Christian Doppler Laboratory for Dependable Wireless Connectivity for the Society in Motion

Three-Dimensional Beamforming

Fjolla Ademaj
15.11.2016
Studying 3D channel models

- Channel models on system-level tools commonly 2-dimensional (2D)
  - 3GPP Spatial Channel Model (SCM)
    - A geometric stochastic model
    - Only linear antenna arrays can be inspected with 2D channel models
  - Three-Dimensional (3D) channel model enable investigations on
    - Full-dimension MIMO
    - 3D Beamforming
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Contents

Modeling the wireless channel in 3-dimensions

Complexity- Simulation run times

Massive MIMO: Spatial resolution of planar antenna arrays

Conclusion and Outlook
Overview

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Conclusion and Outlook
Modeling the wireless channel in 3-dimensions

The 3GPP 3D channel model in Vienna LTE-A system-level simulator

- Considers elevation and azimuth
- Incorporates planar antenna arrays
Reduction in complexity

- The 3GPP 3D model imposes high complexity

- Complexity reduction by:
  - Partition the scenario into equally sized cubes
  - Within a cube UE experiences the same propagation conditions

- Spatial resolution 1 m
- Temporal resolution 1 ms
- UE speed $v = [7.5, 0, 0]$ km/h

- Change the cube each 36 sub-frames

Temporal resolution refers to the length of one LTE sub-frame
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Temporal resolution refers to the length of one LTE sub-frame.
Calibration: Zenith spread

- Comparing system-level simulations and 3GPP TR 36.873 results
Overview

Modeling the wireless channel in 3-dimensions

Complexity - Simulation run times

Massive MIMO: Spatial resolution of planar antenna arrays

Conclusion and Outlook
Simulation run times

- A network of seven hexagonally arranged macro-sites, each employing three eNodeB sectors

- Evaluate the simulation complexity [Ademaj et al., a]:
  - Number of interfering links $N_{\text{sector}} = \{2, 8, 14, 20\}$
  - Number of UEs per sector $K = \{2, 20, 50\}$
  - Number of antenna elements $M = \{8, 24, 40, 80\}$
  - Simulation length $N_{\text{TTI}} = \{10, 50, 100\}$
Simulation run times

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Simulation run times: Varying the size of antenna array

- $K$: Number of UEs
- $N_{\text{sector}}$: Number of interferers
- $N_{\text{TTI}}$: Simulation length in TTIs
- $M$: Number of antenna elements in array

![Graph 1: Simulation runtime vs. Number of UEs and Simulation length in TTIs](image1)

![Graph 2: Simulation runtime vs. Interfering eNodeBs and Number of UEs](image2)
Simulation run times: Varying the size of antenna array

- \( K \) Number of UEs
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- \( N_{\text{TTI}} \) Simulation length in TTIs
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<table>
<thead>
<tr>
<th>( M )</th>
<th>Simulation runtime [s]</th>
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<tbody>
<tr>
<td>8</td>
<td>( \times 10^4 )</td>
</tr>
<tr>
<td>24</td>
<td>( \times 10^4 )</td>
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<tr>
<td>80</td>
<td>( \times 10^5 )</td>
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</table>
Simulation run times: Varying the size of antenna array

- $K$: Number of UEs
- $N_{\text{sector}}$: Number of interferers
- $N_{\text{TTI}}$: Simulation length in TTIs
- $M$: Number of antenna elements in array

Graphs showing simulation run times with varying parameters: $K$, $N_{\text{sector}}$, and $N_{\text{TTI}}$ for different $M$ values ($M = 8$, $M = 24$, $M = 40$, $M = 80$).
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\[ K \] Number of UEs
\[ N_{\text{sector}} \] Number of interferers
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- \( M = 80 \)
- \( M = 40 \)
- \( M = 24 \)
- \( M = 8 \)
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- $K$: Number of UEs
- $N_{\text{sector}}$: Number of interferers
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- $M$: Number of antenna elements in array

![Graph](image)

- $M = 80$
- $M = 40$
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Simulation run times: Varying the size of antenna array

\( K \) \( N_{\text{sector}} \) \( N_{\text{TTI}} \) \( M \)

- Number of UEs
- Number of interferers
- Simulation length in TTIs
- Number of antenna elements in array

![Graph showing simulation runtime vs. number of UEs and simulation length for different sizes of antenna arrays.](image-url)
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<th>$K$</th>
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Simulation runtime [s]

$M = 80$  
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Number of UEs vs. Simulation length in TTIs

Number of interferers vs. Simulation length in TTIs
Throughput performance: Rayleigh versus 3GPP 3D model

- Desired channel modeled by 3GPP 3D model
- Interfering channels modeled as
  - A noise-limited network
  - Rayleigh fading
  - The 3GPP 3D model
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Complexity - Simulation run times

Massive MIMO: Spatial resolution of planar antenna arrays

Conclusion and Outlook
Spatial resolution of planar antenna arrays

- How does the channel impact the spatial resolution of an antenna array?
- What is the spatial separation of narrow beams in LOS and NLOS, outdoors and indoors [Ademaj et al., b]?
Resolution of a uniform vertical linear array

Antenna array radiation pattern in elevation

\[ \omega_M(\theta_s) \times \quad \theta_s = 90^\circ \]

\[ \omega_3(\theta_s) \times \]

\[ \omega_2(\theta_s) \times \]

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\[ M \]

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\[ M = 1 \]

\[ M = 10 \]

\[ M = 100 \]
2D Antenna array structure

- Antenna port configuration: $N_{Tx} \times N_{Rx} = 4 \times 2$
- Antenna array geometry at eNodeB: $N_{Tx} \times M$
Indoor UE: *Channel energy and UE throughput*

- UE height $h_{UE} = 1.5 \text{ m}$
- UE distance $d_{UE} = 150 \text{ m}$
- $M = \{1, 10, 100\}$
- Steering angle $\theta_s = \{0^\circ, 10^\circ, 20^\circ, \cdots, 180^\circ\}$
- Target angle $\theta_s = 98.9^\circ$
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Conclusion and Outlook
Incorporation of the elevation dimension increases the computational complexity by more than three times.

The complexity grows roughly linearly with the number of antenna elements per antenna array.

A more optimistic view on performance observed by 3D model: simple channel models may underestimate the achievable performance.

In terms of spatial resolution, doubling the number of antenna elements in elevation does not double the received channel energy.

The optimal number of antenna elements - ?
Outlook: 5G System Level

The 3GPP 3D channel model
- Reduce the model complexity by pruning the multipath components
- Adapt the model for moving scenarios: spatial correlation and channel transitions
Outlook: 5G System Level

3D Channel models $> 6$ GHz

- 3GPP TR 38.900: Channel models for carrier frequencies 6 GHz – 100 GHz
- Covering many scenarios (rural, urban, street canyons, open area, indoor scenarios, D2D and V2V)
- Three-dimensional beamforming
Outlook: Full-dimension MIMO

- Antenna configurations for 2-dimensional antenna arrays
- New transmitter architectures: TXRU modeling and two-layer mapping
- New precoding strategies to support the element-level antenna structure
Outlook: Full-dimension MIMO

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Precoding on 16 TXRU

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Precoding on 16 TXRU

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Outlook: Full-dimension MIMO in moving scenarios

- Beam alignment schemes for efficient UE tracking
  - Cars and high speed trains

http://www.profheath.org/research/millimeter-wave-cellular-systems/mmwave-for-vehicular-communications-2/
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Three-Dimensional Beamforming

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Evaluating the spatial resolution of 2d antenna arrays for massive mimo transmissions.