MIMO Channel Characteristics Computed with 3D Ray Tracing Model

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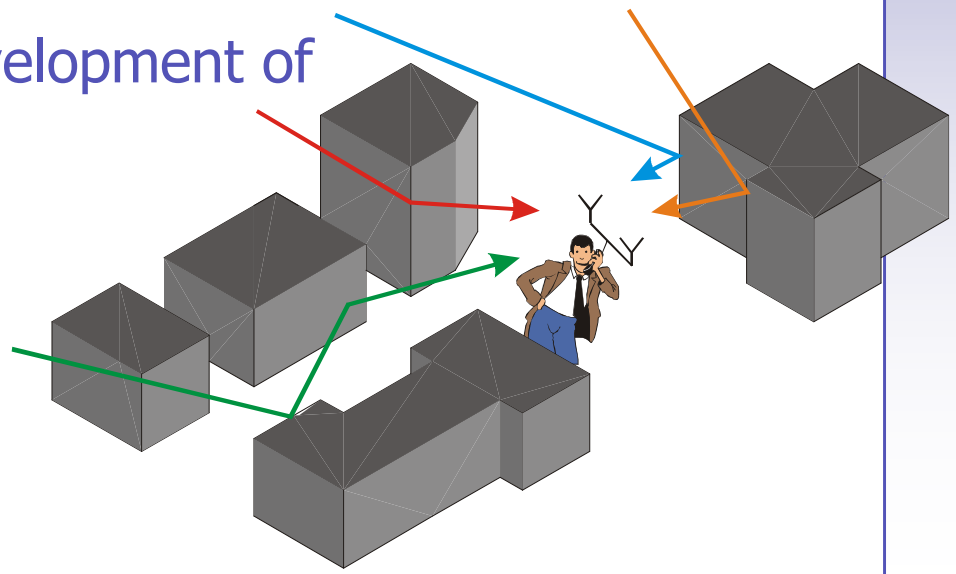
- Motivation
- MIMO Channel Model
  - Overview
  - 3D Ray Tracing
  - MIMO Post-Processing
- Channel Data for Moving Receiver
- Statistical Spatial Channel Model vs. 3D Ray Tracing
- Conclusions
- Further Work

Motivation

- MIMO systems deploy spatially separated antenna elements at Tx and Rx
- MIMO systems provide higher channel capacity
  - influenced by correlation between antenna elements
  - capacity grows linearly with number of antenna pairs in rich scattering environments (urban, indoor)
  - gain depends on the propagation channel
- MIMO channel model required for development of
  - signal processing algorithms
  - coding strategies



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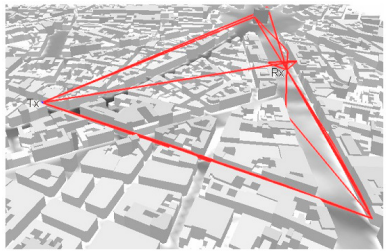
MIMO Channel Model



3D Vector Data

Topography Data

3D Ray Tracing

3D Spatial Channel Impulse Response

Angular Spread

Delay Spread

Post-Processing

Tx & Rx antenna array
- Linear, circular
- Orientation (azimuth, tilt)
- Antenna pattern

Rx locations
- Arbitrary areas
- Trajectory generation
- Monte-Carlo distribution

N x M MIMO Channel Matrix

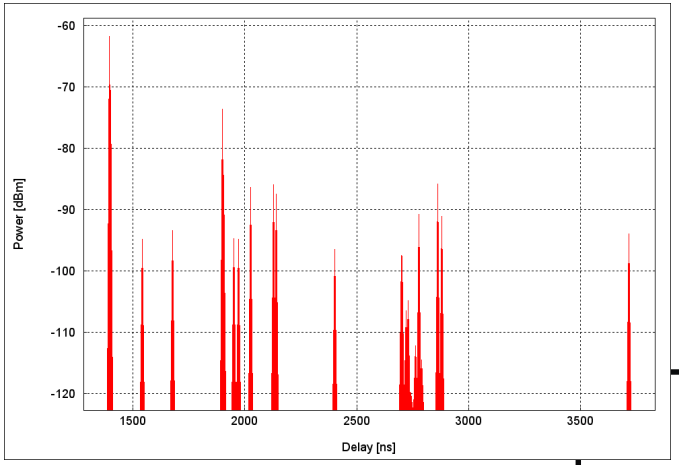
MIMO Channel Capacity

Power Azimuth Spectrum

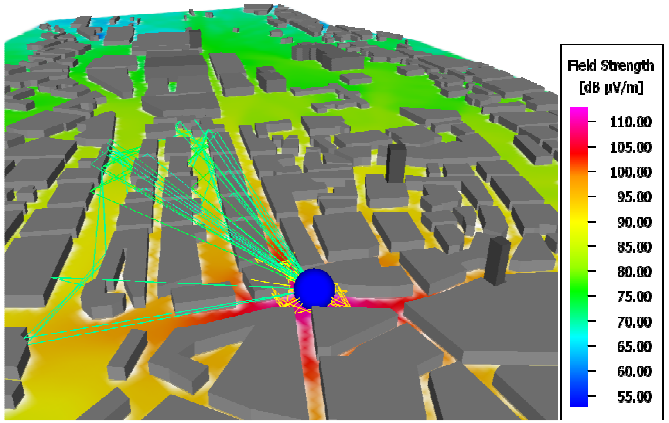
Doppler Shift, Doppler Spread

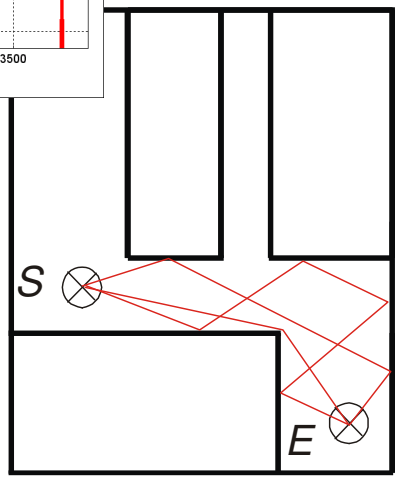
3D Ray Tracing

- Based on 3D building data in vector format
- Ray tracing considers dominant characteristics
  - Reflection (Fresnel coefficients)
  - Diffraction (GTD/UTD)
  - Shadowing
  - Wave guiding
- Prediction of radio channel in time, spatial and frequency domain
- High accuracy of prediction results



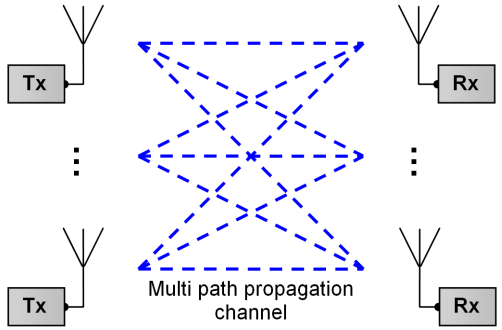
Multi path power delay profile





Multi path contributions

MIMO Post-Processing

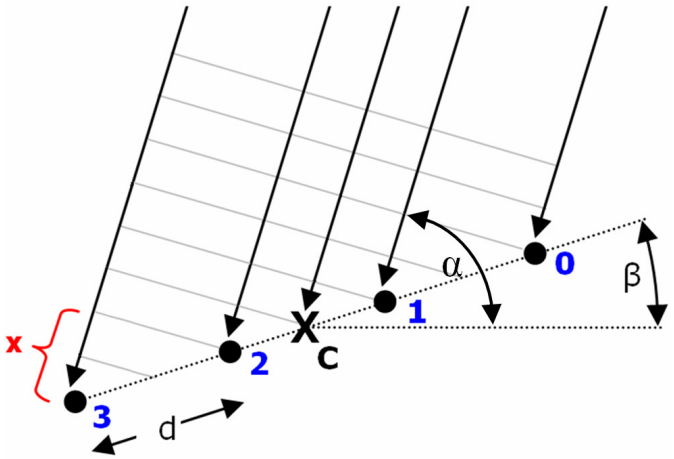


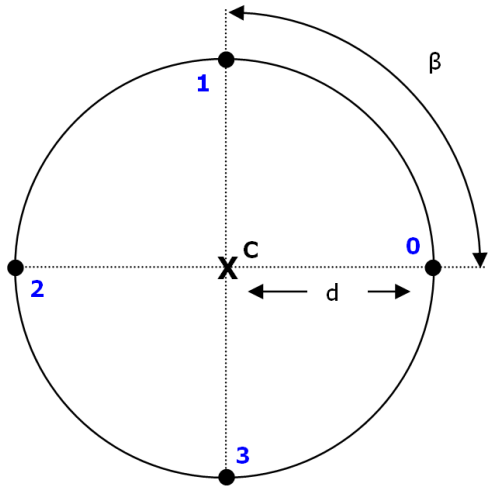
- Determination of relevant paths between Tx and Rx very time consuming
- Rather small spacing between antenna elements of array (a few λ at a maximum)

- Same multi paths exist for all antenna elements of the array
- Constant power, angular spread and delay spread of all multi path contributions at each antenna element
- Only phase is changing from element to element

MIMO Post-Processing

- Calculation of Phase Shifts (plane wave incidence)





$$\varphi = \frac{360°}{\lambda} \cdot k \cdot \frac{d}{2} \cdot \cos(\alpha - \beta)$$

$$k \in [1,3,5,\ldots]$$

$$\varphi = \frac{360°}{\lambda} \cdot d \cdot \cos(\alpha - i \cdot \beta)$$

$$i \in [0,1,2,3,\ldots]$$

- Ray Tracing provides magnitude and phase of CIR between the array centers
- Modular approach avoids re-computing the ray tracing between all elements

MIMO Post-Processing

- Calculation of N x M Channel Matrix

$$h_{n,m}(t) = \sum_{\tau=0}^{L} h_{n,m,\tau}(t)$$

Phase shifts due to geometry

φ

$$H(t) = \begin{pmatrix} h_{11}(t) & \dots & h_{1,N_T}(t) \\ \dots & \dots & \dots \\ h_{N_R,1}(t) & \dots & h_{N_R,N_T}(t) \end{pmatrix}$$

- Coherent addition of all multi path contributions at each Rx location
- Only phase is changing from element to element while keeping same MPC
- Phase adjustment according to geometry of Tx and Rx array

MIMO Post-Processing

- Calculation of MIMO Channel Capacity
  - Derived from Shannon's standard capacity formula
  - MIMO systems usually use wide channel bandwidths (WiMAX, 3G LTE)
    - ➔ Frequency selective MIMO channels
  - N_F-point Fast Fourier Transformation of channel matrices

$$C = \frac{1}{\mathrm{N_F}} \sum_{l=0}^{N_F-1} \log_2 \left(\det \left[I_{N_R} + \frac{P}{N_T \cdot \sigma_n^2} \cdot H_F(l) \cdot H_F(l)^H \right] \right)$$

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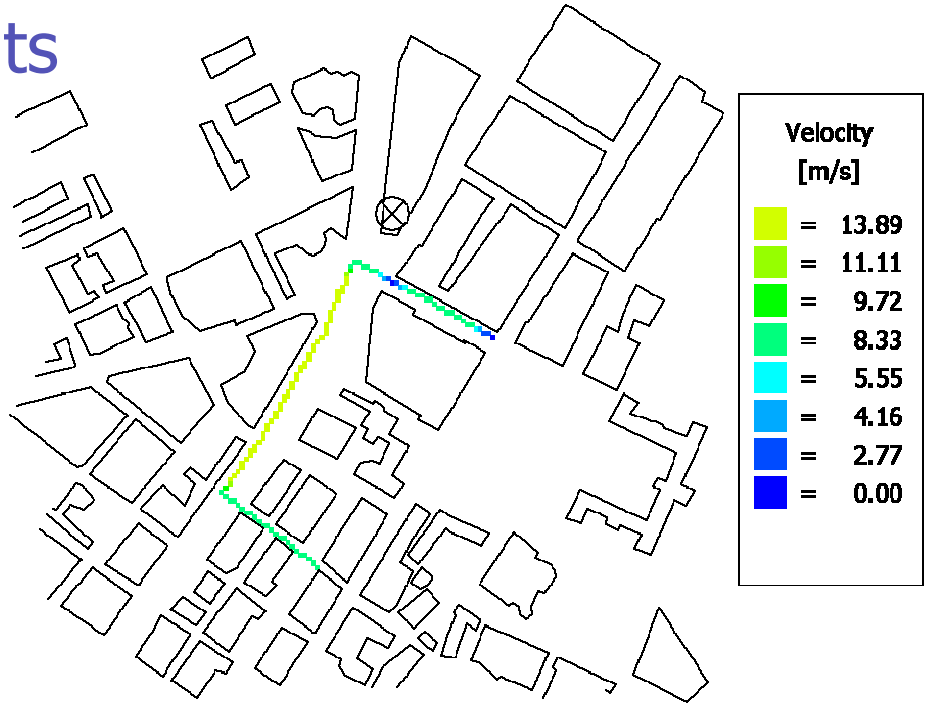
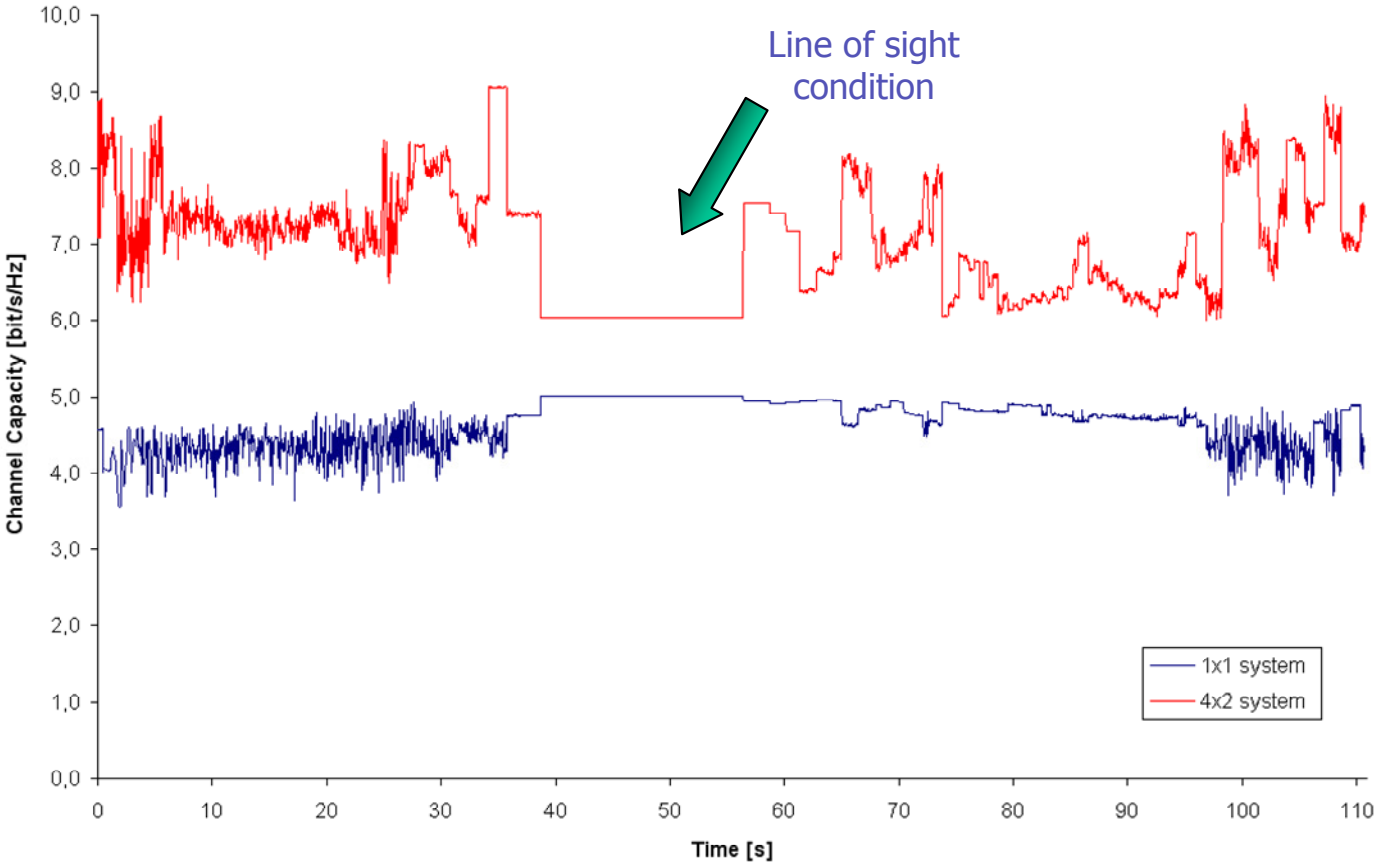
Channel data for moving receiver

Scenario

- 4 x 2 MIMO system with receiver moving on a trajectory
- Linear Tx array with 4 elements (2.15 GHz, 30W)
- Tx antenna spacing 10 λ
- Linear Rx array with 2 elements moving on trajectory
- Rx antenna spacing 0.5 λ
- Rx array axis perpendicular to direction of movement
- Resolution in time: 50ms

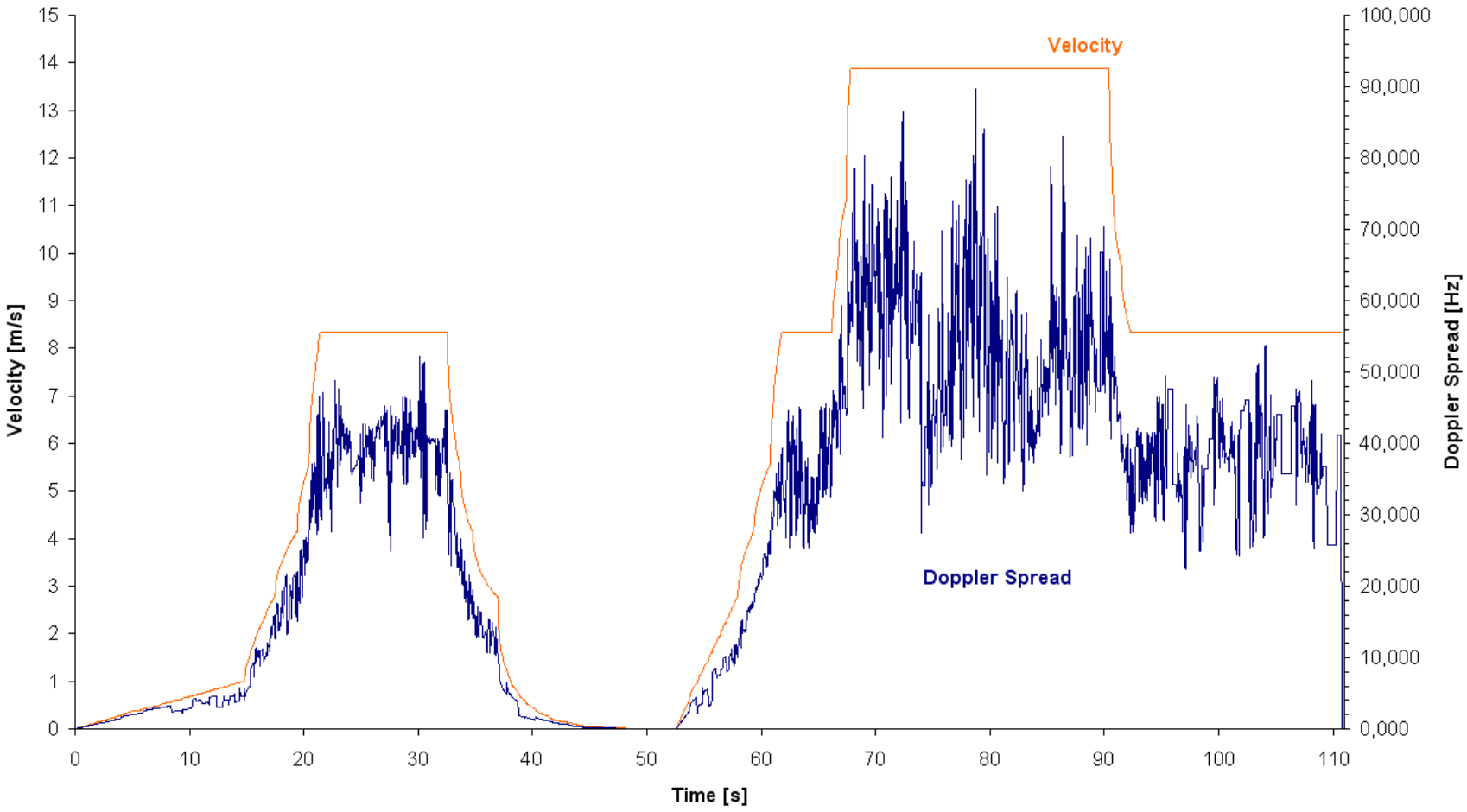


Estimated Channel Capacity



- Mean SNIR: 15dB
- Lower angular spread in LOS condition results in lower MIMO channel capacity
- Average capacity 4.6 bit/s/Hz for 1x1 system vs. 7.0 bit/s/Hz for 4x2 system

Doppler Spread



- Doppler spread inversely proportional to coherence time of the channel
  - ➔ Doppler spread increases with increasing Rx velocity

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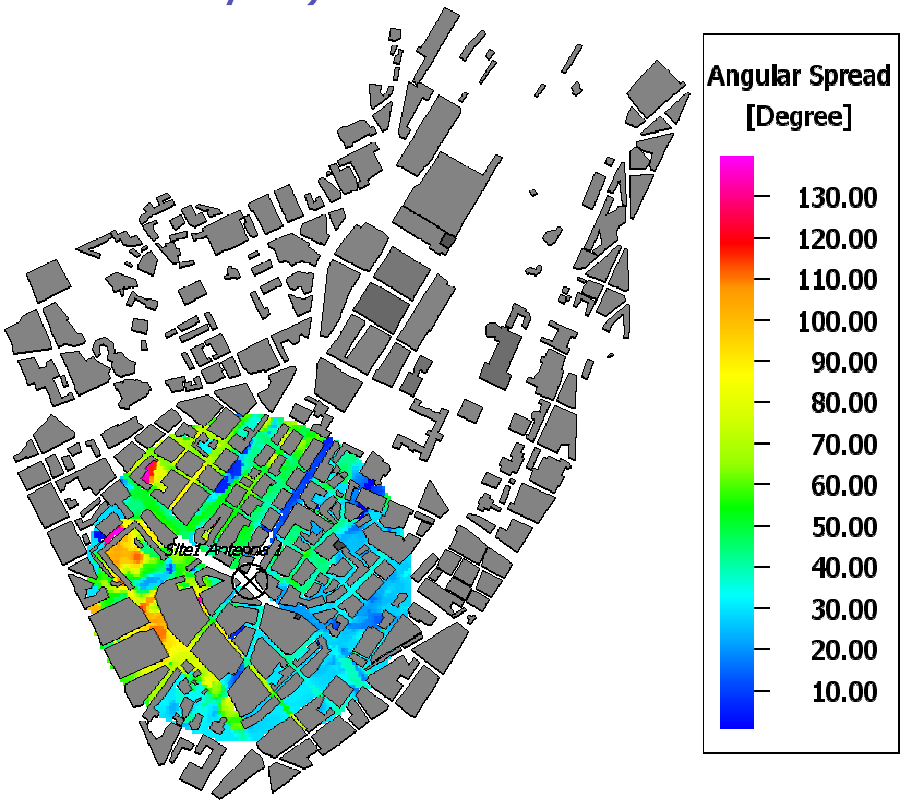
Comparison for Urban macro cells

- 3GPP Spatial Channel Model (SCM) vs. 3D Ray Tracing

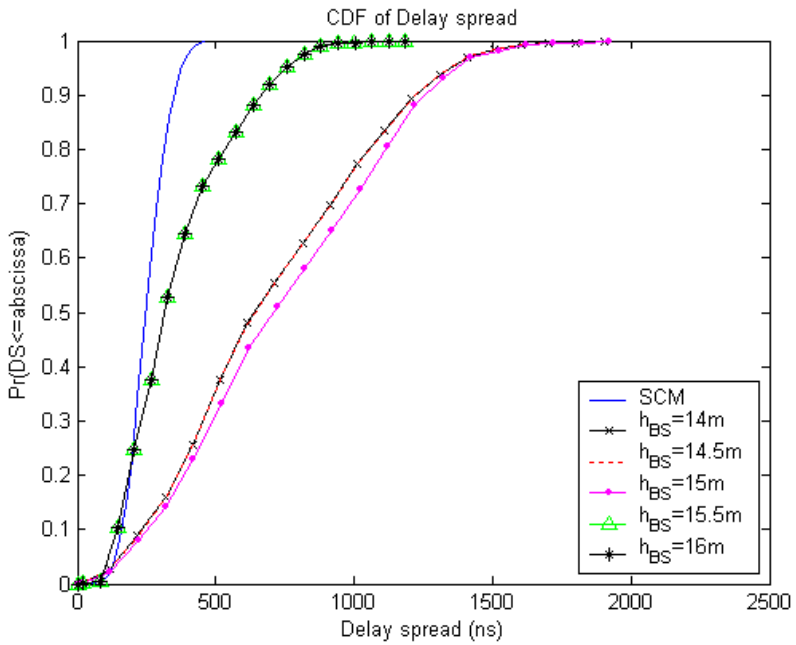
Example: Urban micro cell scenario with 500m cell radius in NLOS condition
BS antenna height 14…16m (mean building height 15m)
MS antenna height 1.5m (in street canyon)
2x2 MIMO system

- Comparison of
  - Delay spread
  - Angular spread
  - Channel capacity

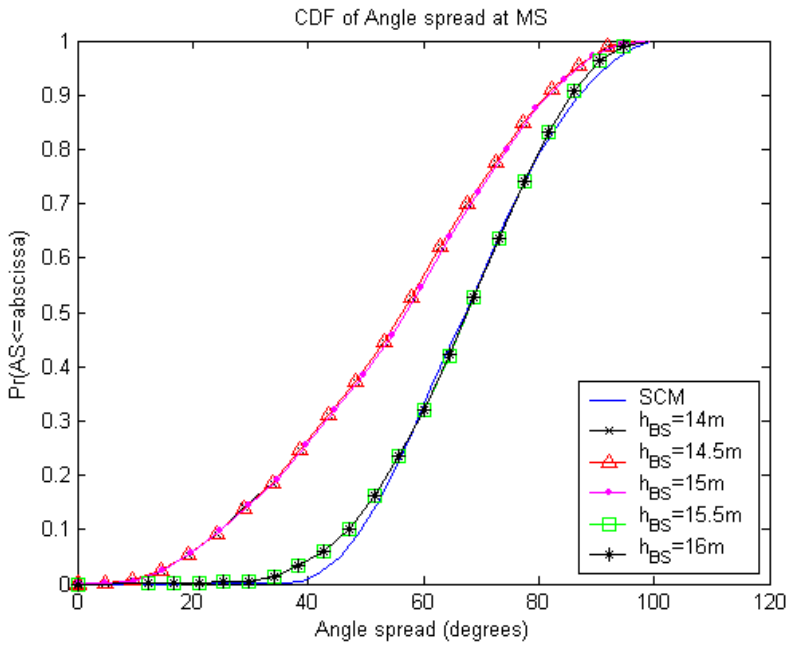


Delay Spread and Angular Spread

Delay Spread

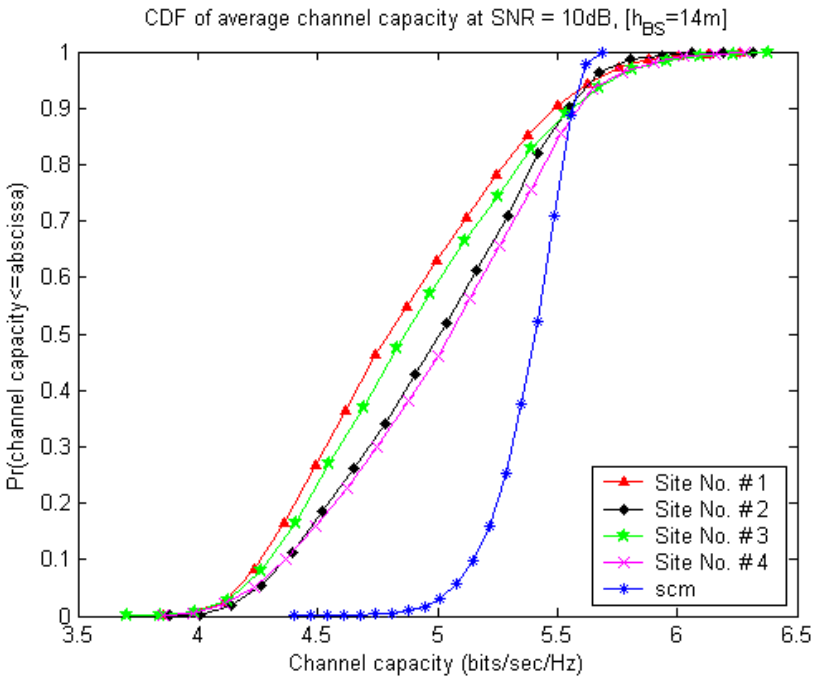


Angular Spread (MS)

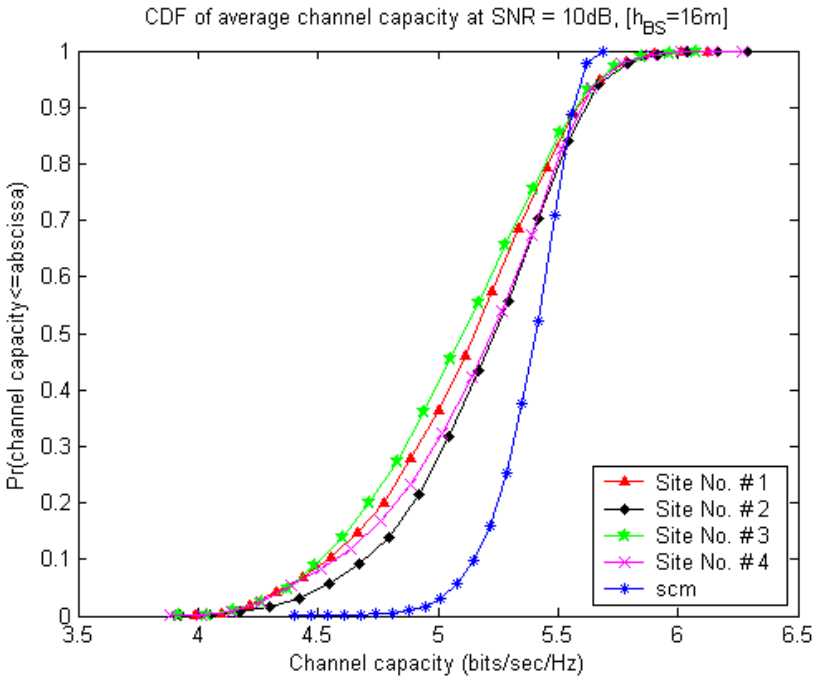


- Delay spreads as well as angular spread highly depend on propagation conditions
- Statistical channel models only valid for specific predefined environment

MIMO Channel Capacity



Capacity (BS < rooftop)



Capacity (BS > rooftop)

- *BS below rooftop level*
  - ➔ *street canyon prop. dominant*
  - ➔ *lower angular spread*
  - ➔ *higher correlation*
  - ➔ *lower MIMO capacity*

- *BS above rooftop level*
  - ➔ *over rooftop prop. dominant*
  - ➔ *higher angular spread*
  - ➔ *lower correlation*
  - ➔ *higher MIMO capacity*

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Conclusions

- Standardized stochastic MIMO channel models have been proposed for different scenarios
- Models are based on statistical information evaluated from measurement data

  ➔ Model are only valid for measured scenarios
- MIMO channel model based on 3D Ray Tracing to predict system performance under various circumstances

Further Work

- Determine achievable performance gain of MIMO systems in already existing and future radio networks (WiFi, WiMAX, 3G LTE,…)
- Use calculated MIMO channel characteristics for hardware and system design

Thank you for your attention!