DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

Impact of Channel Models on the End-to-End Performance of mmWave Cellular Networks

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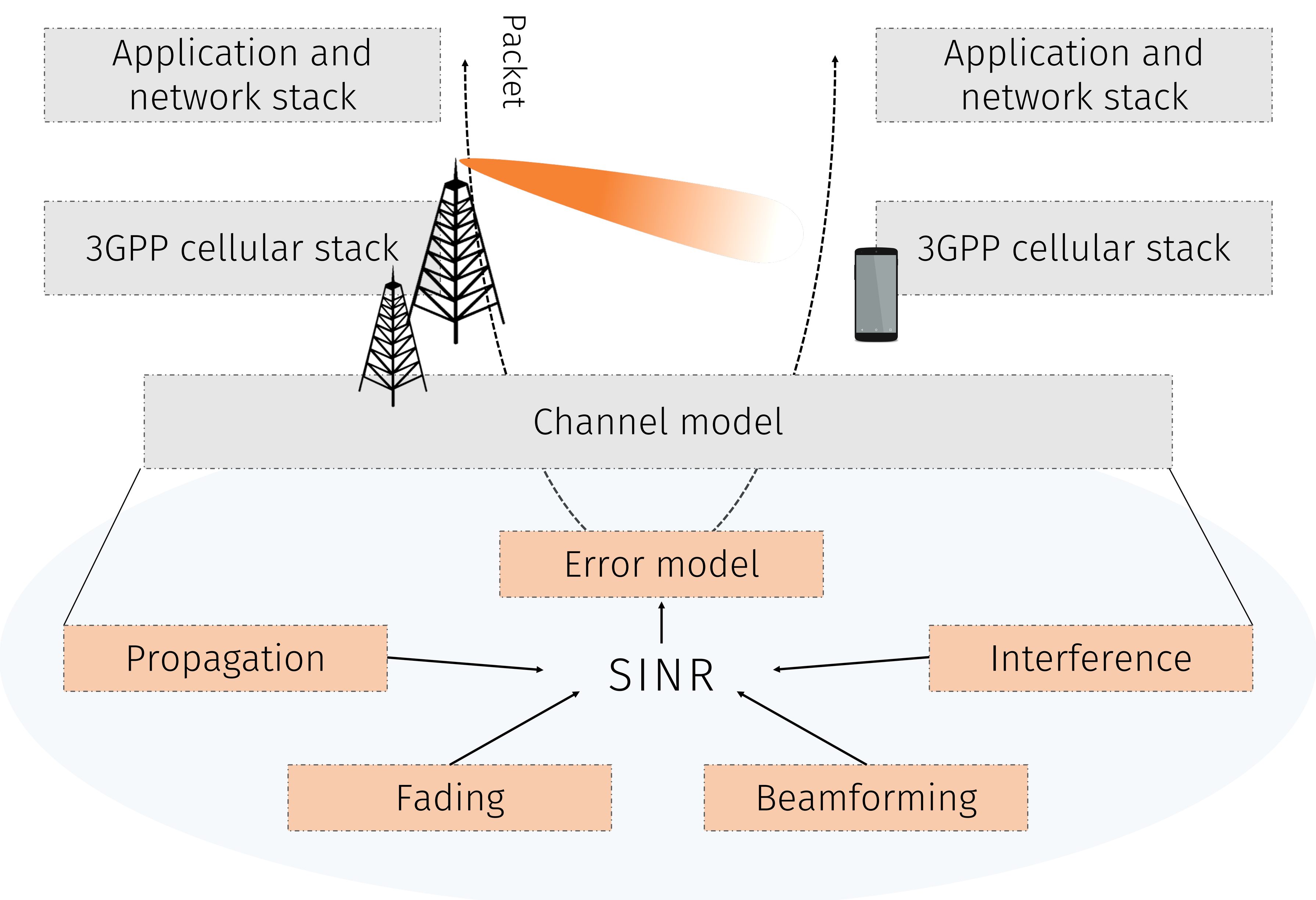
mmWave Networks Simulations



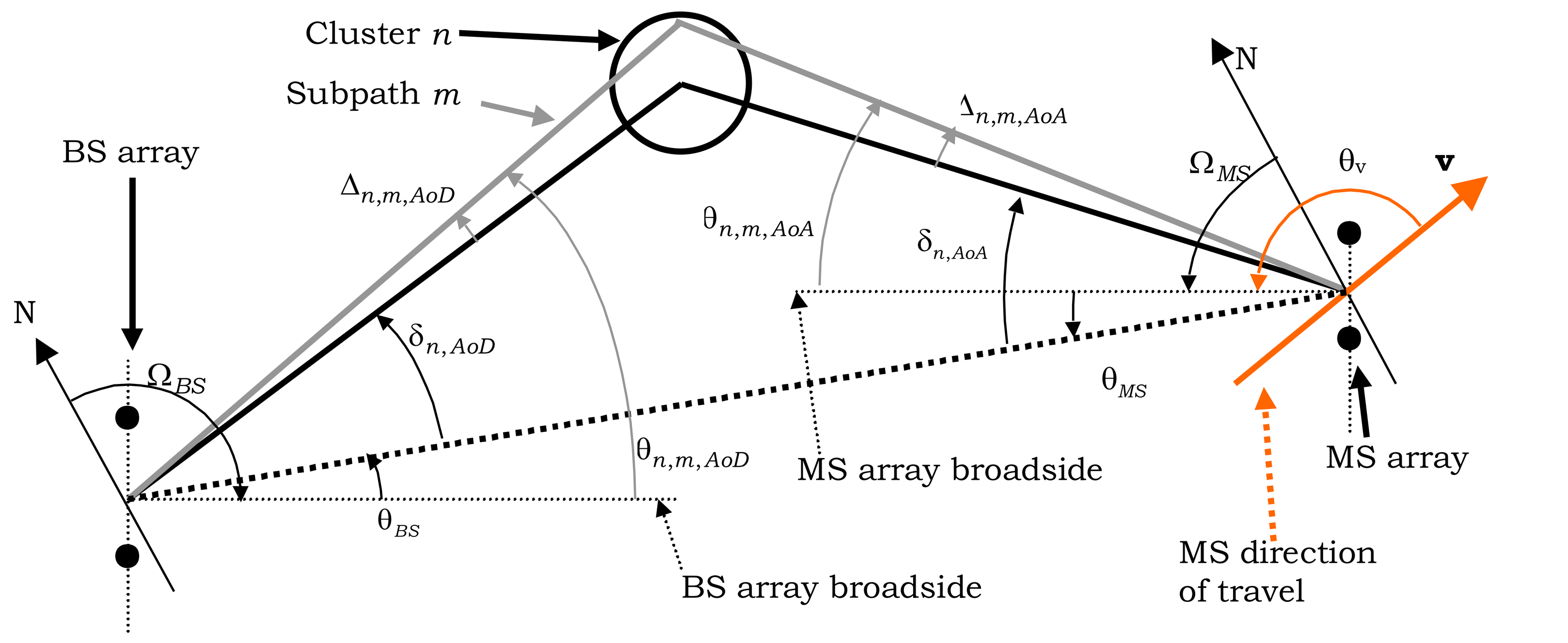
Channel model is key for wireless system level simulations
Accuracy - Complexity

mmWave frequencies introduce new challenges for channel modeling:
- Beamforming and MIMO with many antenna elements
- Rapid channel variations due to LOS/NLOS transitions
- Sparsity in the angular domain

mmWave Channel Models

- Spatial Channel Models

E.g.: 3GPP 38.900 and 38.901, NYU, QuaDRiGa

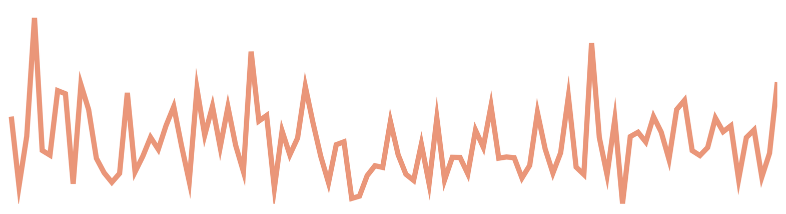


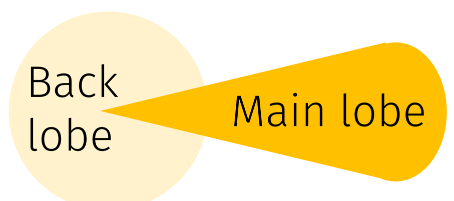
3GPP TR 25.996 - V14.0.0, Spatial channel model for Multiple Input Multiple Output (MIMO) simulations

Pros:
- Model complex interactions – interaction with beamforming vectors
- Chosen by 3GPP for system level evaluation of 5G networks

Cons:
- Compute a channel matrix with $U \times S \times N$ elements (Number of RX antennas, Number of TX antennas, Number of clusters)
- Fading is computationally intensive due to the high number of random variables and complex numbers involved
- Cannot be used for analysis

- Nakagami-m Channel Models





Pros:
- Simple and widely-used for analytical papers on mmWaves
- Parameter m controls severity of fading, different conditions for LOS and NLOS ($m = 1$ for Rayleigh)

Cons:
- Non-geometric model
- Usually coupled with simple sectorized beamforming model

Comparison: 3GPP vs Nakagami-m

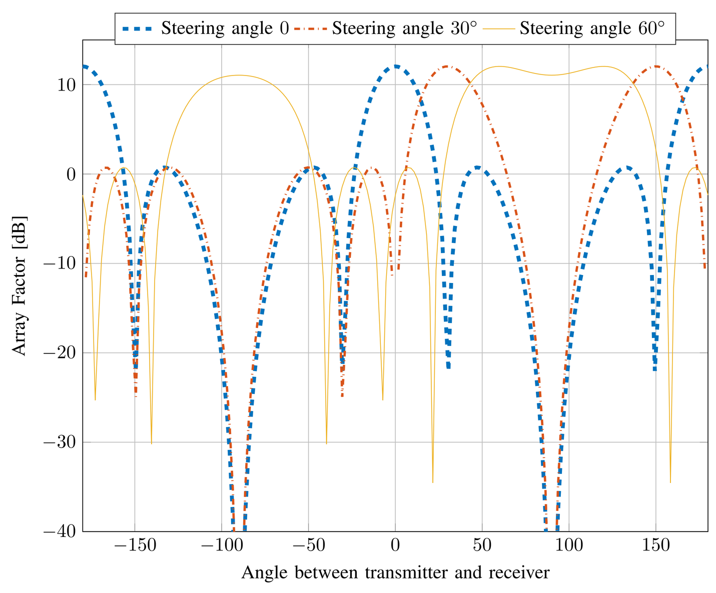
ns-3 network simulator with mmWave module
- 3GPP 38.900 channel model implementation
- Full stack: TCP/IP + 3GPP-like layers in the RAN
- https://github.com/nyuwireless-unipd/ns3-mmwave

+ *simple* channel model

$$P_{rx,j} = \frac{P_{tx,i} h_{i,j} G_{i,j} L_{i,j}}{\sigma^2 + \sum_{k \in \mathcal{I}} P_{tx,k} h_{k,j} G_{k,j} L_{k,j}}$$

Nakagami-m fading with different m parameters for LOS and NLOS [1], [2]

Pathloss from 3GPP TR 38.900



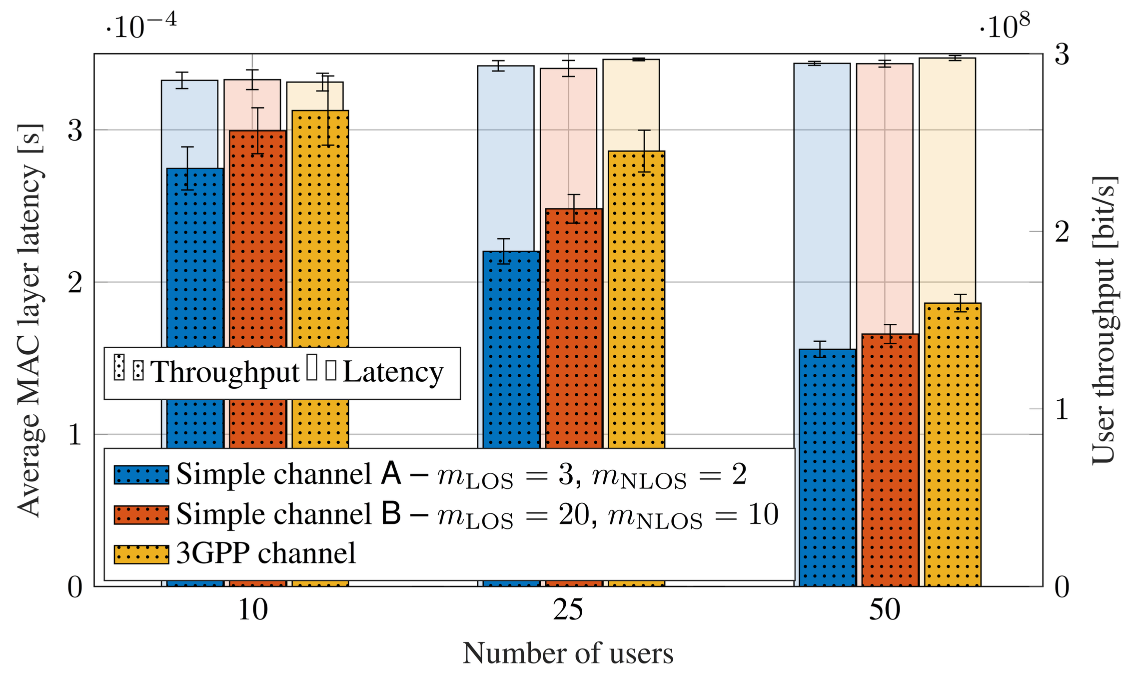
UPA beamforming patterns (using 3GPP approach)
- Array factor for each device

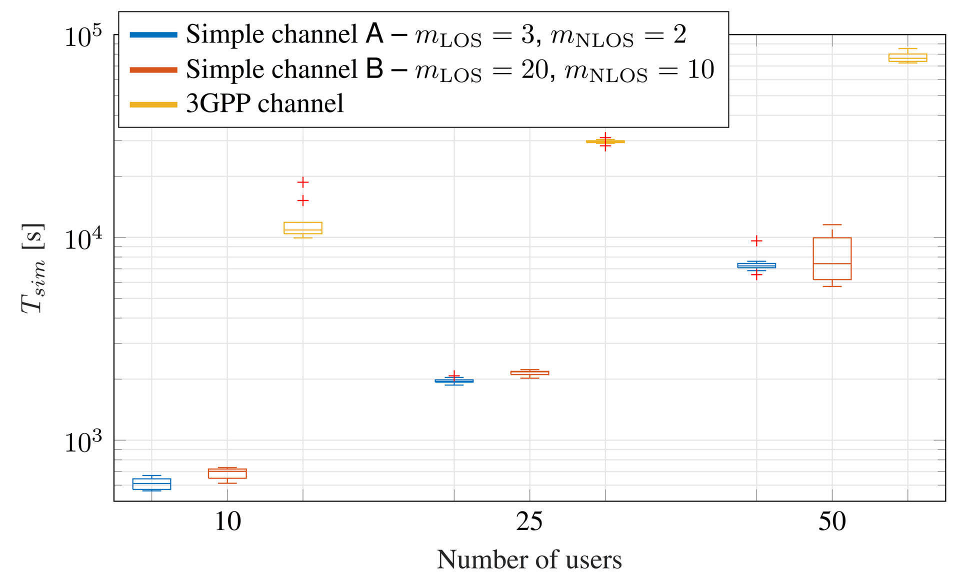
$$A_{F,i}(\theta,\phi,\theta_s,\phi_s) = 10\log_{10}\left[1+\rho(|\mathbf{a}(\theta,\phi)\mathbf{w}^T(\theta_s,\phi_s)|^2-1)\right]$$
$$\overset{\rho=1}{=} 10\log_{10}\left(|\mathbf{a}(\theta,\phi)\mathbf{w}^T(\theta_s,\phi_s)|^2\right),$$

- Steering direction towards connected gNB/UE
- Updated every 20 ms (candidate periodicity for NR)
- G is given by the sum of TX and RX array factors
- Future work: non-uniform antenna patterns

Performance Evaluation

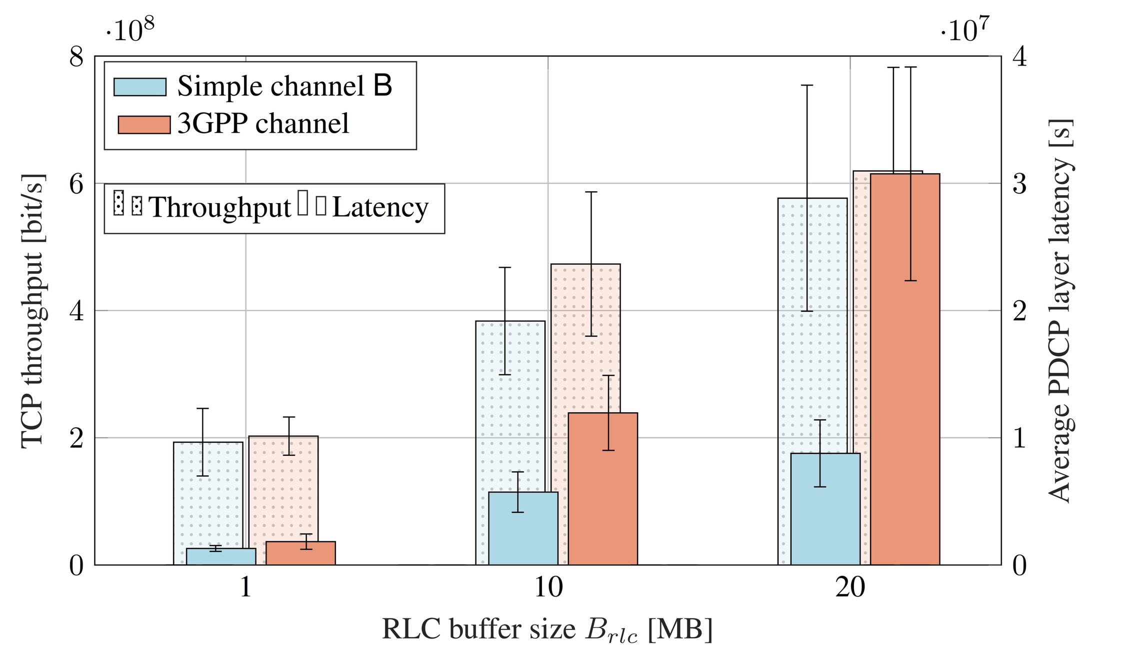
- UDP experiment
  - 5 mmWave gNBs
  - 10, 25 or 50 users with local mobility
  - UDP traffic
  - Compare 3GPP and simple channel with different m values [1], [2]
  - Similar trend for throughput
  - Equivalent latency





Simulation execution time:
- 3GPP takes 10 times longer
- Higher traffic also translates into high execution time
- A factor of 5 in the number of users is a factor > 10 in the execution time

- TCP experiment
  - 3 mmWave gNBs
  - 1 sub-6 GHz LTE eNB
  - 1 user moving across the scenario with handovers
  - Similar trend for throughput
  - Latency diverges as RLC buffer size increases



[1] T. Bai and R. W. Heath, "Coverage and rate analysis for millimeter-wave cellular networks," IEEE Trans. Wireless Commun., vol. 14, no. 2, pp. 1100–1114, Feb 2015.
[2] A. K. Gupta, J. G. Andrews, and R. W. Heath, "On the feasibility of sharing spectrum licenses in mmwave cellular systems," IEEE Trans. Commun., vol. 64, no. 9, pp. 3981–3995, Sep 2016.

Conclusions

- The 3GPP channel is much more complex to simulate, but it is the reference model for 3GPP NR performance evaluation at mmWaves
- When the cross-layer interactions and effects are limited (e.g., UDP), the results are qualitatively similar

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