NS-3 AND 5G-LENA EXTENSIONS TO SUPPORT DUAL-POLARIZED MIMO

22/06/2022, WORKSHOP ON NS-3

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OUTLINE

• Introduction and contribution
• DP-MIMO model
• Implementation in *ns-3*
  • *ns-3-dev*: antenna, spectrum
  • *nr*: PHY, MAC
• Results
• Conclusions
INTRODUCTION AND CONTRIBUTION

- MIMO spatial multiplexing is an essential feature to increase the communication data rates in current and future cellular systems.

- Currently, the ns-3 LTE module leverages an abstraction model for 2x2 MIMO with spatial multiplexing of two streams, while mmwave and nr modules lack the spatial multiplexing option until this work.

- In this paper, we propose, implement, and evaluate models for ns-3 and the nr module to enable DP-MIMO.

  - The proposed extension for the ns-3 supports multiple antennas for DP-MIMO with spatial multiplexing of two streams.
  - It can be used by any ns-3 module compatible with the ns-3 antenna array-based models, such as nr and mmWave modules.
  - We leverage this ns-3 extension to model DP-MIMO by exploiting dual-polarized antennas and their orthogonality under line-of-sight conditions, as it happens at high-frequency bands, to send the two data streams.
  - The proposed model does not rely on abstraction, as the MIMO model in the ns-3 LTE module and can thus model more realistically the propagation differences of the two streams, correlation, and inter-stream interference.
  - It allows the design and evaluation of the rank adaptation algorithms.
  - Additionally, we propose and evaluate an adaptive rank adaptation scheme and compare it with a fixed scheme.
DP-MIMO MODEL

• Cross-polarized antenna arrays in 3GPP

(a) Cross-polarized panel array antenna model in 3GPP, with M=2, N=4, P=2

(b) MIMO model for mmWave with cross-polarized antennas
DP-MIMO MODEL

- Subarray partition concept
IMPLEMENTATION IN NS-3

- *ns-3-dev*
  - *ns-3 antenna*
    - *UniformPlanarArray* extended to consider the polarization slant angle (PolSlantAngle)
  - *ns-3 spectrum*
    - *ThreeGppChannelModel* extended to be able to distinguish the channel parameters that are common for all the channels among the same pair of the transmit/receive (TX/RX) nodes and those that are specific for the TX/RX antenna subpartition array pair.
    - *GetNewChannel* split into *GetNewChannelParams* and *GetNewChannelMatrix*, which update the respective parameters
      - *ChannelParams* - per node pair and *ChannelMatrix* - per phased antenna array pair
    - Spectrum module extended to support multiple antenna arrays per device (and per Spectrum-Channel instance): new *PhasedArraySpectrumPropagationLossModel*
IMPLEMENTATION IN NS-3

- *ns-3-dev* spectrum

- Split of the Channel Matrix and the Channel Parameters into the Two Structures to Support DP-MIMO

```cpp
MatrixBasedChannelModel::ChannelMatrix
+ m_channel: Complex3DVector
+ m_delay: Double2DVector
+ m_angle: Double2DVector
+ m_generatedTime: Time
+ m_frequency: std::pair<uint32_t, uint32_t>

MatrixBasedChannelModel::ChannelMatrix
+ m_channel: Complex3DVector
+ m_delay: Double2DVector
+ m_angle: Double2DVector
+ m_generatedTime: Time
+ m_antennaPair: PhaseAntennaPair

MatrixBasedChannelModel::ChannelParams
+ m_delay: DoubleVector
+ m_angle: Double2DVector
+ m_generatedTime: Time
+ m_antennaPair: PhaseAntennaPair
+ m_alpha: DoubleVector
+ m_D: DoubleVector

ThreeGppChannelModel::ThreeGppChannelMatrix
+ m_lossCondition: LossConditionValue
+ m_e21Conditon: E21ConditionValue
+ m_nonSelfBlocking: Double2DVector
+ m_pair: Vector
+ m_locUI: Vector
+ m_normalAngles: Double2DVector
+ m_Bs: double
+ m_K: Double
+ m_numCluster: uint8_t
+ m_clusterPhase: Double3DVector
+ m_speed: Vector
+ m_dis2: double
+ m_dis3: double
+ m_rayAoA: Double2DVector
+ m_rayAoD: Double2DVector
+ m_rayAoD: Double2DVector
+ m_clusterPower: DoubleVector
+ m_attenuation: double
+ m_cluster1: uint8_t
+ m_cluster2: uint8_t
```
IMPLEMENTATION IN NS-3

- ns-3-dev spectrum changes to support DP-MIMO
IMPLEMENTATION IN NS-3

• *ns-3 nr* module

  • **PHY**
    • Rank Indicator (RI) Computation and Rank Adaptation Algorithm:
      • Fixed RI scheme, set using *UseFixedRi* and *FixedRankIndicator* attributes
      • Adaptive RI scheme, adaptive algorithm based on two SINR thresholds to compute an RI value
    • CQI and RI Reporting:
      • CQI is reported per stream
      • *DlCqiInfo* structure extended
    • PHY TX/RX through Multiple Streams
      • *NrPhy* class extended to aggregate multiple *NrSpectrumPhy* instances; there is one *PhasedArrayModel* per each *NrSpectrumPhy* instance
      • Two *NrSpectrumPhy* instances are installed per *NrGnbPhy* and *NrUePhy*, with two *UniformPlannarArray* instances, and two antenna array subpartitions belonging to the same *NrGnbPhy* or *NrUePhy* are configured to be cross-polarized
IMPLEMENTATION IN NS-3

- *ns-3 nr* module
  - **PHY**
    - Beamforming per Antenna subpartition
      - There is a *BeamManager* per *NrSpectrumPhy*
      - BF framework extended to support multiple antenna arrays
    - HARQ and SINR Reporting for Multiple Streams
      - *nr* PHY model, including *NrSpectrumPhy* and *NrUePhy*, is extended to support HARQ and SINR reporting per stream
    - TX Power per Stream
      - Uniformly distributed among the number of active streams
    - Inter-Stream Interference
      - New *ThreeGppChannelModelParam*, based on *ThreeGppChannelModel*, with which we can parametrize the inter-stream interference correlation, based on the 3GPP cross-polarization correlation parameter
      - *InterStreamInterferenceRatio* can tune the level of inter-stream interference, depending on RX capability
    - Support for OFDMA Scheduling
      - *beamConfId* structure based on *BeamId*, which identifies uniquely the pair of beams (one for each stream)
IMPLEMENTATION IN NS-3

• *ns-3 nr* module

  • PHY
    • Changes in NR PHY to Support DP-MIMO: Multiple Antenna Arrays per PHY and the Beamforming Management
IMPLEMENTATION IN NS-3

• *ns-3 nr* module

  • **MAC**
    • CQI Management
      • *DlWbcQlReported* updated to read the new *DlCqiInfo* structure and compute MCS per stream
    • DCI Creation
      • *VarTtiAllocInfo* extended to support multiple streams (*DciInfoElementTdma* and *RlcPduInfo* structures)
    • Scheduling (Retransmissions and Rank Adaptation)
      • Number of streams for scheduling set based on the RI
      • TB scheduled independently per stream until UE can decode both streams or the maximum number of retransmissions is reached
    • HARQ Feedback Processing
      • *DlHarqInfo* structure updated
      • *ProcessHarqFeedbacks* function extended to read the HARQ feedback of each stream
IMPLEMENTATION IN NS-3

- *ns-3 nr module*
  - MAC
    - Updated *VarTtiAllocInfo* Structure to Support MIMO spatial multiplexing
RESULTS

• Example: cttc-nr-mimo-demo.cc

• Scenario:
  • Single gNB and single UE, at a fixed pre-configured distance
  • Downlink UDP CBR
  • UMi propagation conditions
  • gNB/UE antenna height: 10m/1.5m
  • gNB tx power: 30dBm
  • 3.5 GHz band with 15KHz SCS and 20MHz bandwidth
  • 2x2 dual-polarized antenna at gNB (8 elements), 1x1 dual-polarized antenna at the UE (2 elements)
  • MCS Table 2 (up to 256QAM)

• Evaluation varying the gNB-UE distance
  • Fixed RI scheme (RI=1 and RI=2)
  • Adaptive RI scheme: RiSinrThreshold1= 7 dB and RiSinrThreshold2= 12 dB
• Example: cttc-nr-mimo-demo.cc

• Throughput (Mbps) versus Distance (m) for the Fixed RI (1 and 2) and the Adaptive RI Algorithm
CONCLUSIONS

• In this paper, we presented an extension of the *ns-3* simulator and the *5G-LENA* module to support DP-MIMO with spatial multiplexing of two streams.

• The developed MIMO model in the *5G-LENA* exploits dual-polarized antennas to send two streams.

• The extension has implied major implementation changes in PHY and MAC layers of the *nr* module and significant extensions in the *ns-3* spectrum and antenna modules.

• We described the implementation changes and design choices in detail.

• Finally, we validated the developed DP-MIMO model in an Urban Micro scenario for various gNB-UE distances under a fixed rank (1 and 2) and the proposed rank adaptation algorithm.