ns-3 Implementation of the 3GPP MIMO Channel Model for Frequency Spectrum above 6 GHz

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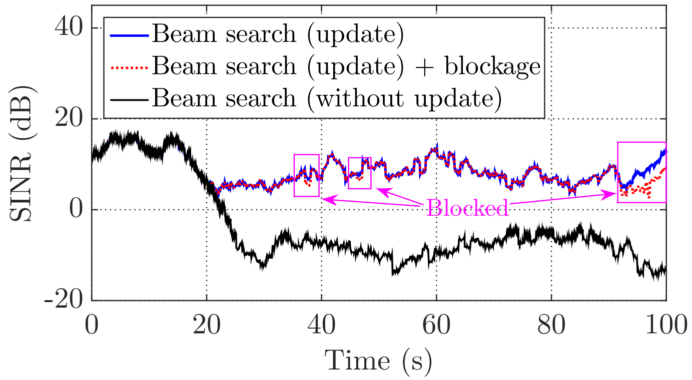
Outline

- Introduction
- mmWave channel models
  - 3GPP channel model for freq. above 6 GHz
- ns-3 implementation
  - Antenna model
  - Propagation
  - Fading
- Beamforming
- Optional features
- Conclusions

mmWave simulation

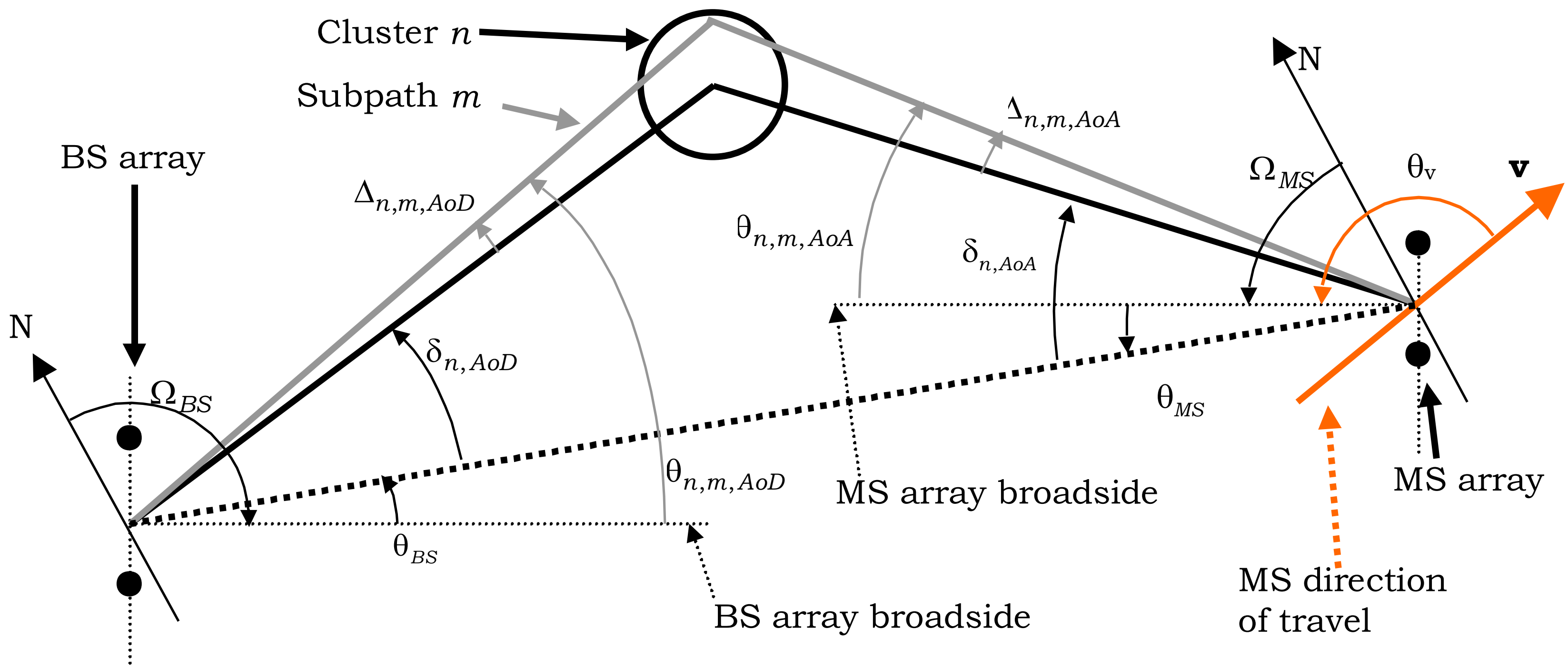
- Candidate technology for 3GPP NR
  - End-to-end simulation to evaluate protocol stack performance over mmWaves
  - ns-3-based mmWave module
- Contributions:
  - Implementation of 3GPP Channel Model for frequencies above 6 GHz
  - MIMO beamforming architectures



mmWave channel models

- Spatial Channel Model (SCM) based:
  - METIS model (380 MHz - 86 GHz)
  - ITU-R
  - QuaDRiGa
  - NYU statistical model (28 and 73 GHz)
- MiWEBA (60 GHz)
- COST 2100

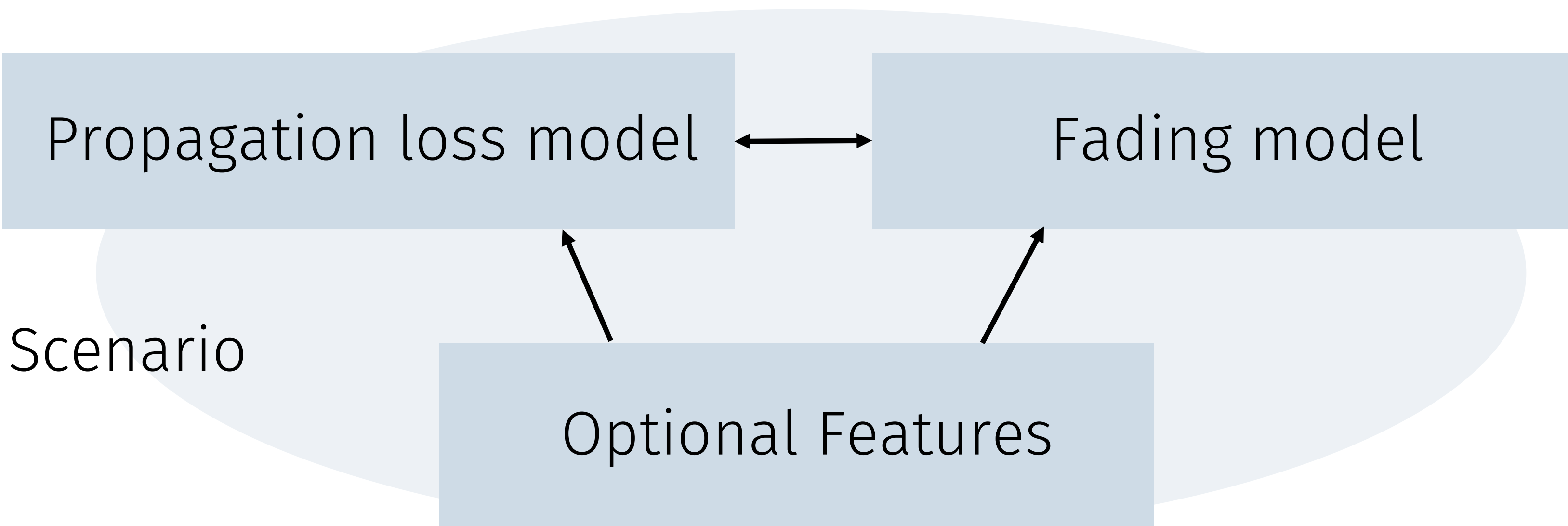
SCM models



From: 3GPP Spatial Channel Model

3GPP TR 38.900

- December 2016
- SCM-based channel model
- 6 – 100 GHz band
- Max 2 GHz bandwidth



Scenarios

- Urban Microcell (UMi)
- Urban Macrocell (UMa)
- Rural Macrocell (RMa)
- Indoor Office - open (InOO) or mixed (InMO)

Different parameters & possible deployments for each scenario

LOS - Pathloss

- Statistical model for LOS probability
- Pathloss depends on
  - LOS condition
  - 2D and 3D distance
  - Elevation of base station and mobile terminal
  - Carrier frequency
- Additional loss factor for
  - Outdoor to indoor
  - Vehicular

Fading

- Channel matrix $H(t,\tau)$ of size $U \times S$

num RX antennas

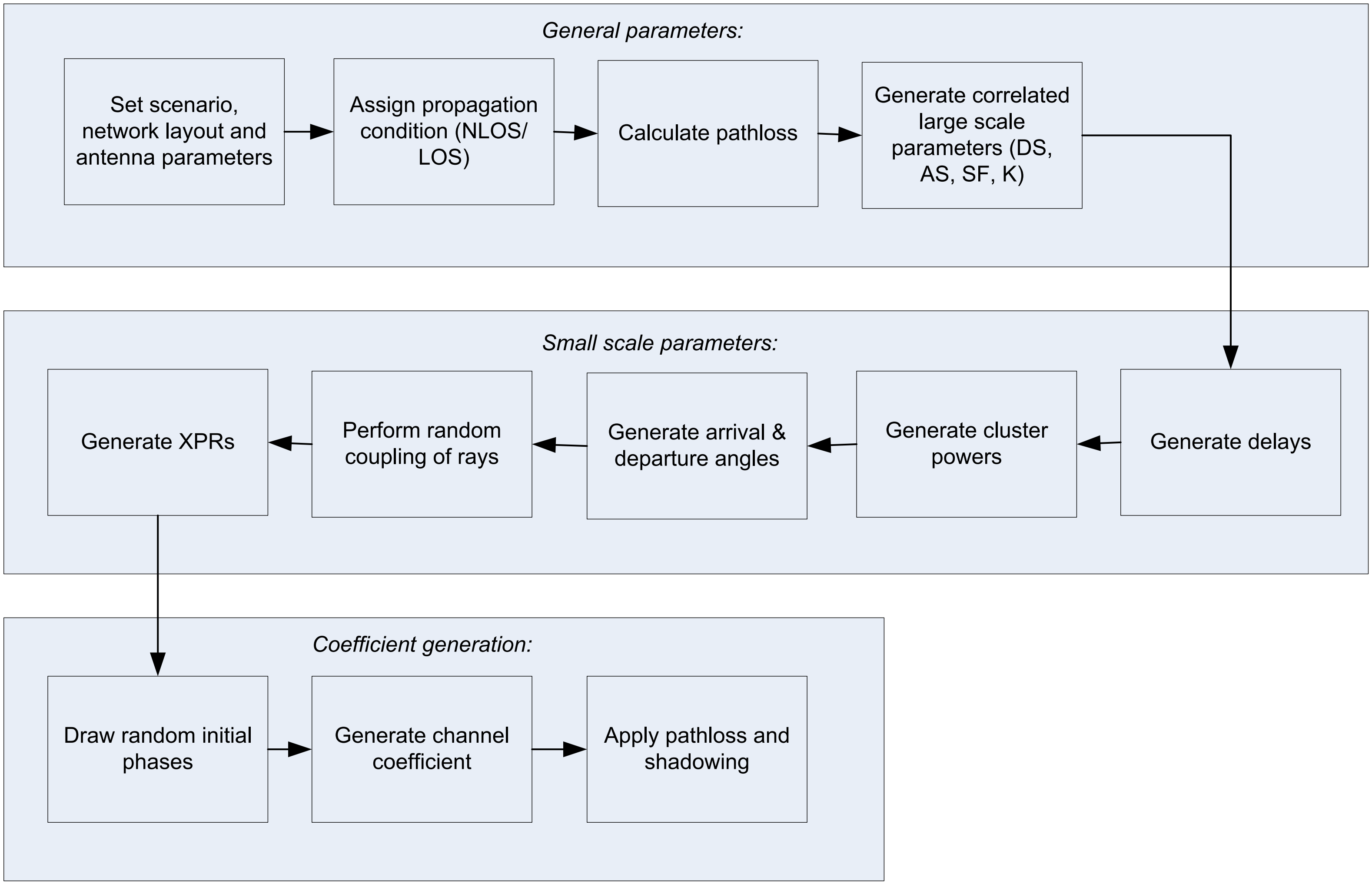
num TX antennas

- Each entry depends on
  - N clusters of M rays
  - LOS condition
  - Carrier frequency
  - Distance
  - Mobility
  - Indoor/outdoor state
  - Scenario

Optional Features

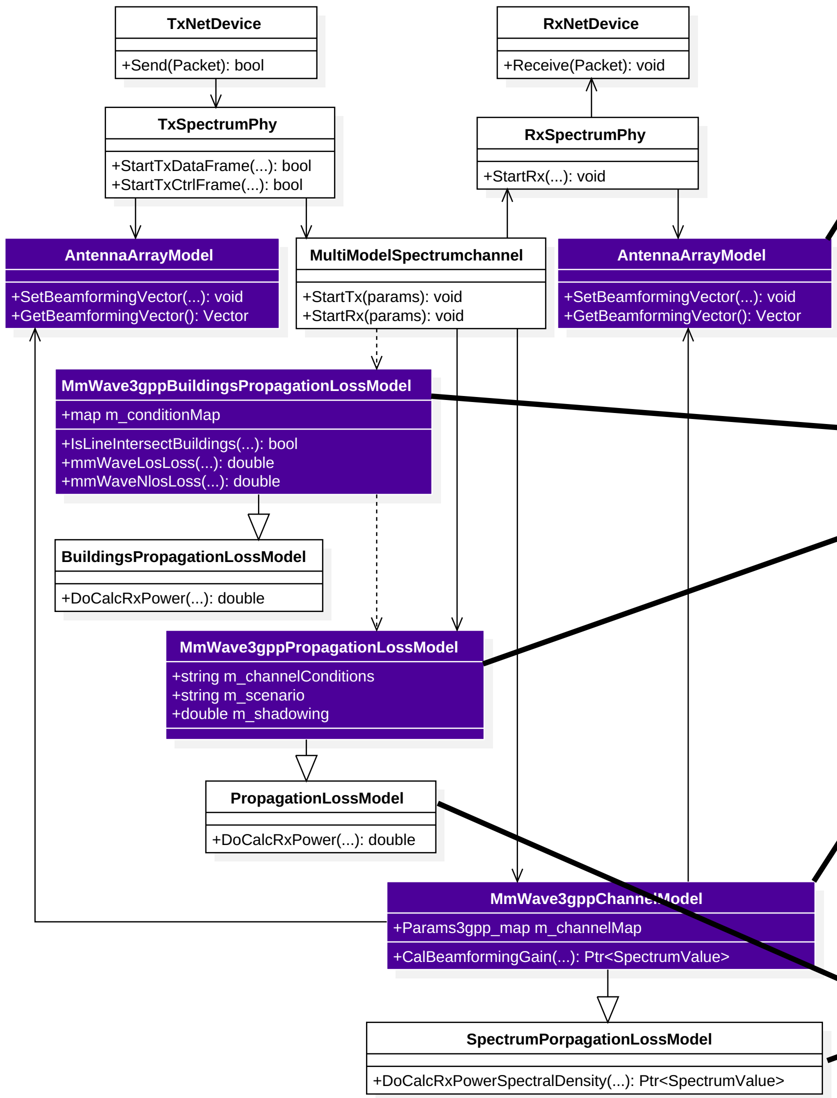
- Basic model (propagation and fading) can be extended with
  - Spatial consistency (update the channel parameters in a correlated way in mobility scenarios)
  - Oxygen absorption (additional pathloss)
  - Blockage (some clusters are removed)
  - Support for larger bandwidth

Channel generation procedure



From: 3GPP TR 38.900

ns-3 implementation



AntennaArrayModel

Propagation with
- MmWave3gppBuildingsPropagationLossModel (obstacles-based LOS)
- MmWave3gppPropagationLossModel (statistical LOS)

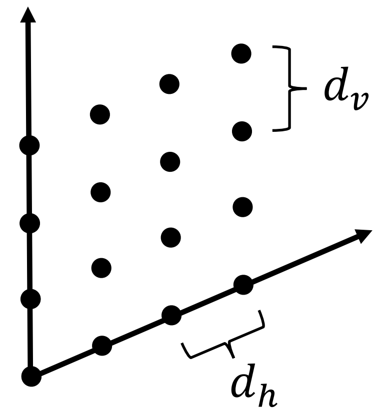
MmWave3gppChannelModel

Basic ns-3 interfaces for
- Propagation loss
- Fading and PSD

Configuration

- Currently based on MmWaveNetDevices
  - Generalization as future work
- Example: `MmWave3gppChannelExample`
  - Select the pathloss model
  - Select the channel model
  - Force LOS condition
  - Activate optional features

Antenna Modeling



- AntennaArrayModel class
- Uniform Planar Array
  - Rectangular panel
- Configurable parameters
  - Number of antennas in base stations and users
  - Horizontal and vertical spacing (d_h, d_v)
- Different radiation patterns
- Single panel per base station
  - Future work: extend to multi-sectors

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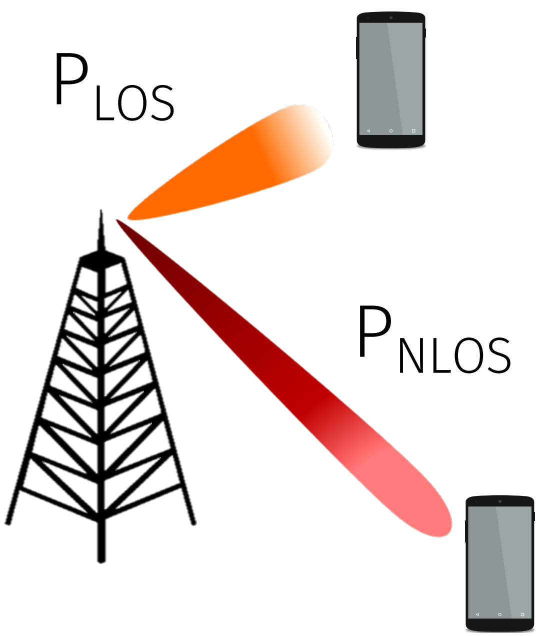
LOS and propagation

3GPP Statistical Model

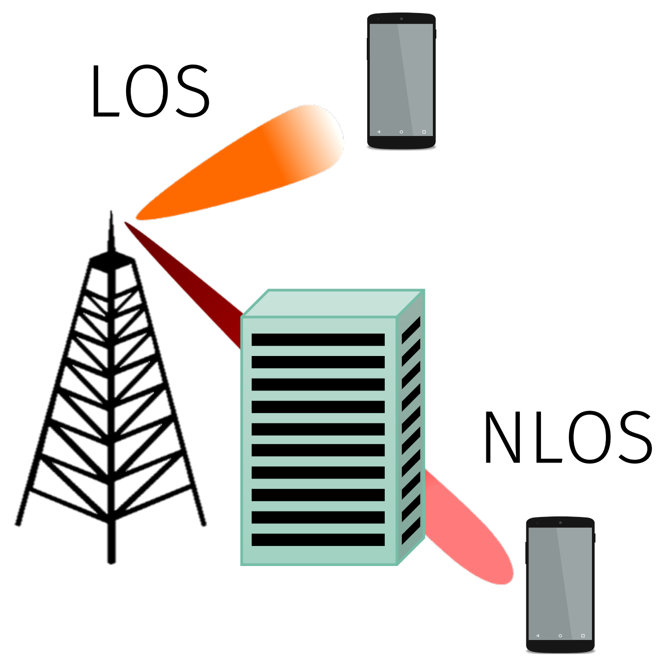
MmWave3gppPropagationLossModel



$$P_{los}(d_{2D}, scenario, h_{user})$$

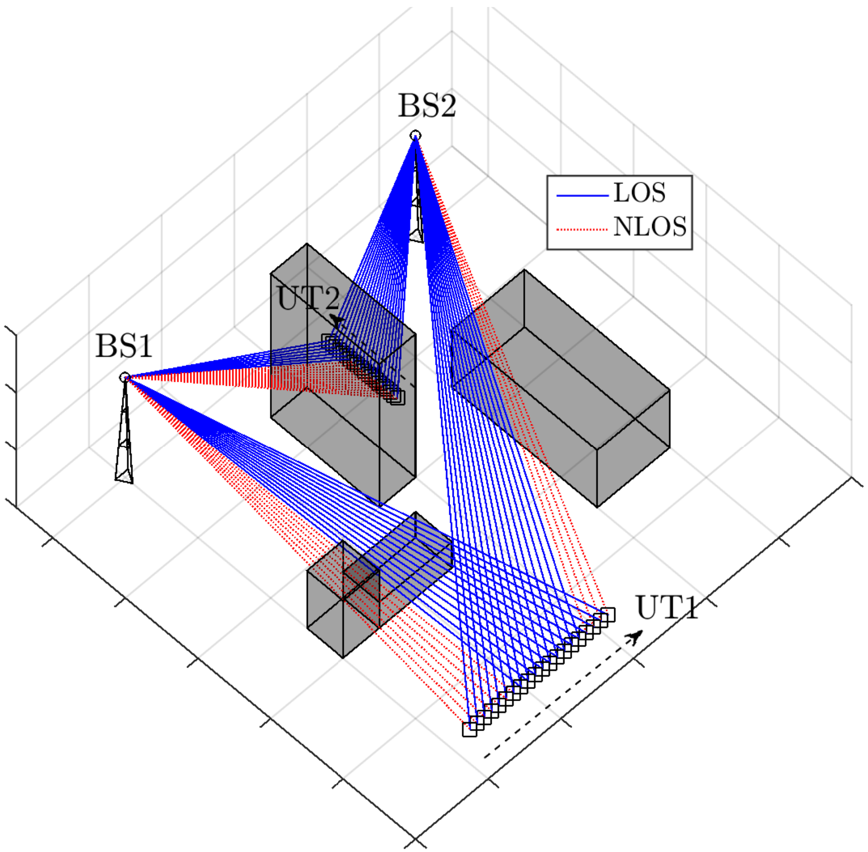
Geometric Model

MmWave3gppPropagationBuildings-LossModel



ns-3 buildings module to simulate obstacles

Geometric LOS



- Random or deterministic objects
- 3D tracing
- Correlated LOS/NLOS conditions
- Outdoor to indoor penetration
- Different penetration loss for BuildingTypes

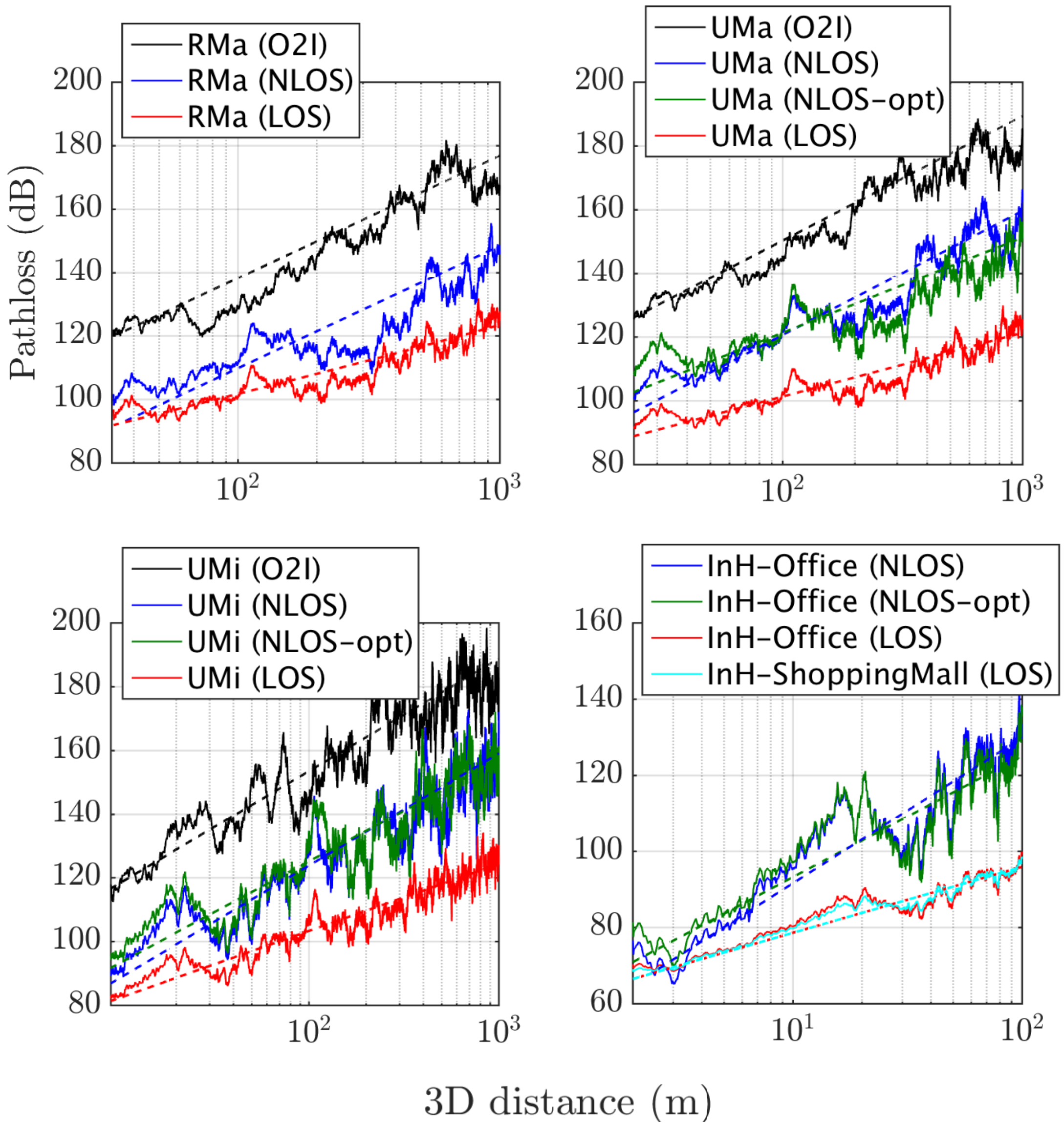
Shadowing

- Optional
- Spatially correlated for a moving user
- Shadowing s_t at time t is

$$s_t = R(\Delta d_{2D}) s_{t_{prev}} + \left(\sqrt{1 - R^2(\Delta d_{2D})}\right) \sigma_{SF} z, \quad z \sim N(0,1),$$

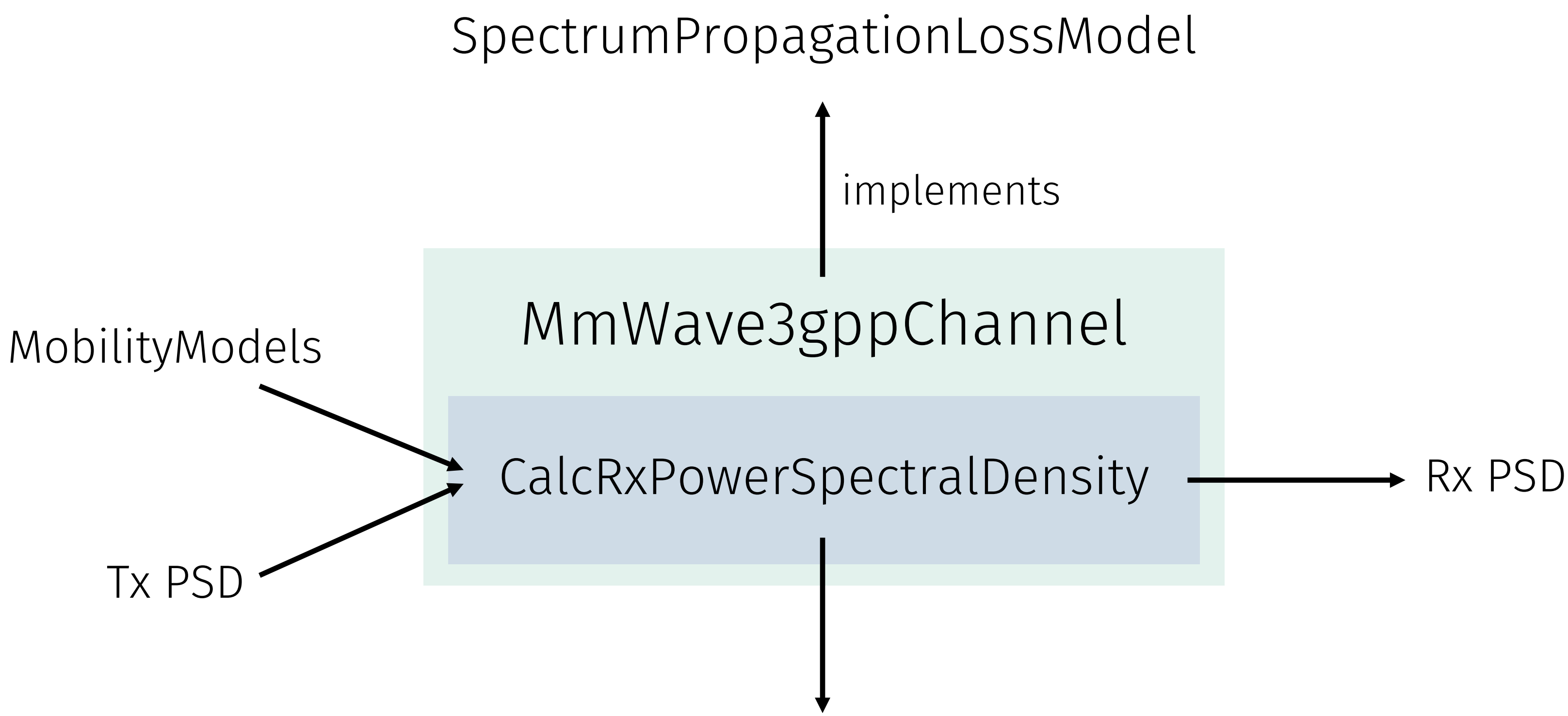
  - Decorrelation coefficient (exp in the distance Δ_{2D} from last update)
  - Decorrelation distance and shadowing standard deviation dependent on the scenario

Pathloss



RMa (O2I)
RMa (NLOS)
RMa (LOS)
UMa (O2I)
UMa (NLOS)
UMa (NLOS-opt)
UMa (LOS)
UMi (O2I)
UMi (NLOS)
UMi (NLOS-opt)
UMi (LOS)
InH-Office (NLOS)
InH-Office (NLOS-opt)
InH-Office (LOS)
InH-ShoppingMall (LOS)
Pathloss (dB)
3D distance (m)

MmWave3gppChannel class



1. Compute or update matrix $H(t, \tau)$
2. Apply beamforming and compute gain

Data structures

- For each TX-RX pair we store the useful variables

Param	Description
`m_txW`	complex vector with antenna weights for the tx
`m_rxW`	complex vector with antenna weights for the rx
`m_channel`	complex 3D matrix $\hat{\mathbf{H}}$
`m_delay`	double vector with cluster delays d_n, $n \in [1, N]$
`m_angle`	double matrix with AoA, ZoA, AoD and ZoD
`m_longTerm`	complex vector with long term fading parameters

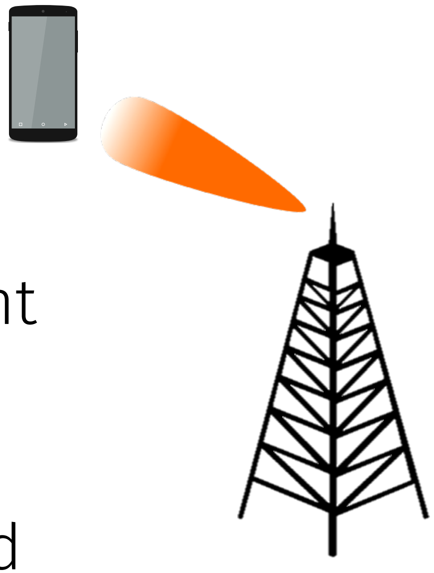
- Large scale fading correlation coefficients are generated offline

Assumptions

- One antenna panel per each base station
- Vertical polarization
- Doppler effect applied only to central ray of each cluster

Beamforming

- TDD frames at physical layer
- Analog MIMO beamforming
  - Phase shift for each antenna element
- Two options
  - Long-term Covariance Matrix method
  - Simplified Cell Scan
- BF vectors updated after large scale fading update



Long Term Covariance Matrix

- Optimal beamforming vectors w_{tx}, w_{rx}
- Assumption -> channel matrix $H(t, \tau)$ is known
- Procedure for w_{tx}

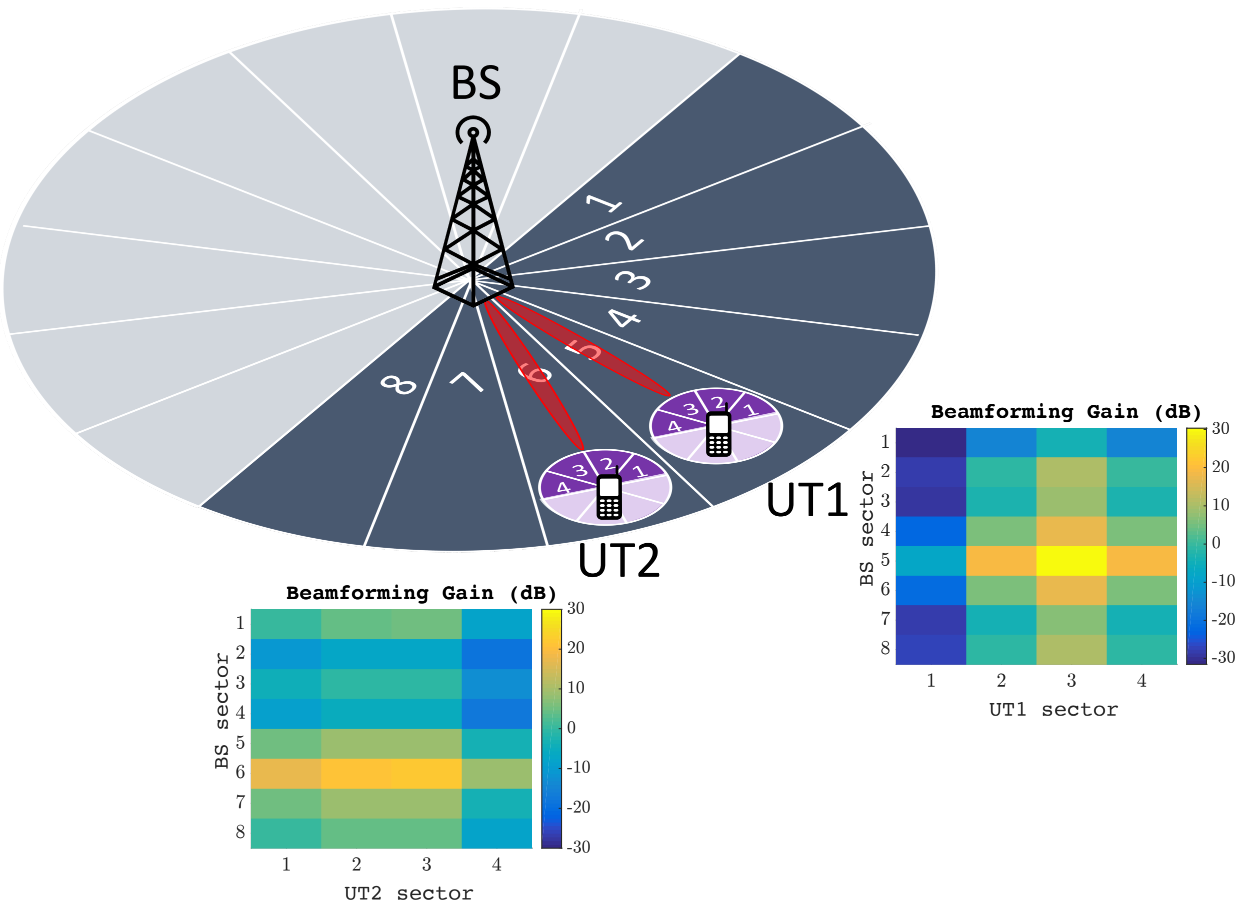
1. Compute spatial correlation matrix $\mathbf{Q}_{\mathbf{tx}} = \mathbf{E}[H^{\dagger} H]$
2. Pick the eigenvector associated to the largest eigenvalue

- Possible extensions
  - Delay between channel update and BF update
  - Limit BF update frequency

Cell Scan method

- No need to know channel matrix $H(t, \tau)$
- Limited set D of possible directions
- Scan set D at Tx and Rx
- Current implementation -> simplified
- Possible extensions
  - More realistic beam tracking mechanisms
  - Interaction and feedback between Tx and Rx

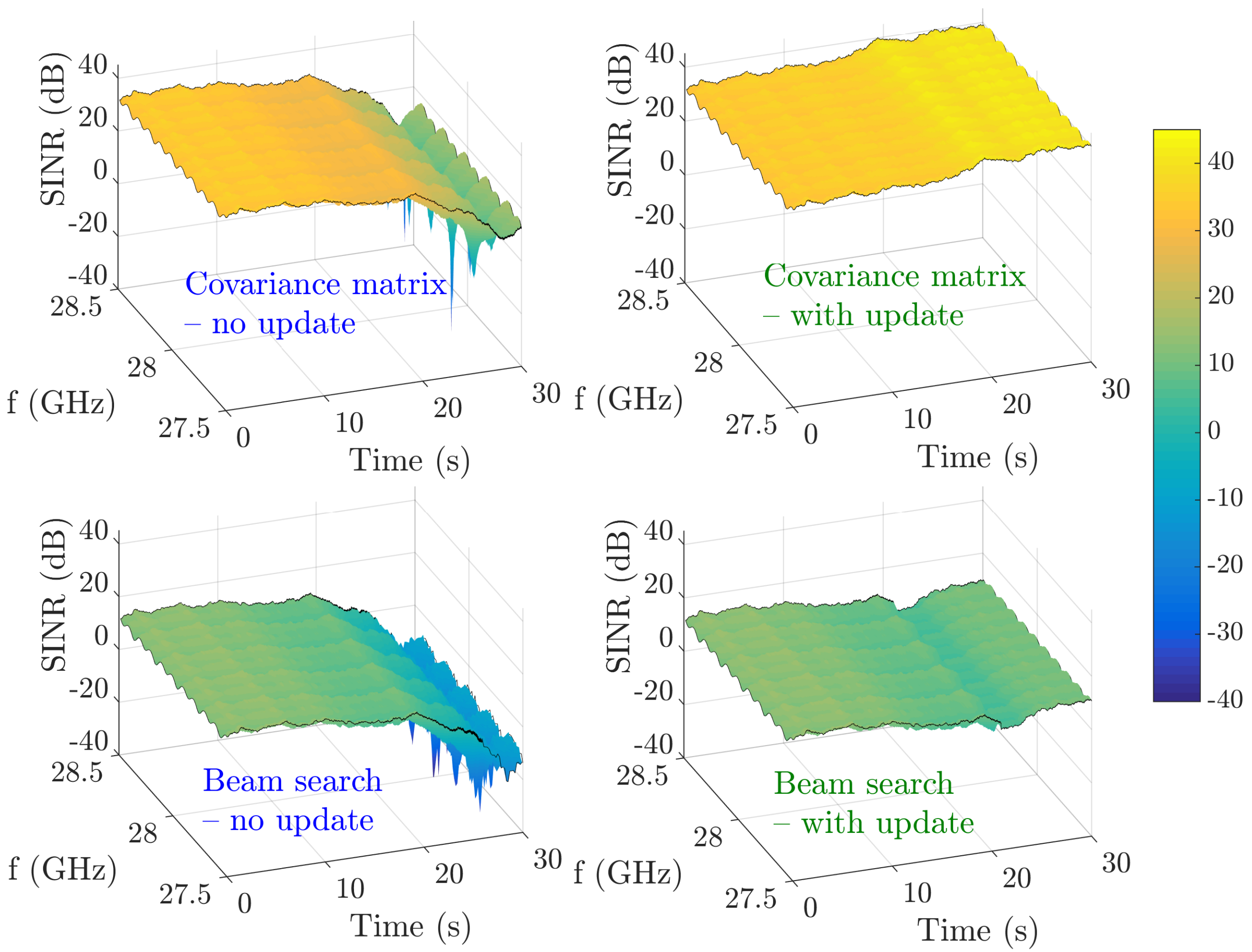
Cell Scan example



Spatial Consistency

- Useful for mobility-based simulations
- Every t_{per} (configurable) update consistently
  - Cluster delays
  - Cluster powers
  - Angles of arrival and departure
- Re-compute the beamforming vectors

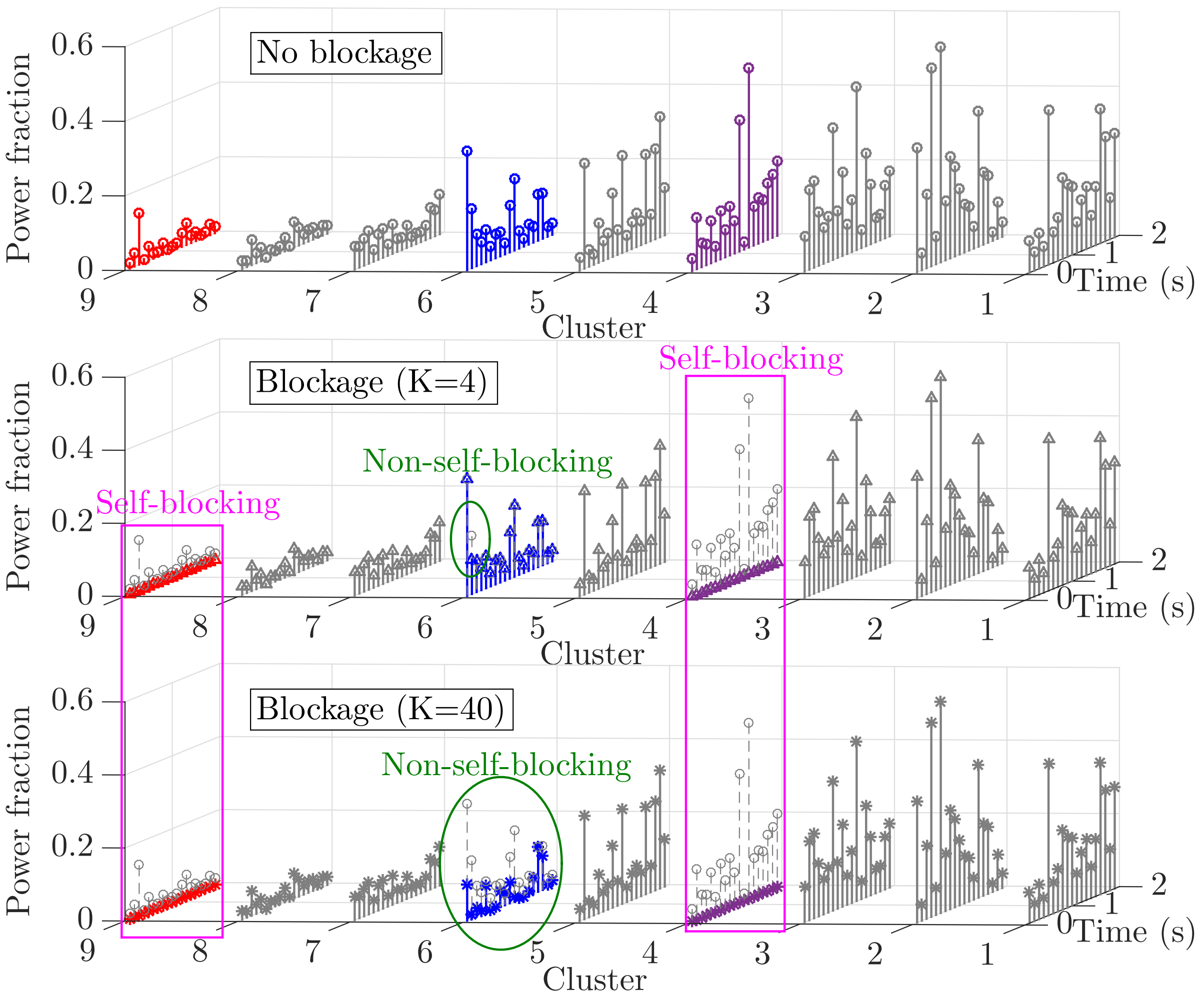
Spatial Consistency



Blockage

- Additional per-cluster attenuation
  - Self-blocking -> 30 dB
  - Non-self-blocking -> dependent on scenario and angles
- Correlated blocking in space and time
- Number of blockers K is configurable

Blockage



No blockage
Blockage (K=4)
Blockage (K=40)
Self-blocking
Non-self-blocking
Power fraction
Cluster
Time (s)
0.6
0.4
0.2
0
9
8
7
6
5
4
3
2
1

Conclusions

- Implementation of the 3GPP channel model for the mmWave module
  - LOS
  - Propagation
  - Fading
  - Beamforming
  - Optional features
- Future works
  - Extension of beamforming models
  - Possible integration with other ns-3 modules

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