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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

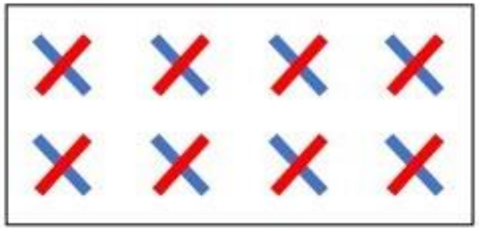
INTRODUCTION AND CONTRIBUTION

- 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.

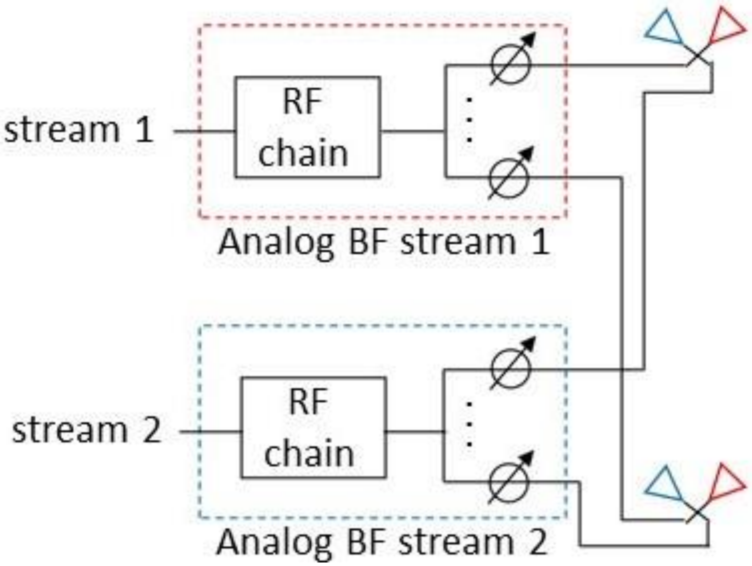
DP-MIMO MODEL

- Cross-polarized antenna arrays in 3GPP

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

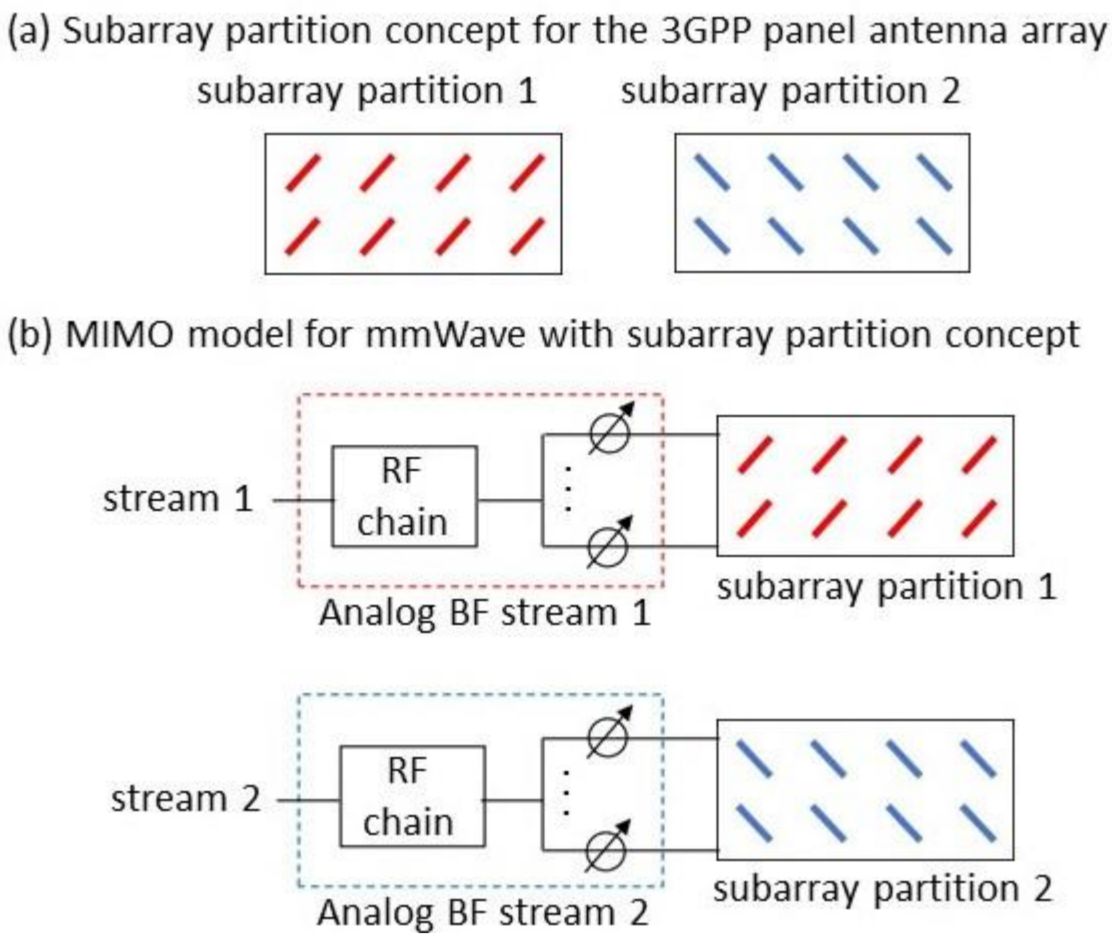


(b) MIMO model for mmWave with cross-polarized antennas



DP-MIMO MODEL

- Subarray partition concept

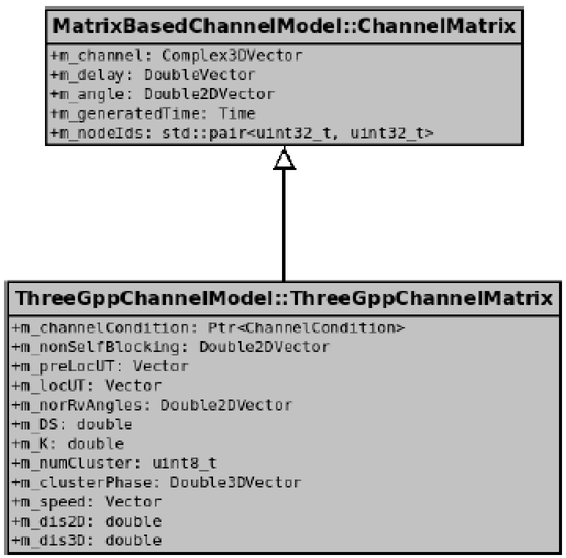


IMPLEMENTATION IN NS-3

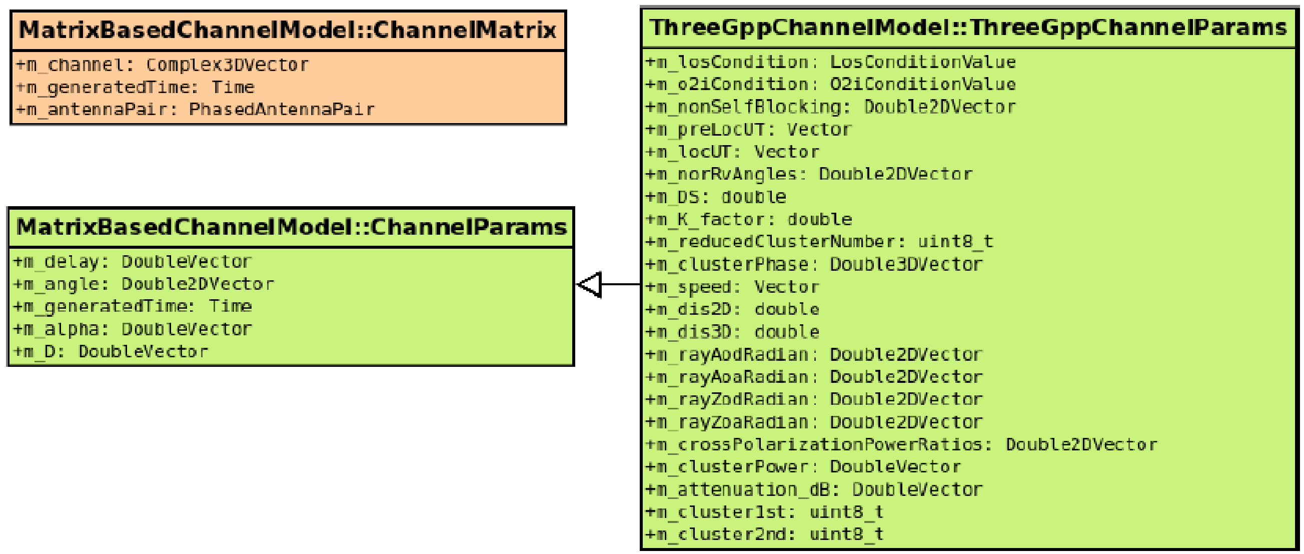
- *ns-3-dev*
  - ***ns-3* antenna**
    - *UniformPlanarArray* extended to consider the polarization slant angle (PolSlantAngle)
  - ***ns-3* spectrum**
    - *ThreeGppChannelModel* extended to be able to distinguish the channel parameters that are common for all the channels among the same pair of the 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



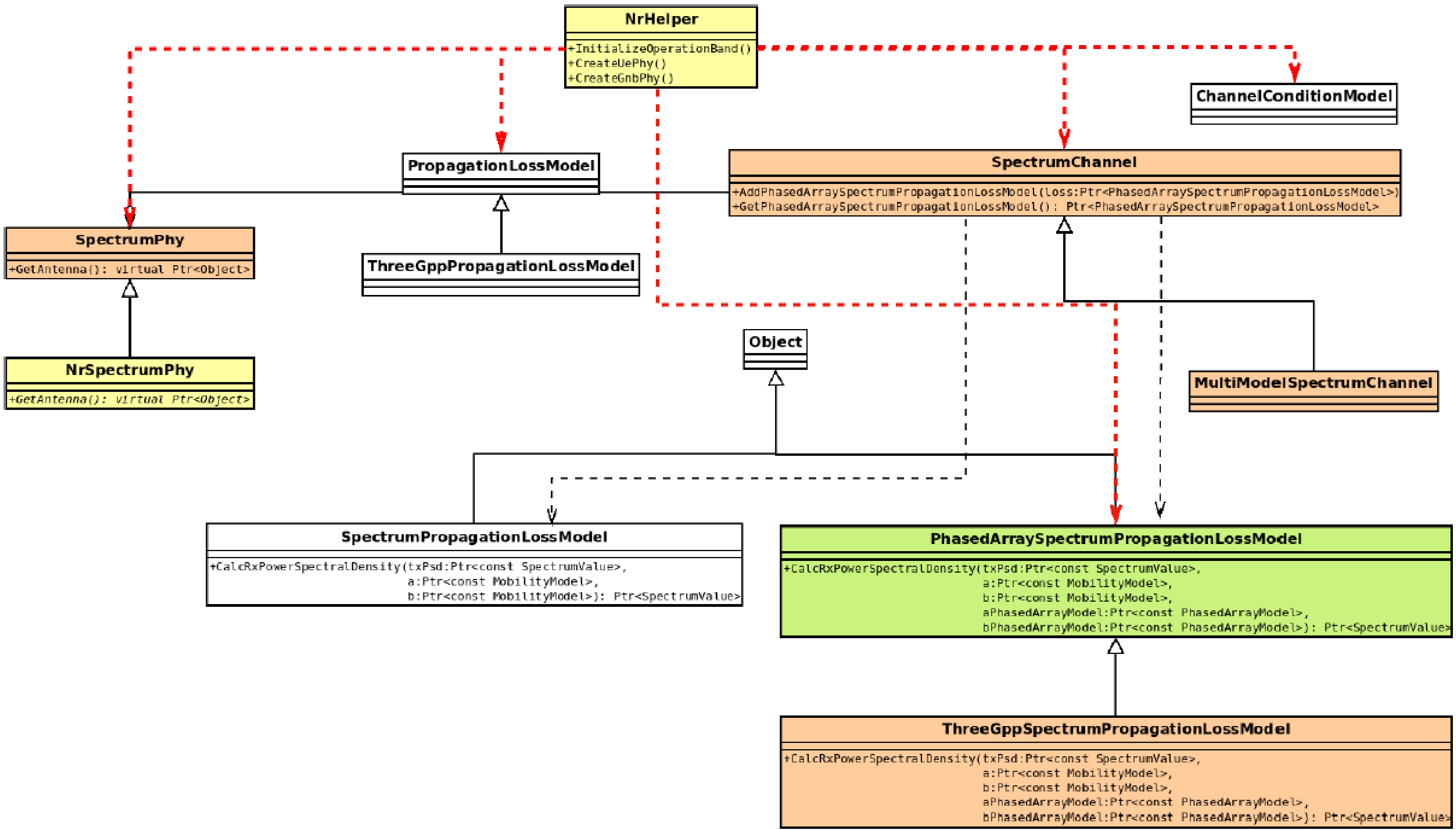
(a)



(b)

IMPLEMENTATION IN NS-3

- ns-3-dev spectrum changes to support DP-MIMO



IMPLEMENTATION IN NS-3

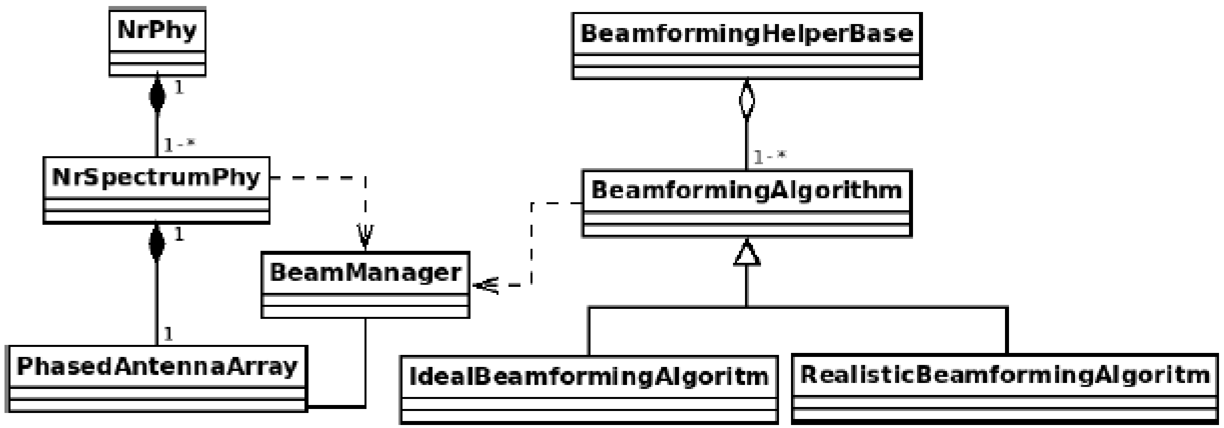
- *ns-3 nr* module
  - **PHY**
    - Rank Indicator (RI) Computation and Rank Adaptation Algorithm:
      - Fixed RI scheme, set using *UseFixedRi* and *FixedRankIndicator* attributes
      - Adaptive RI scheme, adaptive algorithm based on two SINR thresholds to compute an RI value
    - CQI and RI Reporting:
      - 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

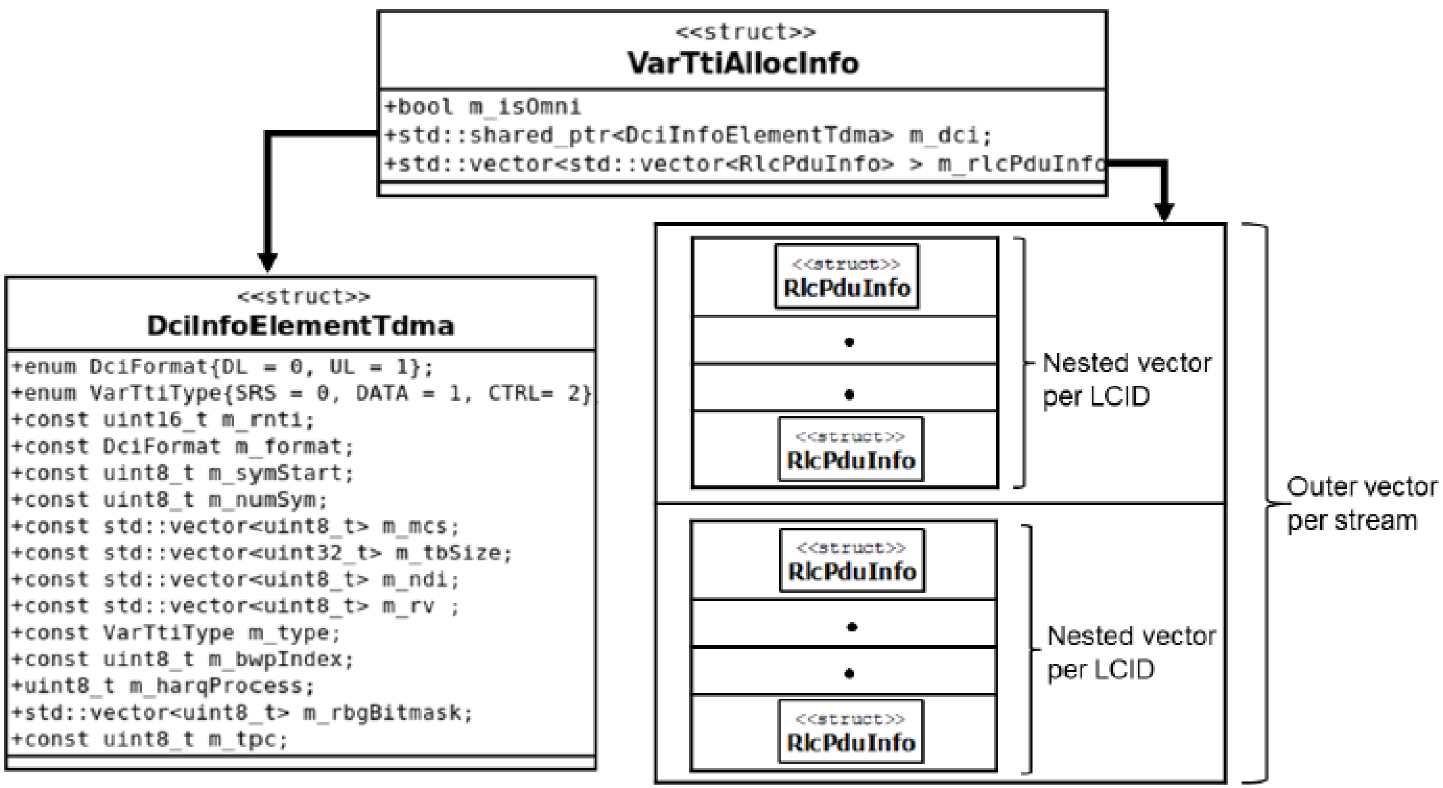


IMPLEMENTATION IN NS-3

- *ns-3 nr* module
  - **MAC**
    - CQI Management
      - *DlWBCQIReported* 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

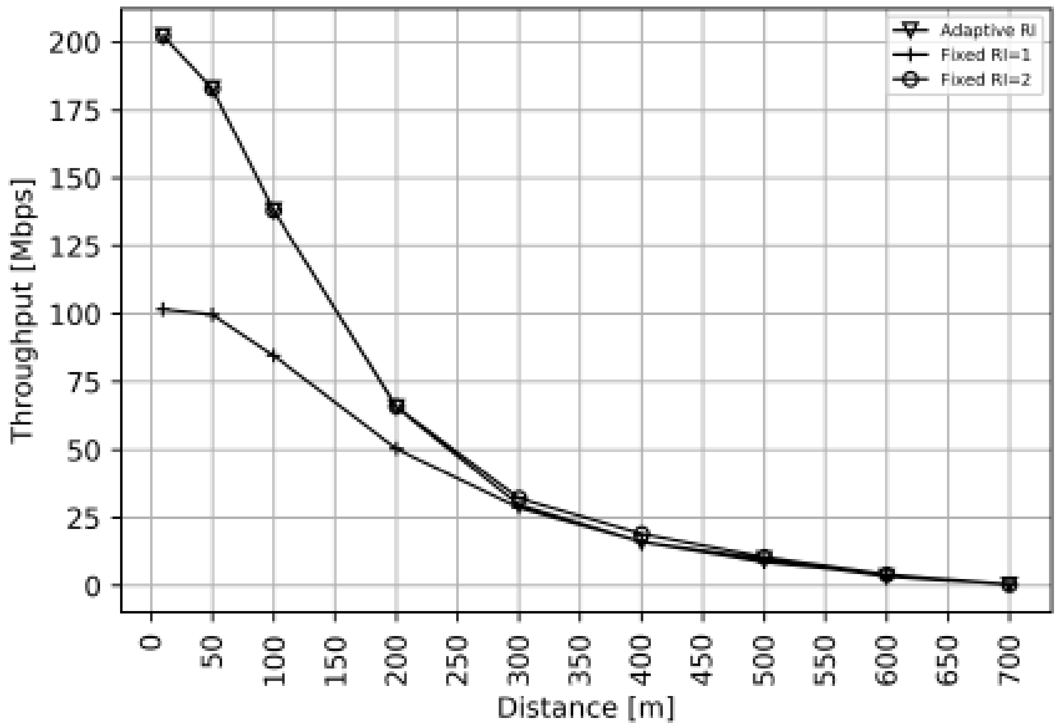


RESULTS

- 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

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.

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