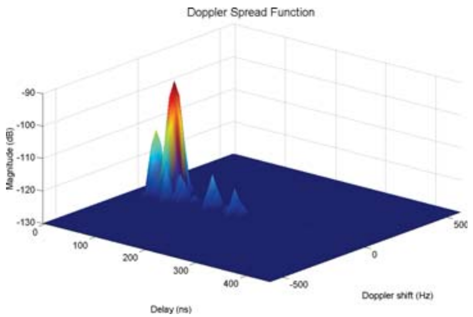


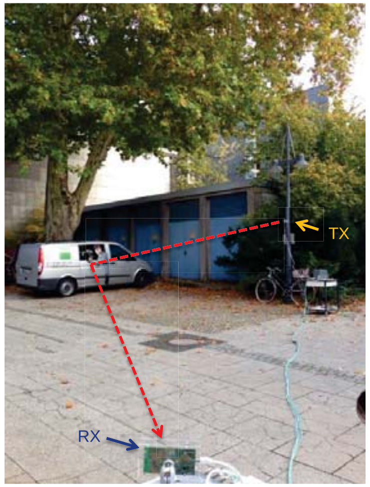


Reflection Paths

Wireless Communication and Networks

- Strong reflections at buildings, pillars, cars
- Reflected path only approx. 5 dB weaker than direct path in shown case
- Strong motivation to utilize best reflection path with beamsteering under OLOS conditions

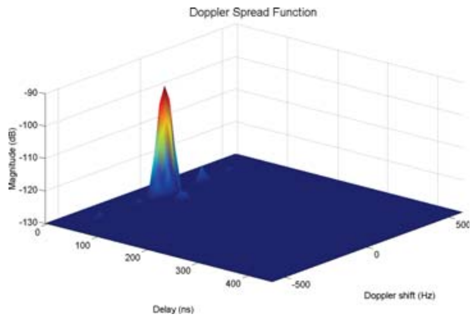


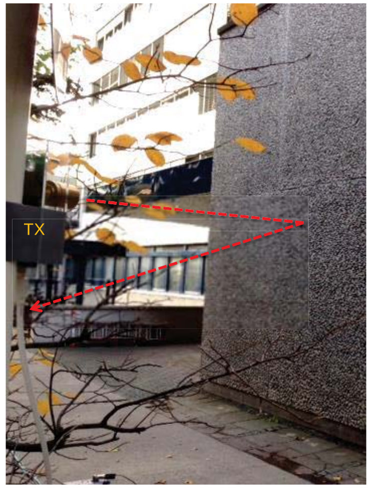


Reflections from Rough Walls

Wireless Communication and Networks

- Reflection at exposed aggregate concrete wall
- Strong reflected path: comparable to even comparable to previous scenario
- Rough walls may me good reflectors!

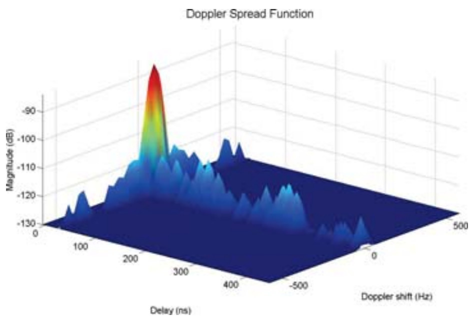


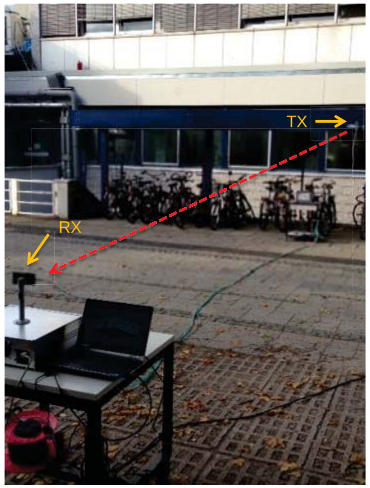


Multiple Reflections

Wireless Communication and Networks

- Multiple perpendicular reflections between walls („ping-pong effect") are possible
- Paths with several hundred ns delay
- Highly multipath-robust and adaptive PHY modes needed to prevent excessive performance loss

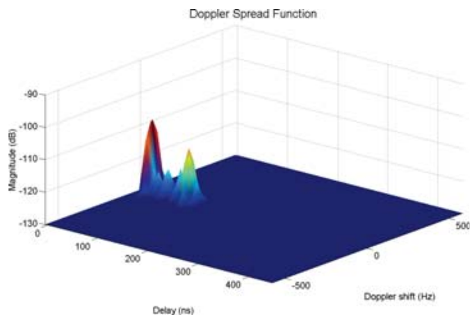




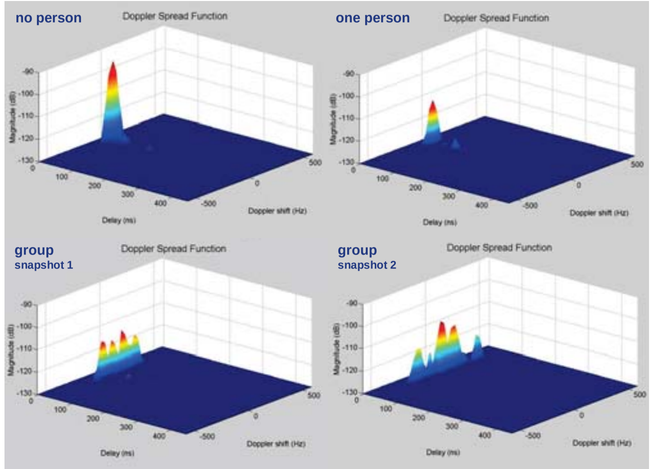
Near LOS

Wireless Communication and Networks

- Little diffraction from corners: very fast loss of power in shadow zone
- Positive effect from scatterers near corner



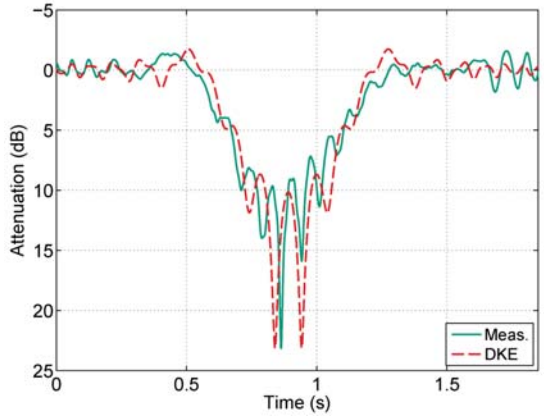
Human Body Shadowing



- Severe blocking effect by single persons
- Strongest effect for person close to antenna
- Short-term effect if person is moving continuously
- Rich multipath scattering by group of walking people
- Significant Doppler spread

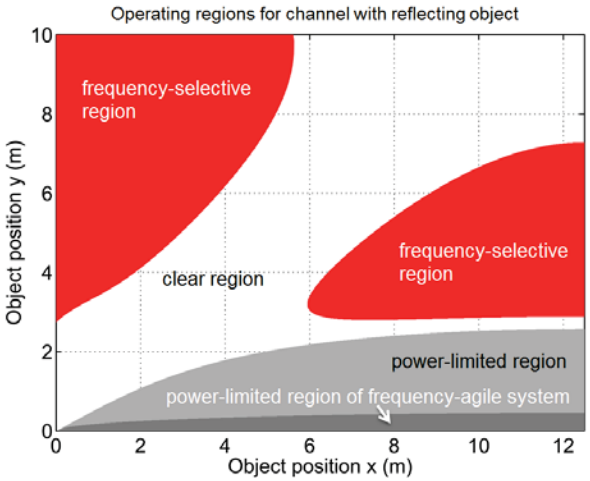
Human Body Shadowing

Attenuation of LOS path caused by human body shadowing (v = 0.5 m/s)



- Large fluctuations of received power level due to human body shadowing
- Characteristic shadowing curves as a function of Tx-Rx distance and shadowing distance
- Extensive measurements and modeling work on HBS
- Fast beamsteering and handover techniques required
- Smart signal-based algorithms for prediction of shadowing possible

Two-Ray Propagation



- Theoretical investigations based on direct path and strong reflector
- Assumptions: symmetric antenna configuration, G_{tot} = 15 dBi: d = 25 m, 60 GHz
- Three regions:
  - Clear
  - Frequency-selective
    ⇨ Equalization
  - Power-limited
    ⇨ Frequency agility

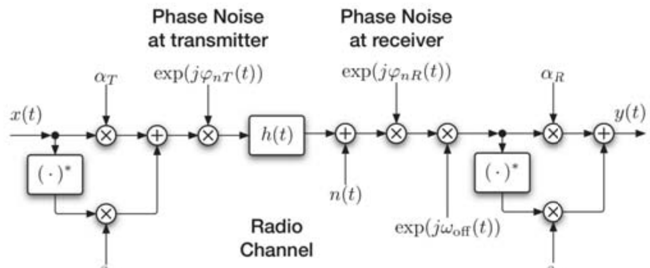
Summary on 60 GHz Outdoor Channel

- Sufficient received power to for very high rate LOS connections
- Significant multipath components: channel length can exceed 400 ns in urban areas
- Obstructed LOS feasible if strong reflection paths are accessible: power loss found to be 5–15 dB for presented measurements in many cases
- Positive effect from scatterers near corners
- Robust (adaptive) links, except for close blocking in open areas

Physical Layer & Beamforming

Error Model

Wireless Communication and Networks



$$\alpha_T = \tfrac{1}{2}(1 + g_T \exp(j\phi_T))$$
$$\beta_T = \tfrac{1}{2}(1 - g_T \exp(j\phi_T))$$

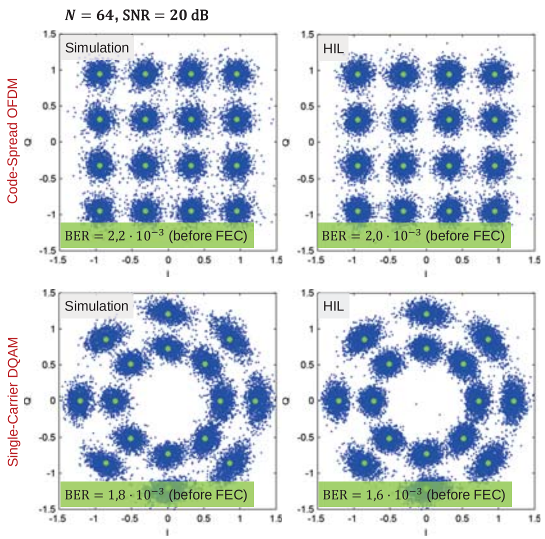
$$\alpha_R = \tfrac{1}{2}(1 + g_R \exp(-j\phi_R))$$
$$\beta_R = \tfrac{1}{2}(1 - g_R \exp(j\phi_R))$$

- Consideration of comprehensive error model required
- Hardware impairments: crucial aspect for system design
  - IQ errors
  - Phase noise
  - Frequency offset
- Parameterization of model based on measurements of real hardware

Waveforms

Wireless Communication and Networks

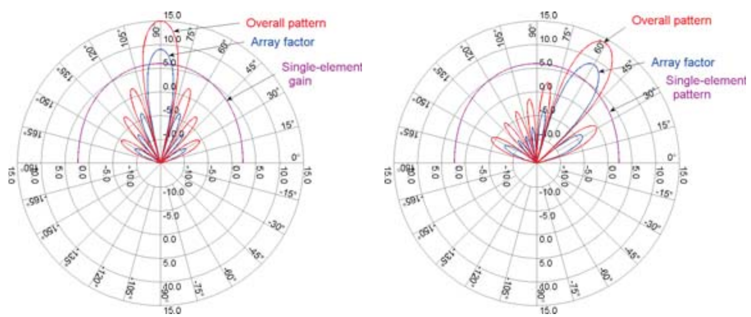
- Investigation of waveforms by link level simulations and HIL experiments (e.g. CS-OFDM, SC-DQAM)
- Strong dependence on hardware parameters
- Decisive: combination of all error effects (partly inseparable!)
- Frequency offset cannot be avoided under mobility
- Results motivate evaluation of
  - alternative modulation techniques
  - novel estimation and compensation techniques



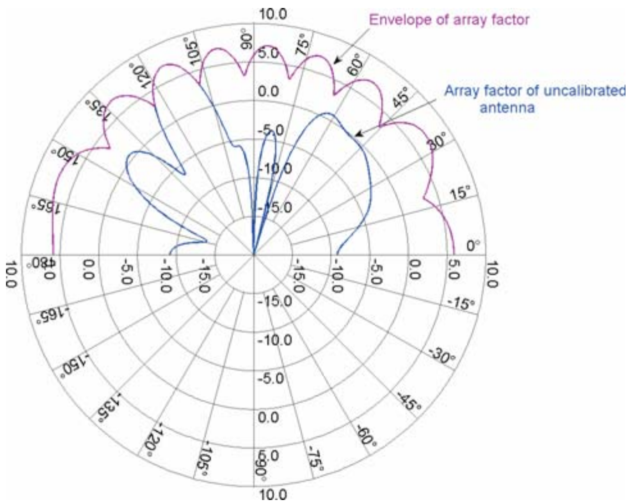
Beamforming: Calibrated Array

Wireless Communication and Networks

- Codebook-based or non-codebook-based approaches
- Training techniques
  - full training with all codebook BF vectors (only codebook-based)
  - iterative estimation
  - estimation of channel matrix and subsequent computation of optimum BF vector

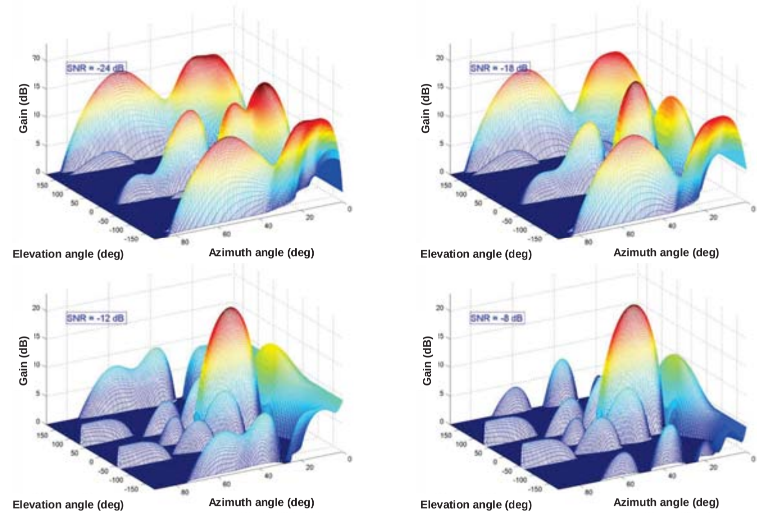


Beamforming: Uncalibrated Array

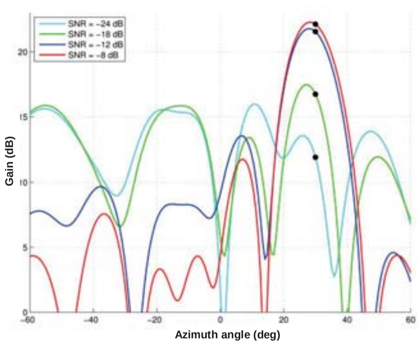


- Approach, where full calibration of antenna + front-end is not needed or not possible
- Unknown (random) phase in each BF branch
- Appropriate methods for low SNR training required
- 1st step to improve SNR: blind BF at Tx
- 2nd step:
  - element-by-element training with reference BF branch or
  - full acquisition of training signals and computational power maximization

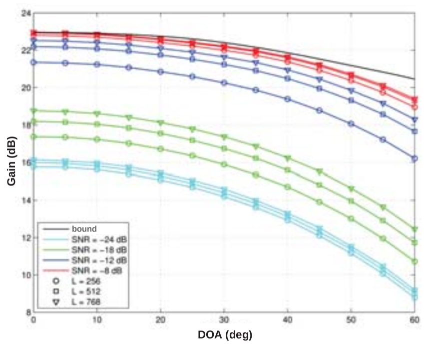
BF Simulation Results (1)



BF Simulation Results (2)



Gain in elevation plane for DOA = 30° and sequence length L = 256



Achievable gain as a function of sequence length and SNR

Conclusion

Channel

- Time-dispersive / frequency-selective (as for classical mobile channel)
- Robust indirect links possible by exploiting strong reflections, but presence of reflectors required

PHY and beamforming

- Appropriate PHY design essential: hardware impairments in combination with frequency offset and Doppler shift
- Several BF training techniques available, even for uncalibrated array and very low SNR

mm-wave transmission is…

- well suited to establish moderate-mobility ultra-high capacity cellular overlay
- technologically feasible