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

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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

(a) Subarray partition concept for the 3GPP panel antenna array

(b) MIMO model for mmWave with 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
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
      - `$DIWBCQIReported$` updated to read the new `$DICqiInfo$` structure and compute MCS per stream
    - DCI Creation
      - `$VarTtiAllocInfo$` extended to support multiple streams (`$DcInfoElementTdma$` 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
RESULTS

- 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.
