5G Channel Modeling for mmW Systems

Andreas F. Molisch
Wireless Devices and Systems (WiDeS) Group
University of Southern California (USC)

Why mm-wave for cellular

- Many GHz of bandwidth available
  - Cellular: 28, 38, 71-76, 81-86
  - WLAN: 58-56
- Short range due to high free-space pathloss
- Natural fit for small-cell communications

- History:
  - Much activity in 1990s
  - Failure due to cost, not operating principles
  - Now CMOS available for mm-wave

- System design requires understanding of channel

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- Motivation and basic propagation effects
- Pathloss
- Delay spread and angular spread
- Modeling approaches

Main application scenarios

- Microcells

- Macrocells

- Backhaul

Free space

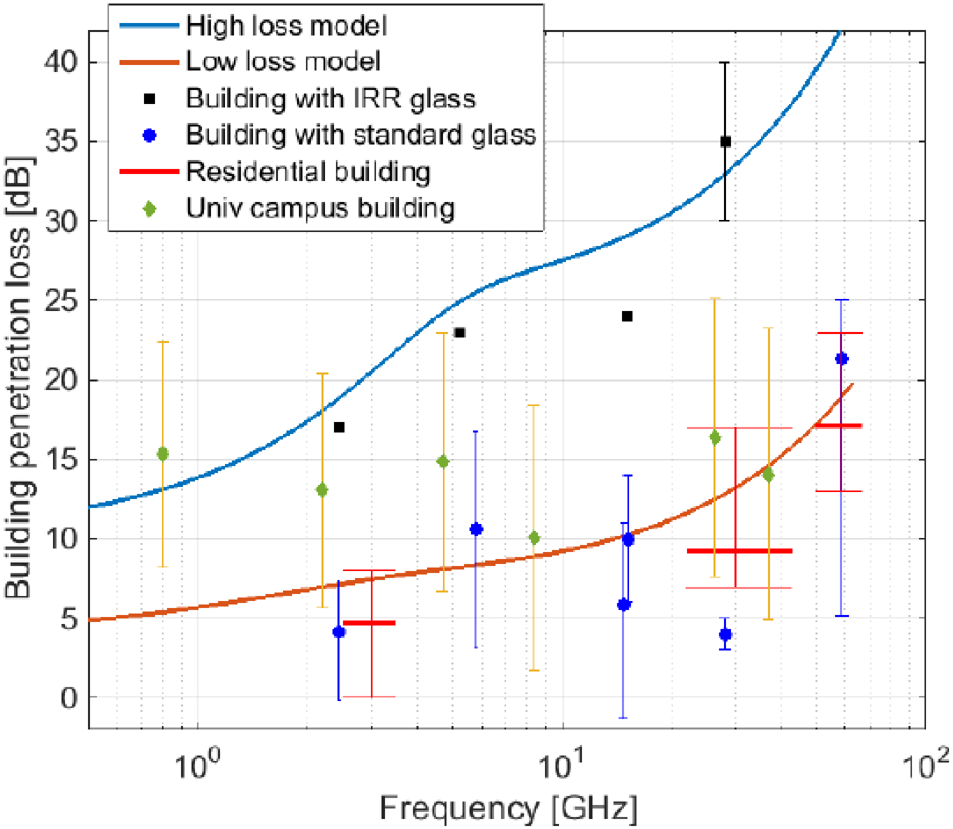
- Free-space pathloss:

$$PL(d,f) = \frac{1}{G_{\mathrm{TX}} G_{\mathrm{RX}}} \left(\frac{4\pi f d}{c_0} \right)^2 \qquad G_{\mathrm{RX}} = \frac{4\pi f^2}{c_0^2} A_{\mathrm{RX}}$$

  - Mm-waves have high pathloss for constant-gain antennas
  - Mm-waves have low pathloss for constant-area antennas
    - Requires adaptive beamforming
- Atmospheric attenuation
  - No major concern at considered distances

Penetration loss

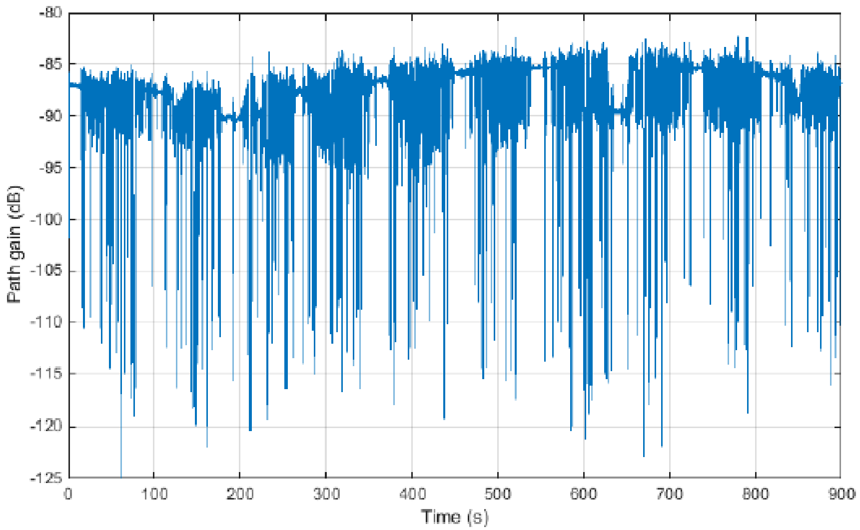
- Outdoor walls:
  - Attenuation up to 60 dB
  - Type of windows very important:
    - Energy saving windows: >20 dB
    - Regular windows: <5 dB



[Haneda et al. 2016]

Body shadowing

- Body shadowing: much more pronounced than at cm-waves
  - Body with device blocks radiation from large angular range
- Bodies and cars blocking LoS (and more)
- >20 dB attenuation
- Implications for system design:
  - Connection might break
  - Or find alternative path (discontinuity in main beam direction)



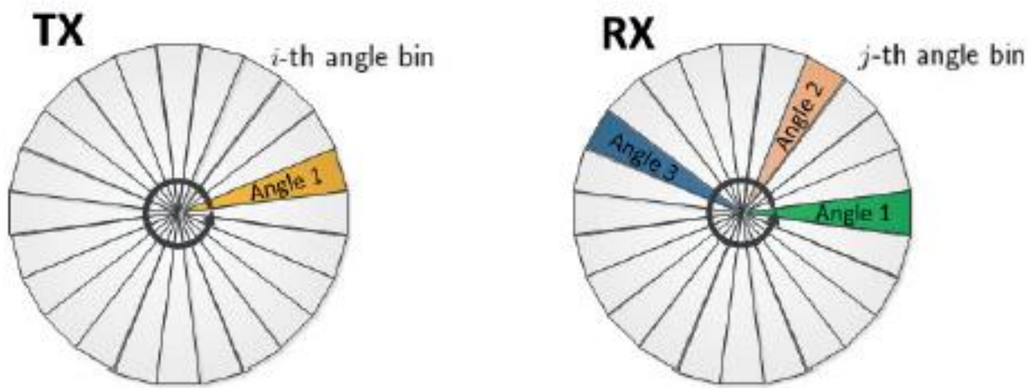
[Haneda et al. 2016]

Propagation Effects

- Diffuse scattering
  - Significant when surface is rough compared to wavelength
  - Excepted to be much more significant at mm-wave frequencies at large distances (but: compare [Haneda et al. 2014], [Sangodoyin et al. 2015])
- Doppler spread
  - Order of magnitude larger than at microwaves
- Foliage:
  - Stronger attenuation than at microwave

Measurement methods (I)

- SISO
  - For pathloss and delay spread only
  - Usually horn antenna at one link end to get link budget
  - Results specific to used horn
  - Can measure dynamic effects
- Rotating horn



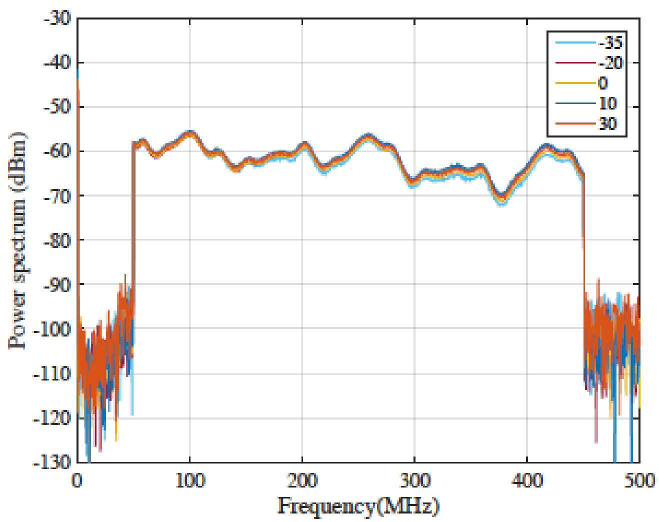
  - Takes long time to measure all combinations
  - Real-time measurements not feasible

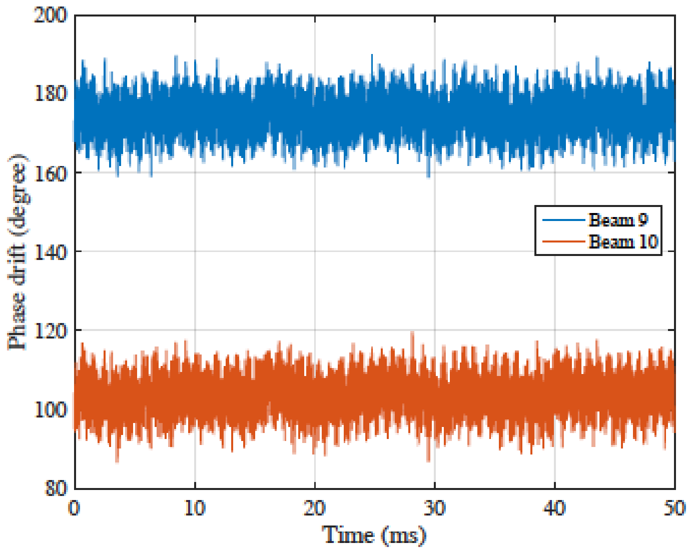
Measurement methods (II)

- Vector Network Analyzer + Virtual Array
  - No real-time measurements
  - Enables high-resolution evaluation (SAGE, RiMax)
  - Requires synchronization within inverse carrier frequency
  - Challenges from high frequencies:
    - Precision of virtual array location
    - Calibration of antennas

Measurement methods (III)

- Switched beam sounder USC/Samsung
  - Real-time measurements
  - 60 dBm EIRP, 170 dB dynamic range without averaging
  - High phase stability suitable for high-resolution parameter extraction without cable connection





[Bas et al. 2017; Arxiv; VTC]

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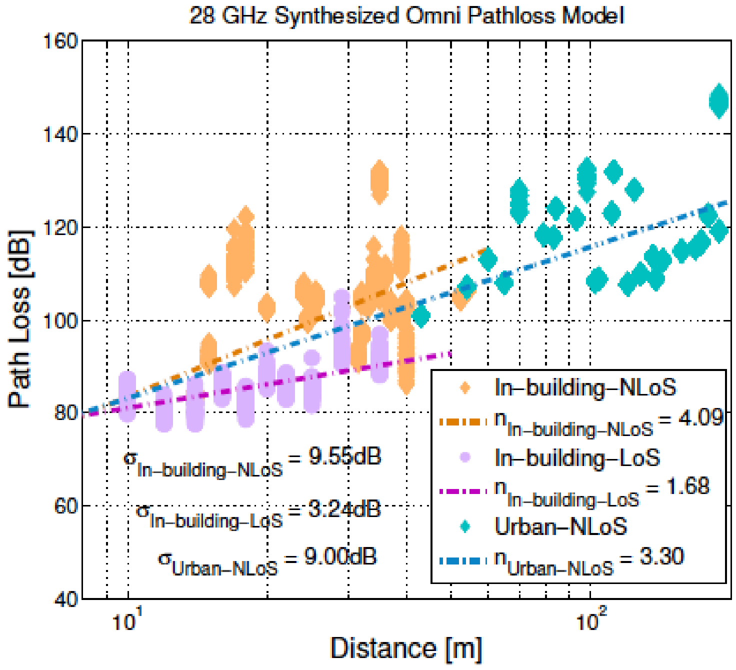
Pathloss outdoor

$$PL_{FI}(d) = 10\alpha \log_{10}(d) + \beta + X_{\sigma_{FI}}$$

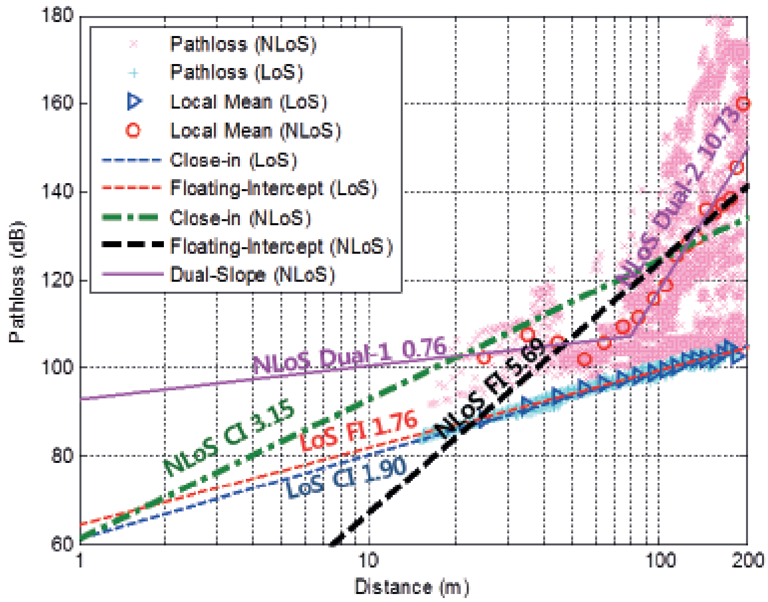
- Cellular access pathloss coefficient
  - LOS: 1.7-2.7
  - NLOS: 2.5-5
- Backhaul pathloss coefficient
  - LOS: 1.7-1.9

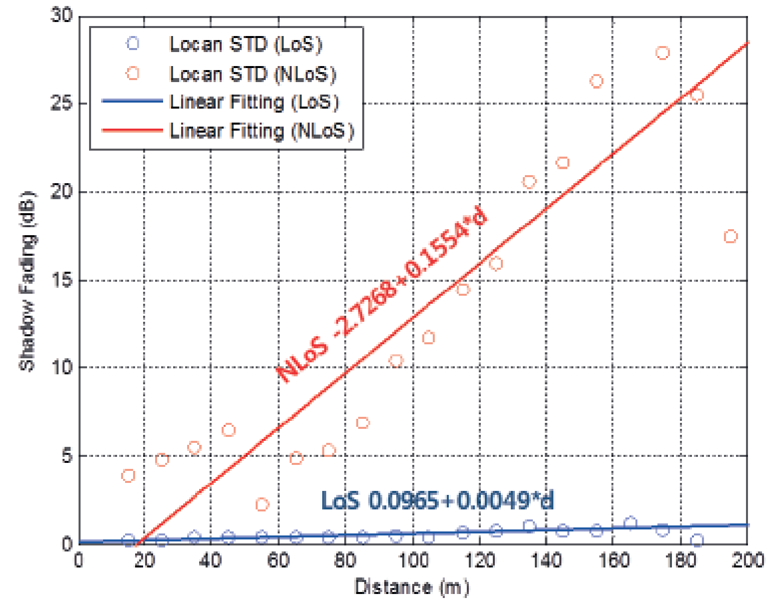
Similar pathloss coefficient as microwave, but higher offset



[Cho et al. 2015]

Pathloss at large distances



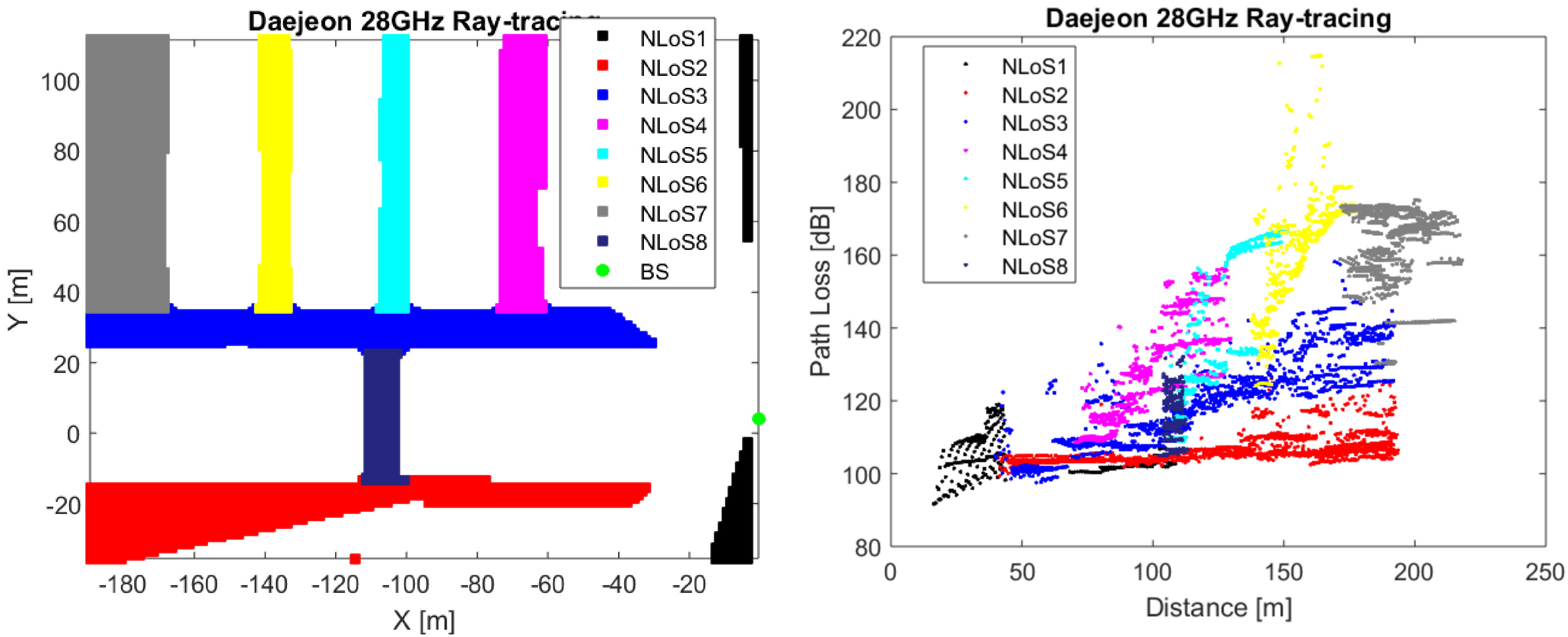


[Hur et al. 2016]

- Larger pathloss variance at larger distances
- Two-slope model can provide better fit

Impact of street canyon

- Cause for spreading of pathloss different streets have different slopes



[Molisch et al. 2016]

Street canyon

- Very strong variations of path loss coefficients from street to street
  - For some streets pathloss curves are almost flat, for others almost vertical
  - Euclidean distance might not be a good metric
- Shadowing
  - on a trajectory along a street has much smaller variance than the “standard deviation” of accumulated measurements from many streets and/or BSs
  - Shadowing within street is less sensitive to cutoff level
- Applicability
  - Applicable, but not necessary when we only want coverage probability (no interference, no spatial correlation) and the pdf of deviation from mean is known

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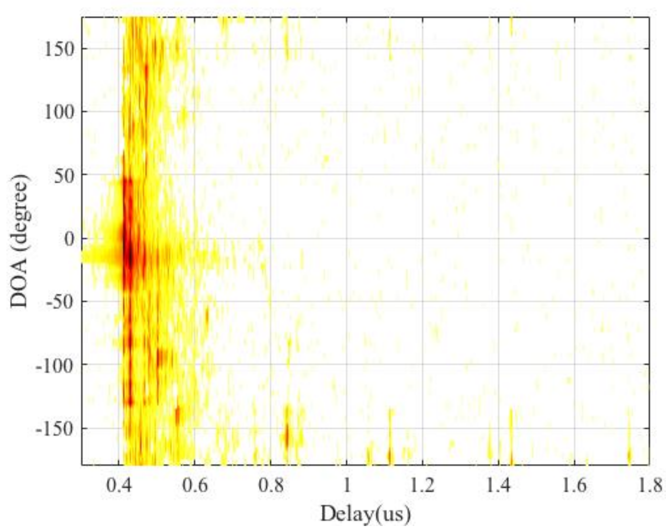
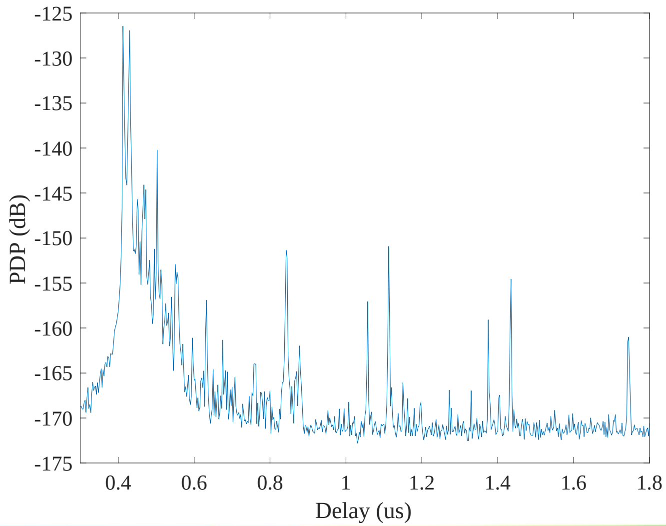
Delay spread

- Comparable to cm-wave
- Sample result in suburban environment

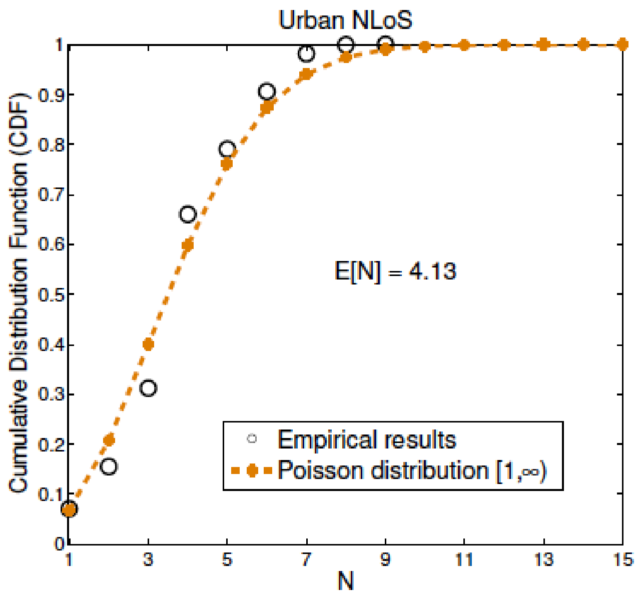
[Bas et al. 2017 Globecom]



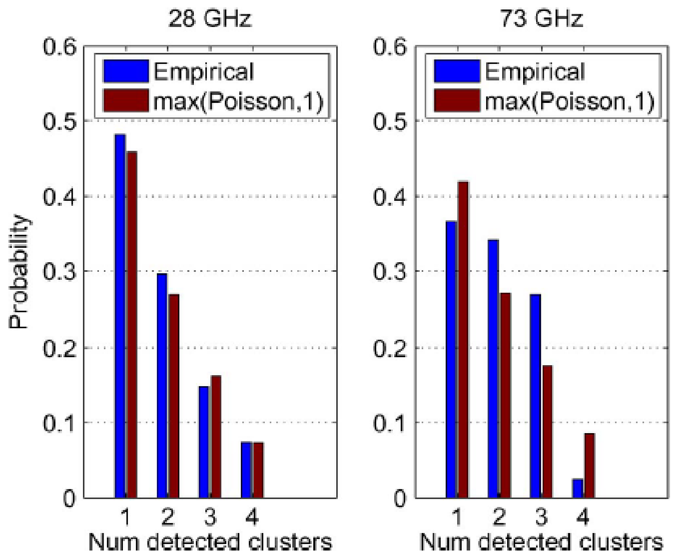


Number of MPCs

- Unresolved question
  - Delay resolution of mm-wave channels is high
  - But: outdoor channels usually measured with low angular resolution
- MPCs occur in clusters
  - Cluster number can be assessed more reliably



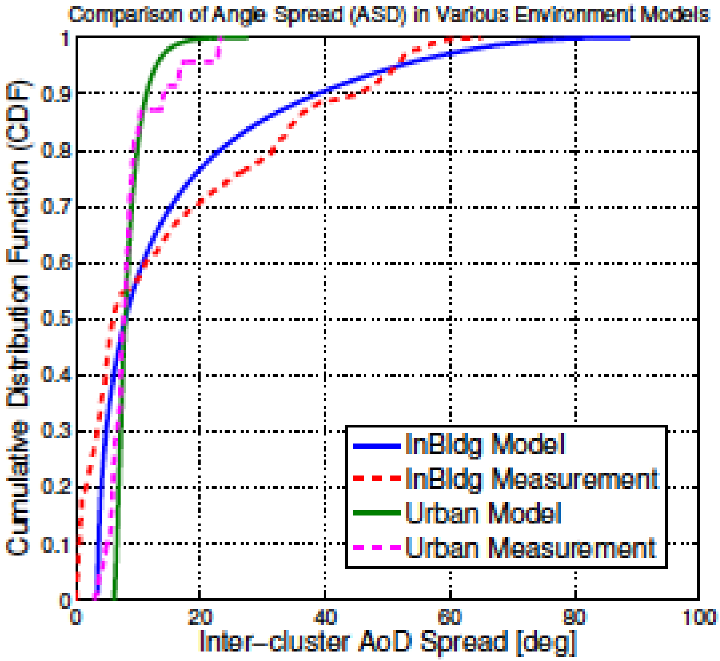
[Cho et al. 2015] Daejon, Korea



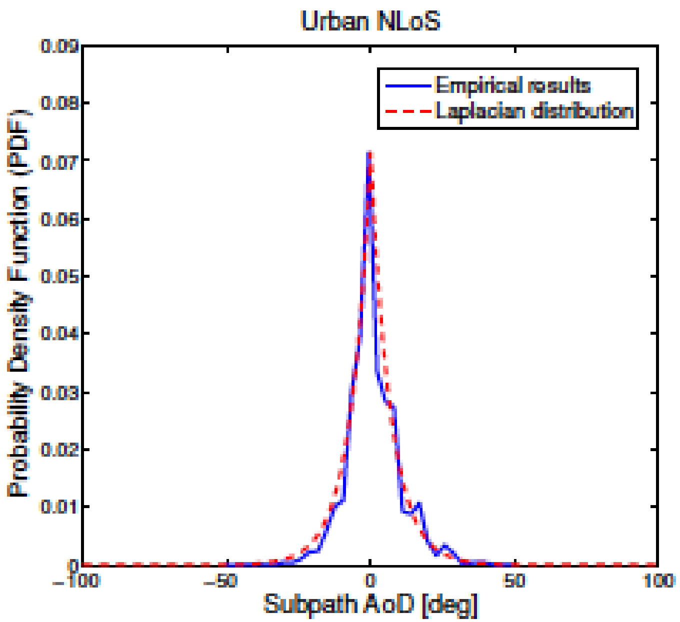
[Akdeniz et al. 2014] New York City

Angular spectra at BS

Inter-cluster



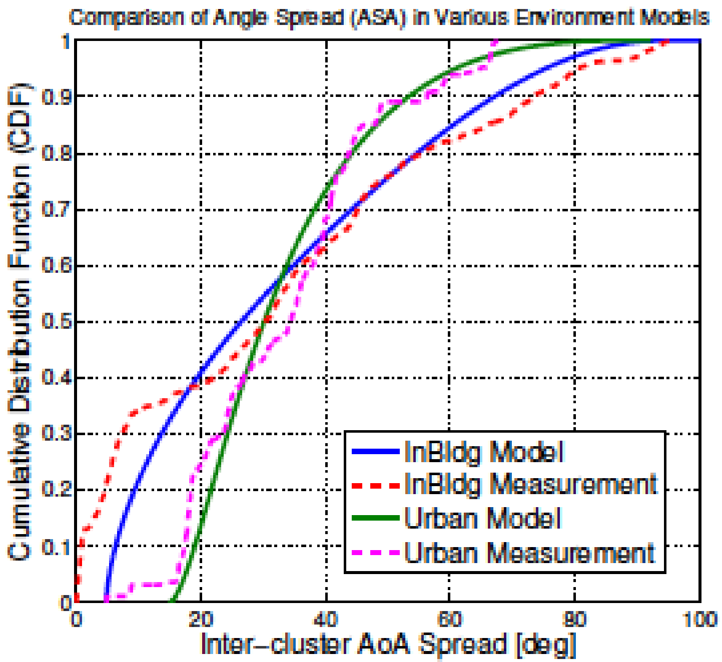
Intra-cluster



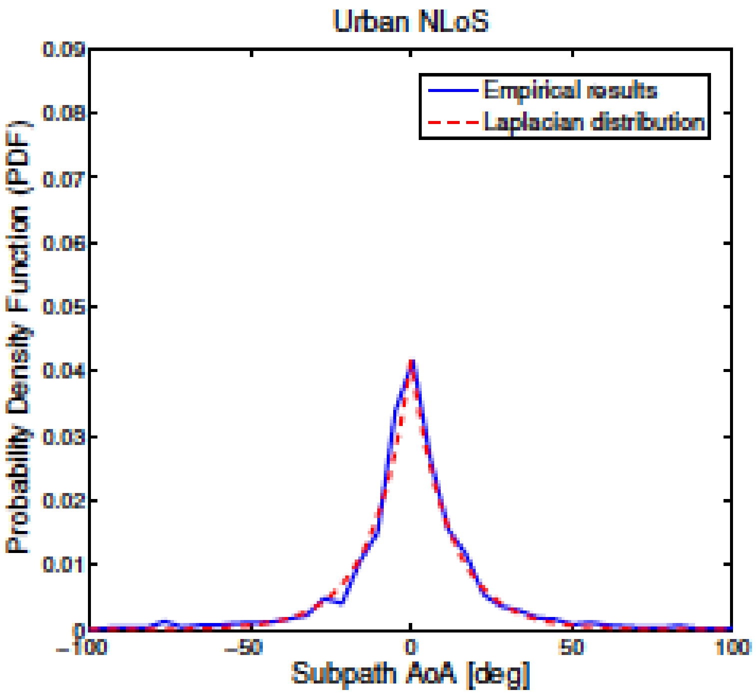
[Hur et al. 2015]

Angular spectra at MS

Inter-cluster



Intra-cluster



[Hur et al. 2015]

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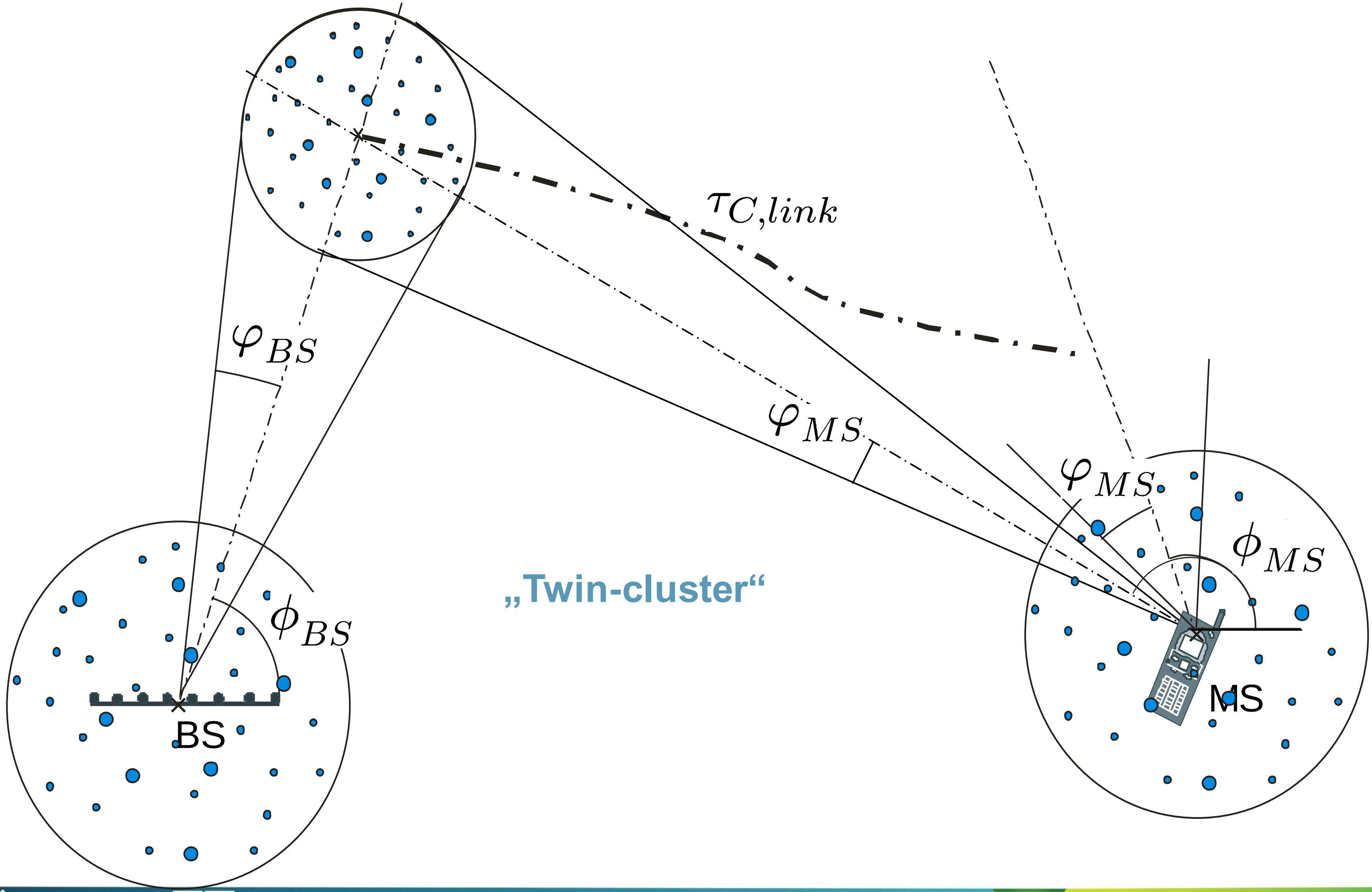
Winner-type

- Winner used for LTE evaluations
- MPCs in “clusters” all have same delay
- Fixed number of MPCs per cluster
- Angular spreads and delay spreads are correlated
- No Kronecker structure

COST-type models

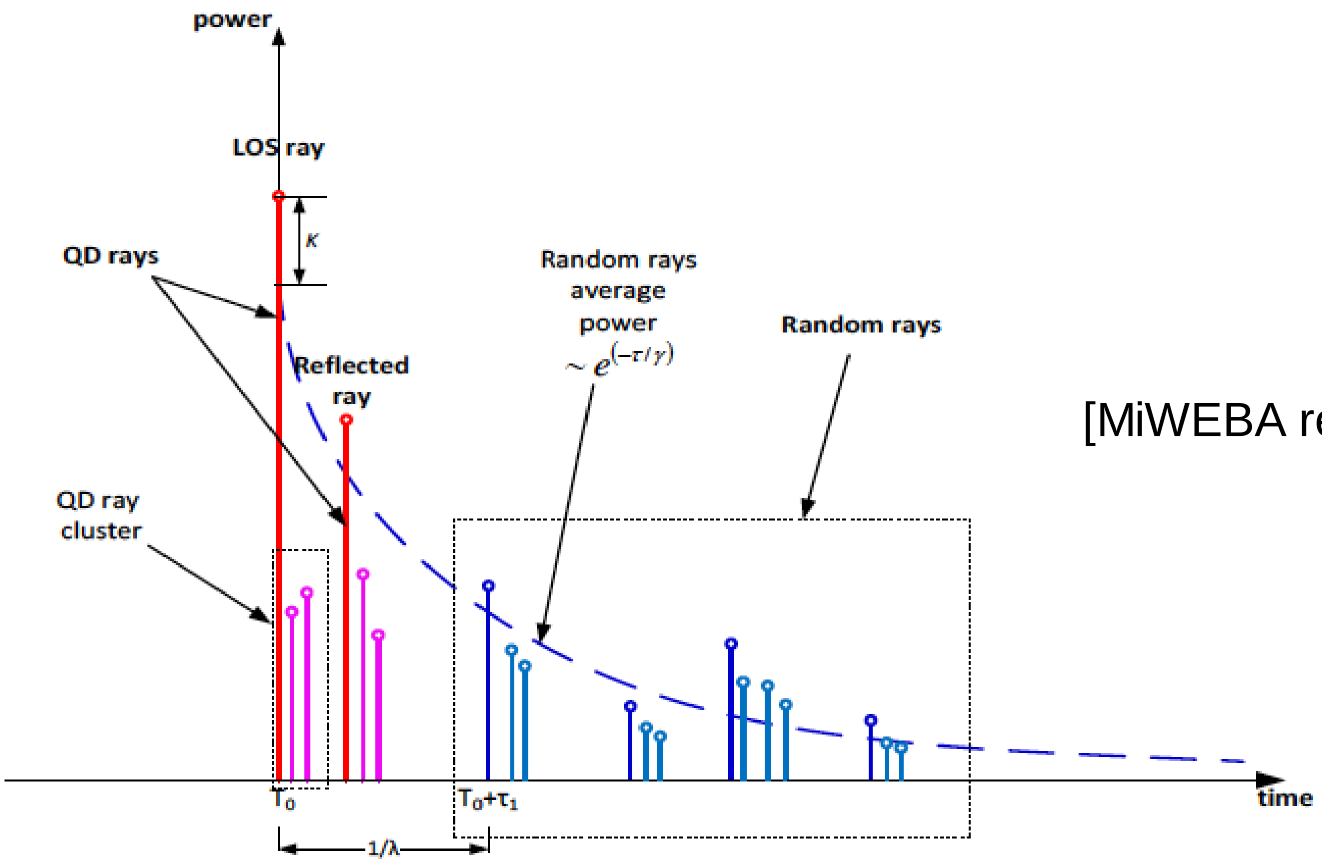
- Intra-cluster: stochastic
- Inter-cluster: geometry-based stochastic
- Allows inclusion of dynamic effects (longer routes)
- Twin-cluster

Twin cluster model



Semi-deterministic

Combination of geometry and random components; similar to VDCA of COST 259 [Steinbauer and Molisch 2000] and [Kunisch and Pamp 2003]



[MiWEBA report D5.1]

Summary

- Mm-wave well suited for small cells
- Higher free-space pathloss, but can be compensated by directive antennas
- Unreliable links
  - Strong pathloss variations
  - Body shadowing
- Angular spreads at MS, BS: comparable to microwave
- Sparse propagation: fewer MPCs
- Still challenges in measurement technology
- Ray tracing: point cloud for good accuracy

Questions?

Thanks to: too many colleagues to list……

Contact information

Andreas F. Molisch

Ph.D., FIEEE, FAAAS, FIET, FNAI, MAASc.
Head, Wireless Devices and Systems (WiDeS) Group
Director, Communications Sciences Institute,
Ming Hsieh Dpt. Of Electrical Engineering
Viterbi School of Engineering
University of Southern California (USC)
Los Angeles, CA, USA

Email: molisch@usc.edu
Website: wides.usc.edu

Mahalo

HAWAI`I 5G Catch the Wave!

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