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

Scenario

Propagation loss model

Fading model

Optional Features
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 $U \times S$.
- Each entry depends on:
  - $N$ clusters of $M$ rays
  - LOS condition
  - Carrier frequency
  - Distance
  - Mobility
  - Indoor/outdoor state
  - Scenario

num TX antennas
num RX antennas
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

General parameters:
- Set scenario, network layout and antenna parameters
- Assign propagation condition (NLOS/LOS)
- Calculate pathloss
- Generate correlated large scale parameters (DS, AS, SF, K)

Small scale parameters:
- Generate XPRs
- Perform random coupling of rays
- Generate arrival & departure angles
- Generate cluster powers
- Generate delays

Coefficient generation:
- Draw random initial phases
- Generate channel coefficient
- Apply pathloss and shadowing

From: 3GPP TR 38.900
ns-3 implementation

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

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

MmWave3gppChannelModel

AntennaArrayModel

TxNetDevice
+Send(Packet): bool

RxNetDevice
+Receive(Packet): void

TxSpectrumPhy
+StartTxDataFrame(...): bool
+StartTxCtrlFrame(...): bool

RxSpectrumPhy
+StartRx(...): void

MultiModelSpectrumchannel
+StartTx(params): void
+StartRx(params): void

MmWave3gppBuildingsPropagationLossModel
+map m_conditionMap
+IsLineIntersectBuildings(...): bool
+mMmWaveLossLoss(...): double
+mMmWaveNlosLoss(...): double

BuildingsPropagationLossModel
+DoCalcRxPower(...): double

MmWave3gppPropagationLossModel
+string m_channelConditions
+string m_scenario
+double m_shadowing

PropagationLossModel
+DoCalcRxPower(...): double

MmWave3gppChannelModel
+Params3gpp_map m_channelMap
+CallBeamformingGain(...): Ptr<SpectrumValue>

SpectrumPorpagationLossModel
+DoCalcRxPowerSpectralDensity(...): Ptr<SpectrumValue>

AntennaArrayModel
+SetBeamformingVector(...): void
+GetBeamformingVector(): Vector

RxSpectrumPhy
+StartRx(...): void

AntennaArrayModel
+SetBeamformingVector(...): void
+GetBeamformingVector(): Vector

RxNetDevice
+Receive(Packet): void

MmWave3gppBuildingsPropagationLossModel
+map m_conditionMap
+IsLineIntersectBuildings(...): bool
+mMmWaveLossLoss(...): double
+mMmWaveNlosLoss(...): double

BuildingsPropagationLossModel
+DoCalcRxPower(...): double

MmWave3gppPropagationLossModel
+string m_channelConditions
+string m_scenario
+double m_shadowing

PropagationLossModel
+DoCalcRxPower(...): double

MmWave3gppChannelModel
+Params3gpp_map m_channelMap
+CallBeamformingGain(...): Ptr<SpectrumValue>

SpectrumPorpagationLossModel
+DoCalcRxPowerSpectralDensity(...): Ptr<SpectrumValue>
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
LOS and propagation

3GPP Statistical Model
MmWave3gppPropagationLossModel

Geometric Model
MmWave3gppPropagationBuildings-LossModel

\[ P_{\text{LOS}}(d_{2D}, \text{scenario}, h_{\text{user}}) \]

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 $\Delta_{2D}$ from last update)
- Decorrelation distance and shadowing standard deviation dependent on the scenario
Pathloss

Graphs showing the relationship between pathloss (dB) and 3D distance (m) for different environments and signal conditions.
MmWave3gppChannel class

MmWave3gppChannel implements SpectrumPropagationLossModel

- MobilityModels
- Tx PSD

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

Rx PSD
Data structures

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

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

- 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 \( H(t, \tau) \) is known
- Procedure for $w_{tx}$
  1. Compute spatial correlation matrix $Q_{tx} = E[H^\dagger H]$ 
  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

Covariance matrix - no update
Covariance matrix - with update
Beam search - no update
Beam search - with update
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
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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