Challenges in building a 5G simulator

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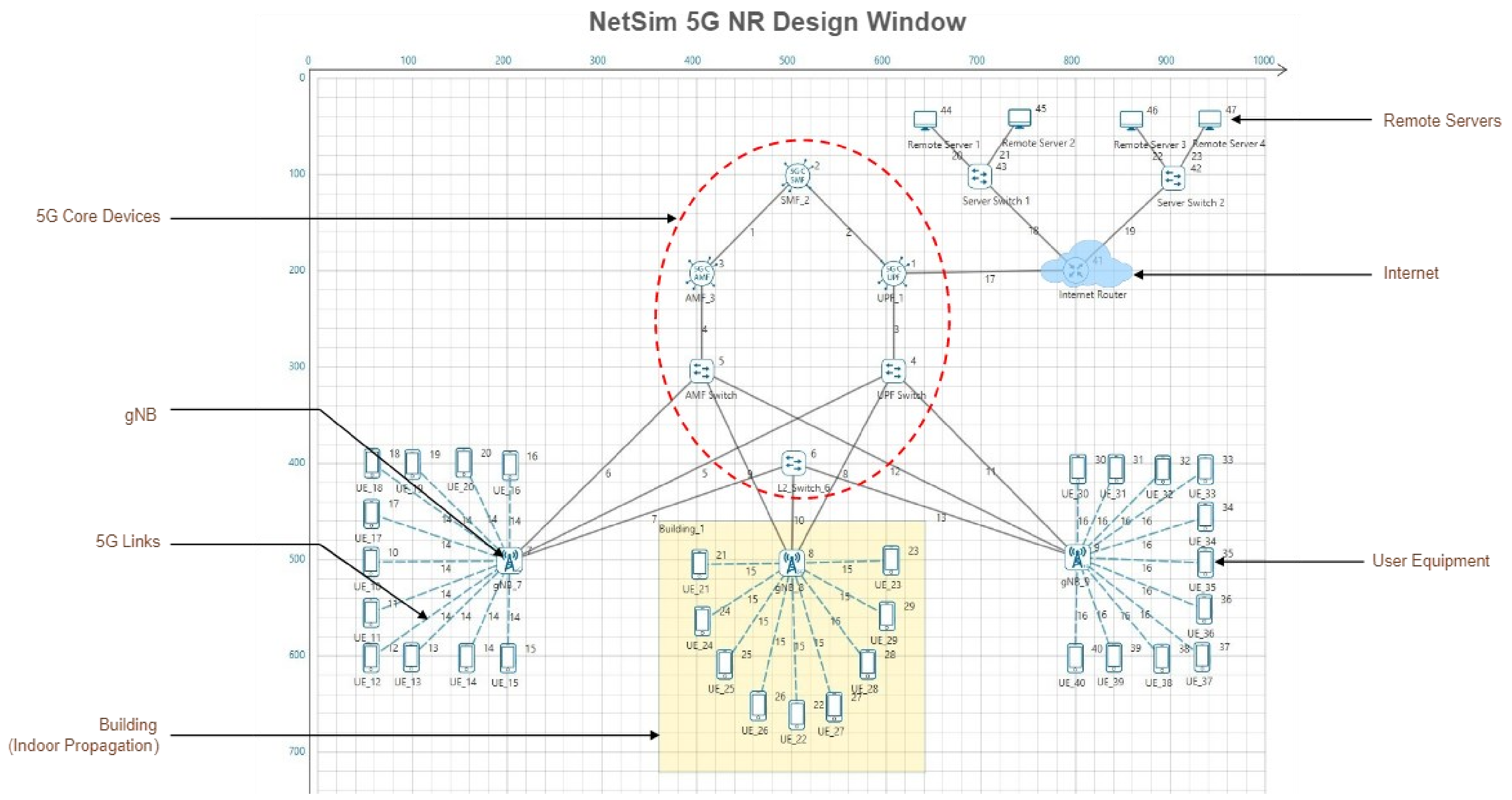
Outline

- NetSim 5G library
- Broad problems faced in:
    - Modeling and simulation
    - Testing
- Focus: Interference
    - Computational requirements
    - Results
- Focus: Outer loop links adaptation (OLLA)
    - Lack of published SINR BLER data
    - Building a proprietary link level simulator
    - Results
- Dev roadmap and new challenges

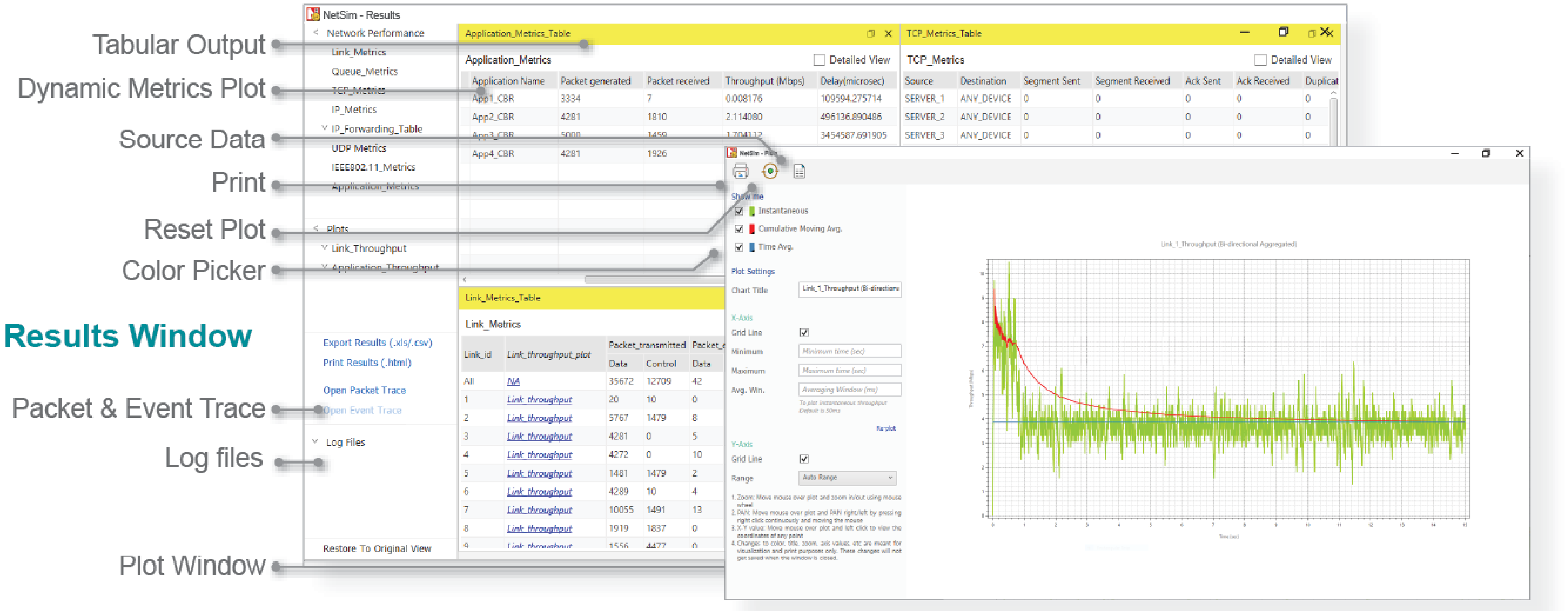
Network Design



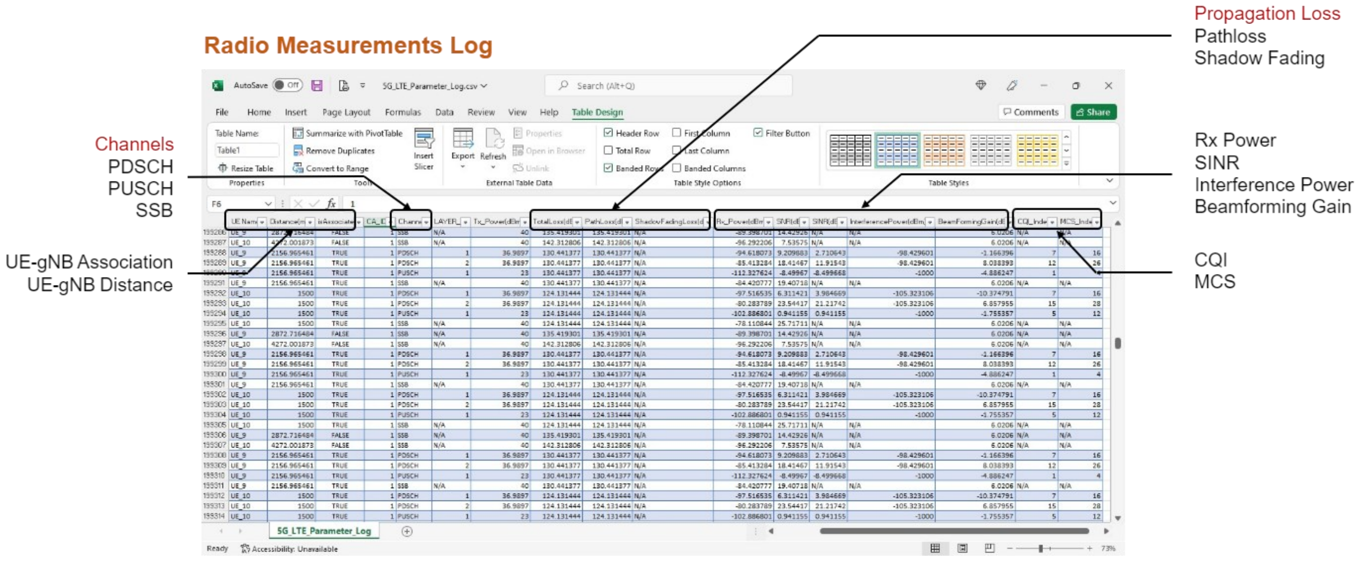
Features

- End-to-end, full stack, packet level simulation
- FR1 and FR2. TDD & FDD
- Flexible numerology.
- SA and NSA deployment modes
- Devices: UEs, gNBs, Core – AMF, SMF, UPF
- MAC Scheduling
- Link adaptation
- MIMO, Beamforming
- 3GPP propagation models
- Mobility and handover
- Applications: Voice, video, e-Mail, HTTP… and more

Results

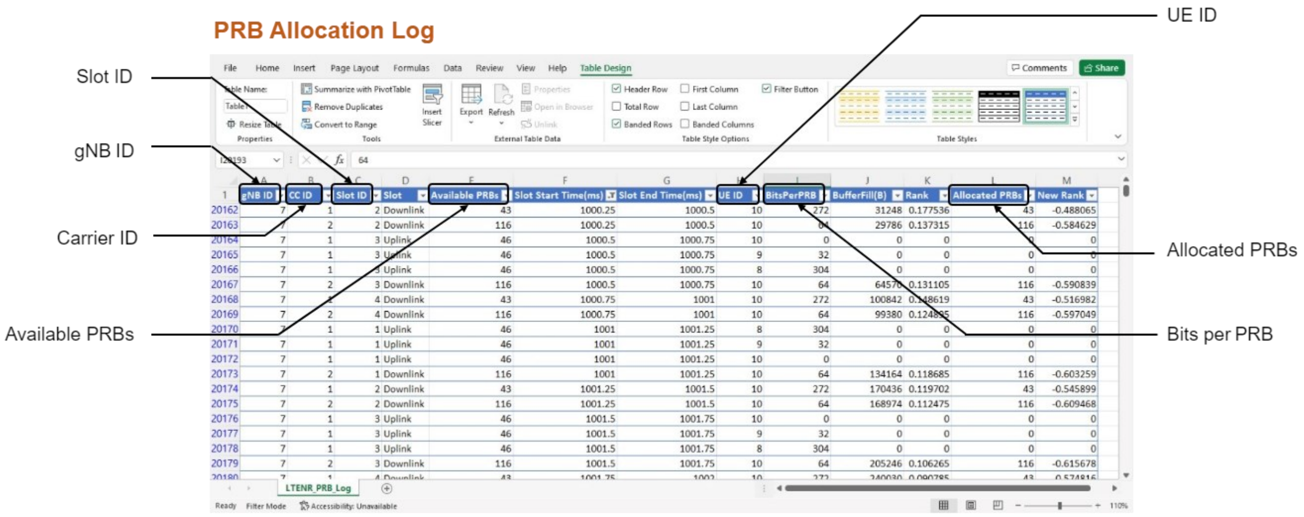

Tabular Output
Dynamic Metrics Plot
Source Data
Print
Reset Plot
Color Picker
Results Window
Packet & Event Trace
Log files
Plot Window
NetSim - Results
Network Performance
Link_Metrics
Queue_Metrics
TCP_Metrics
IP_Metrics
IP_Forwarding_Table
UDP Metrics
IEEE802.11_Metrics
Application_Metrics
Plots
Link_Throughput
Application_Throughput
Export Results (.xls/.csv)
Print Results (.html)
Open Packet Trace
Open Event Trace
Log Files
Restore To Original View
Application_Metrics_Table
Application_Metrics
Detailed View
TCP_Metrics_Table
TCP_Metrics
Link_Metrics_Table
Link_Metrics
Show me
Instantaneous
Cumulative Moving Avg.
Time Avg.
Plot Settings
Chart Title
X-Axis
Grid Line
Minimum
Maximum
Avg. Win.
Y-Axis
Range
Auto Range

Measurements and logs



Radio measurement recorded by (all) UEs at every slot in DL and UL

NetSim 5G Data Files



PRB allocation per carrier per slot between each gNB and its associated UEs

Challenges: modelling and simulation

- Scale
  - Tens of gNBs and 100s of UEs
  - Multi Gbps data speeds (at each gNB)
  - Pathloss and interference
- Granularity
  - Scheduling every TTI (as low as 0.125 ms)
- Complexity
  - Interlinked stochastic computations for Pathloss, Shadowing, Fast fading MIMO, Beamforming, Mobility, Handover, Scheduling, etc.
- Logs
  - Measurements: every slot
  - Packet and evet trace: every packet

Ensuring accuracy and realism in modeling a complex and dynamic system

Challenges: testing and verification

- Need to make sure that our results are "correct"
  - Extensive analytical studies
  - Example: Eigen values of Wishart Matrix asymptotically converge to the Marchenko-Pastuer distribution
- Hundreds of input parameters (p), tens of possible values (v) for each input
  - v^p is the number of test scenarios
  - Curse of dimensionality
- Reproducibility and backward compatibility
  - With every new release

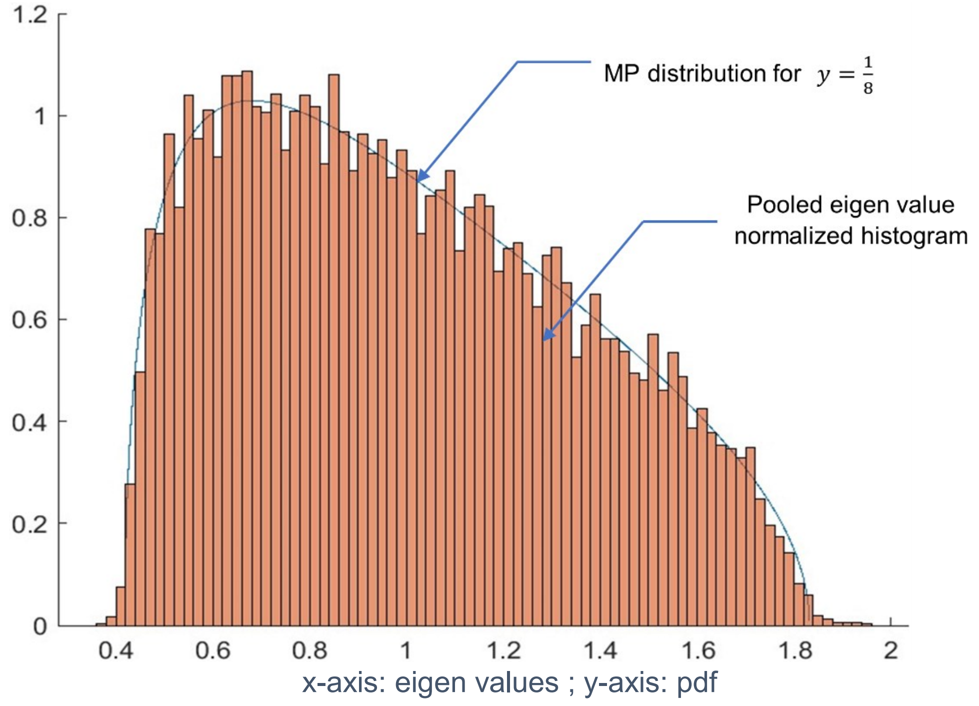
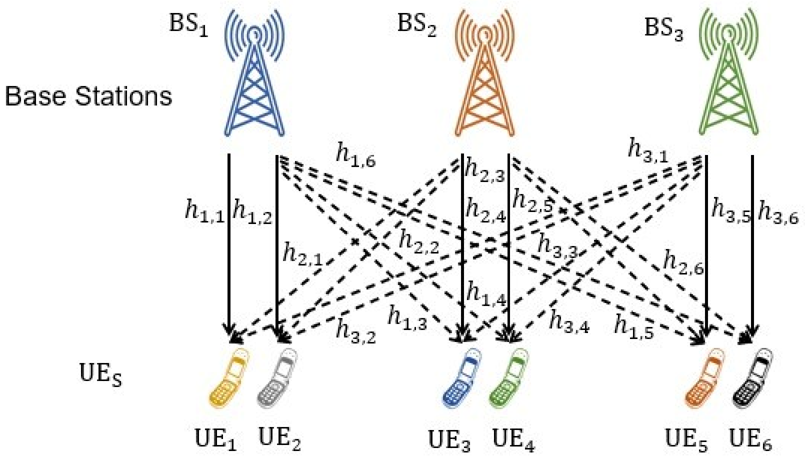


Fig: NetSim Results vs. Marchenko-Pasteur distribution for $N_r = 16$ and $N_t = 128$

Interference modelling in NetSim

- Need to account for the following parameters differently between UE and serving gNB vs. interfering gNB
  - 3G PP propagation model parameters
    - Distance: Different UE-gNB distances.
    - LOS/NLOS
      - UE can be NLOS (or LOS) with serving gNB.
      - LOS with certain interfering gNBs and NLOS with other interfering gNBs
    - Rural/urban. Outdoor/Indoor. O2I losses
  - Transmit power: Each gNB can be set a different transmit power
  - MIMO
    - Serving and interfering gNBs can have different antenna count
    - Impacts the gains
  - Beamforming
    - Beamforming vector and eigen values are different
- No limit in number of interfering gNBs.
  - All UE-gNB pairs to be accounted for in interference computations
- Computed every measurement report (120 ms) to account for mobility and time varying channel conditions

$$\mathrm{SINR}_{ij} = \frac{\frac{P_{Tx}}{PL_{ij}} G_{ij}}{\sum_{k \neq i} \frac{P_{Tx}}{PL_{kj}} G_{kj} + BW \times N_0}$$

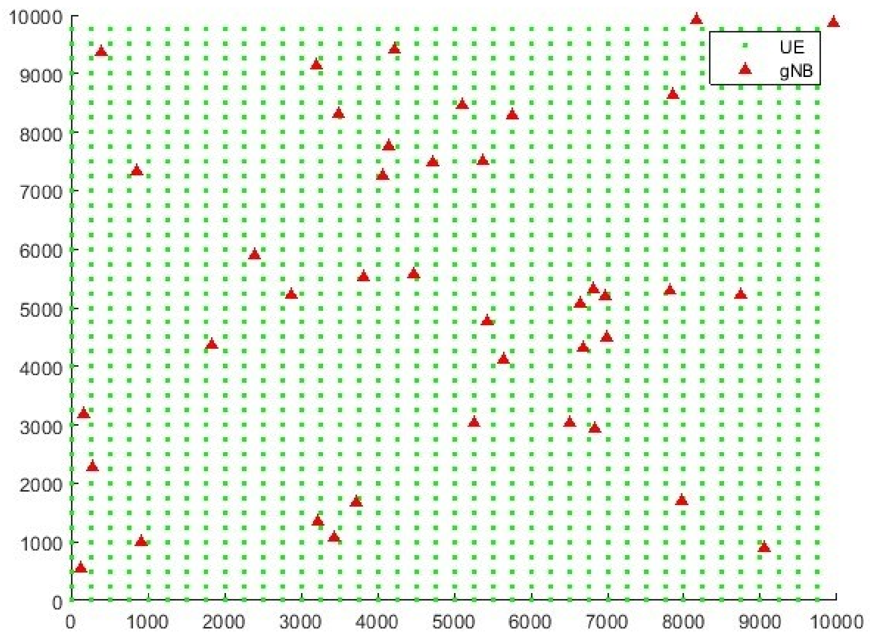


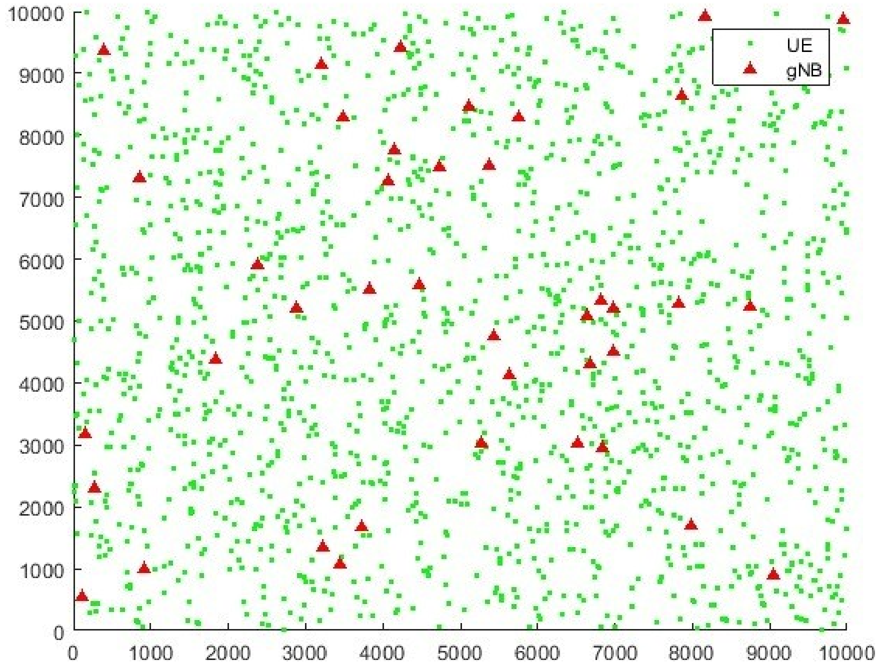
Algorithmic optimization of kernel, offline generation and look-up, multi-threaded parallel programming

Interference results

Simulation Parameters	Values
Environment Size	$10km \times 10km$
Number of gNBs	5, 10,15, 20, 25, 30, 35, 40
UE Locations (1600 Nos)	Every 250m in X and Y
gNB locations	Random
Tx Power (dBm)	40 dBm
CA Type	Single Band (n78)
DL:UL Ratio	4:1
Channel Bandwidth	100 MHz
Tx*Rx Antenna Count	1*1
Pathloss Model	3GPP
LOS Probability	1
Outdoor Scenario	Rural Macro
Interference	Exact Geometric Model

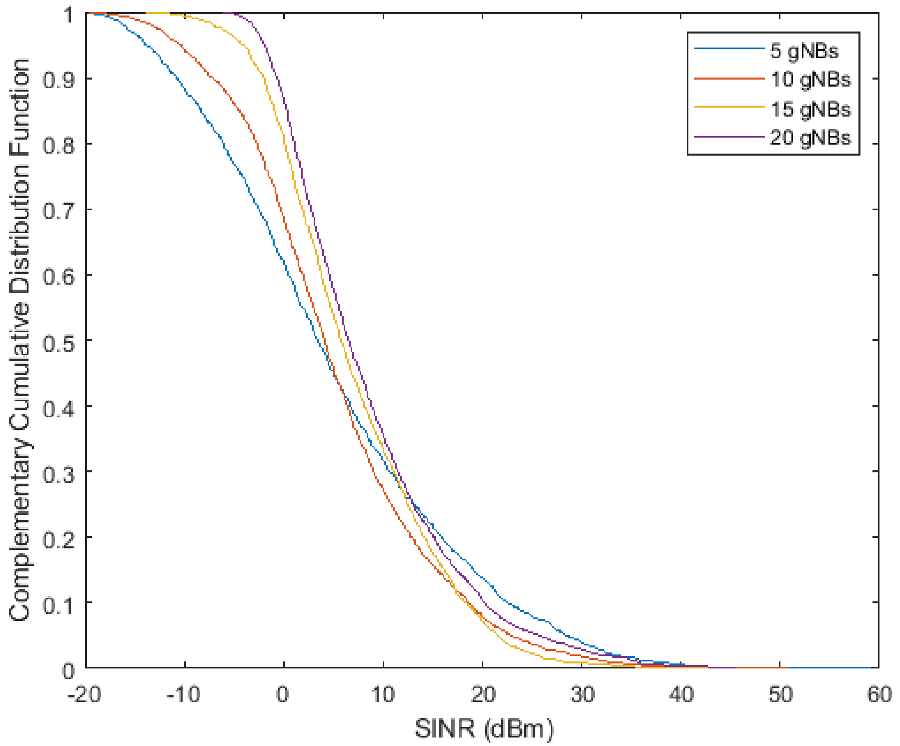
1600 UEs, 40 gNBs. Top: gNBs random, UEs uniform.
Bottom: gNBs random, UEs random. Highest SINR Association

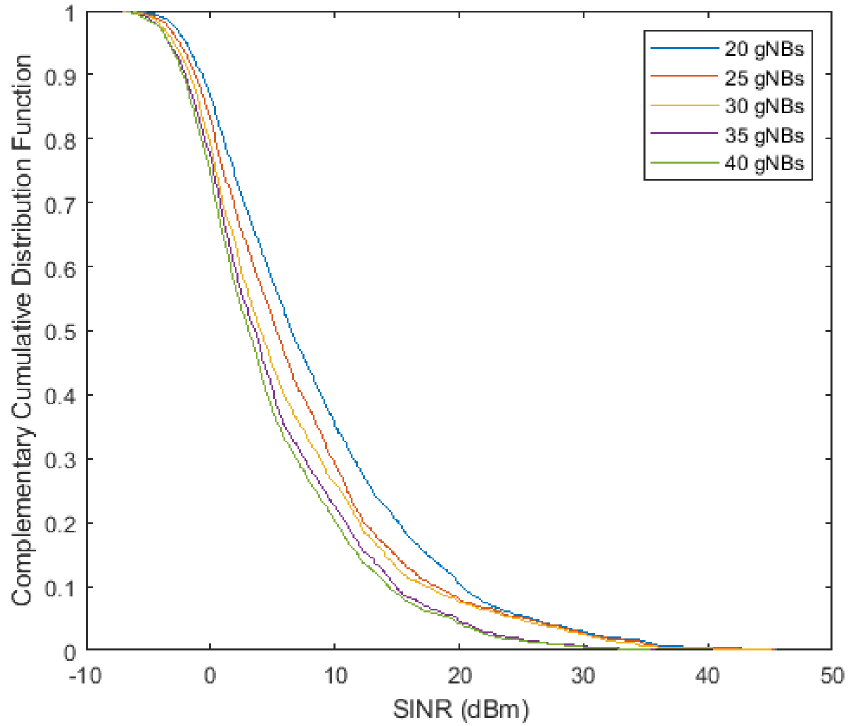




Results. gNBs Random, UEs uniform

Increasing trend (5 to 20 gNBs) decreasing trend (20 to 40 gNBs)



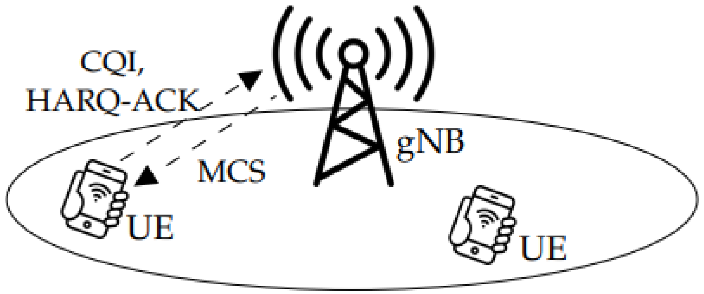


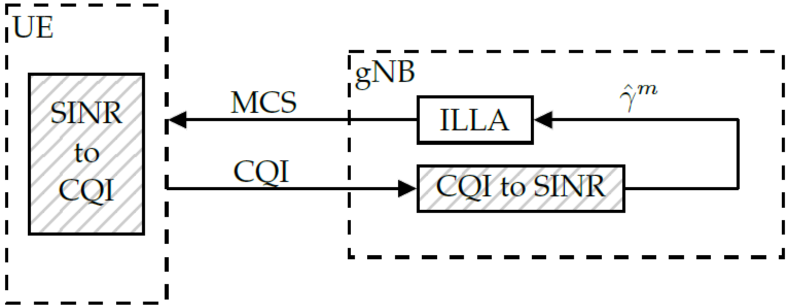
- Lesser gNBs give worse performance for lower SINR and better performance for higher SINR. This is due to very low interference
- As gNB count increases min SINR seen by UEs improve. However, Max SINR seen by UEs reduce. This is due to high interference

- Beyond 20 gNBs, increasing gNB count leads to performance degradation
- Min SINR, Max SINR and CCDF vs SINR falls as gNB count is increased
- <u>gNB count should be optimized for coverage. Maximizing will NOT lead to better coverage</u>

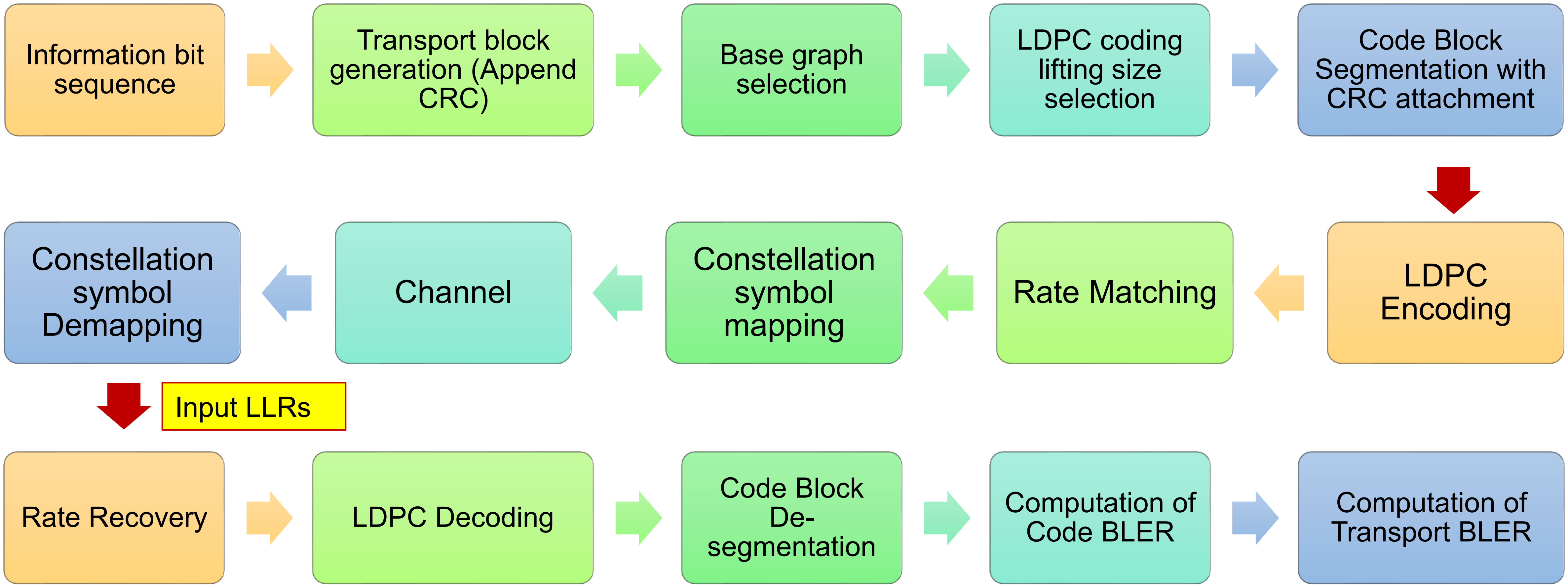
Link adaptation in NetSim

- Block error: NetSim hitherto modeled zero BLER (no error) assuming a "conservative" MCS selection.
- Goal was to allow users to set a target BLER (e.g., 10%).
- SINR-BLER curves in literature has many problems
  - Not available for table-3
  - Code block size not defined, and numbers don't comply with standards
  - Various assumptions made, and details hidden
  - Claims that codes are available online were incorrect
  - Authors did not respond to our emails soliciting additional information
- Therefore, the need to develop a custom program to generate the SINR-block error rate (BLER) lookup tables and verify
- A difficult problem requiring R & D from the ground up





Link level simulation using MATLAB

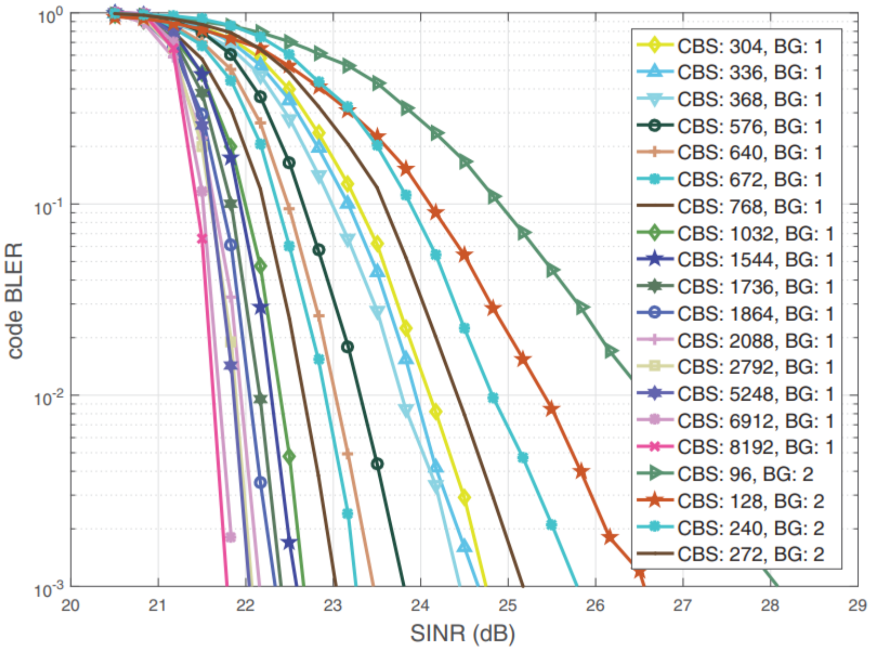


Generalized code for all tables and for all MCSs

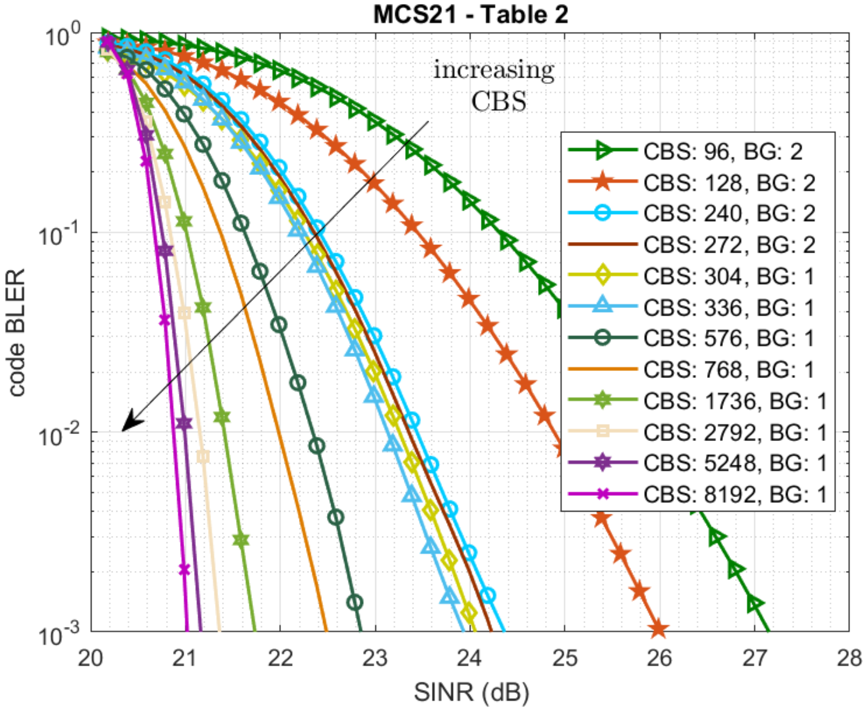
Simulator output

Code BLER vs SINR for MCS index 21 of Table 2

Results from "standard reference"



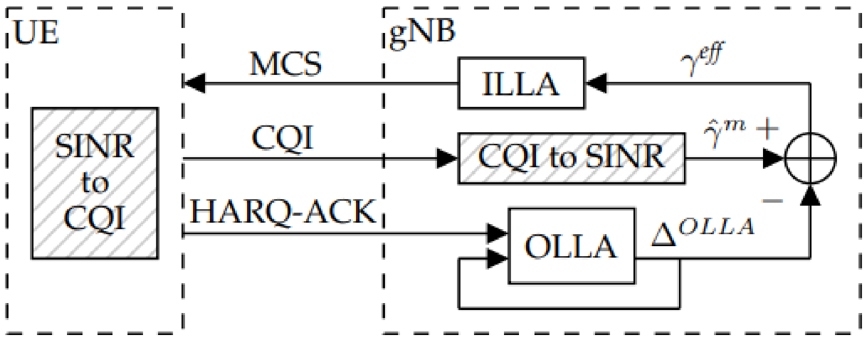
Results from "our program"



Results match well with the reference. Gap < 1 dB

Outer loop link adaptation

- Hence SINR-BLER data was generated using an in-house proprietary link-level simulation program.
  - The results were carefully validated against published literature.
  - BLER now looked up from SINR-BLER data tables
  - NetSim has exhaustive SINR-BLER data for various transport block sizes for all MCSs (1, 2, ..., 28) for Base graphs (1, 2) for all three tables (1, 2, 3). In total 28*3*2 = 168 files.
- Outer loop link adaptation:
  - Once the t-BLER is set an initial MCS is "guessed" (ILLA)
  - Subsequently, the MCS is dynamically adjusted based on an outer-loop link adaptation algorithm that uses HARQ ACK-NACK messages.



$$\Delta_{OLLA}(k) = \Delta_{OLLA}(k-1) + \Delta_{up} \times e(k) + \Delta_{down} \times (1 - e(k))$$

Where $e(k)$ s an indicator variable whose value is 0 for ACK and 1 for NACK

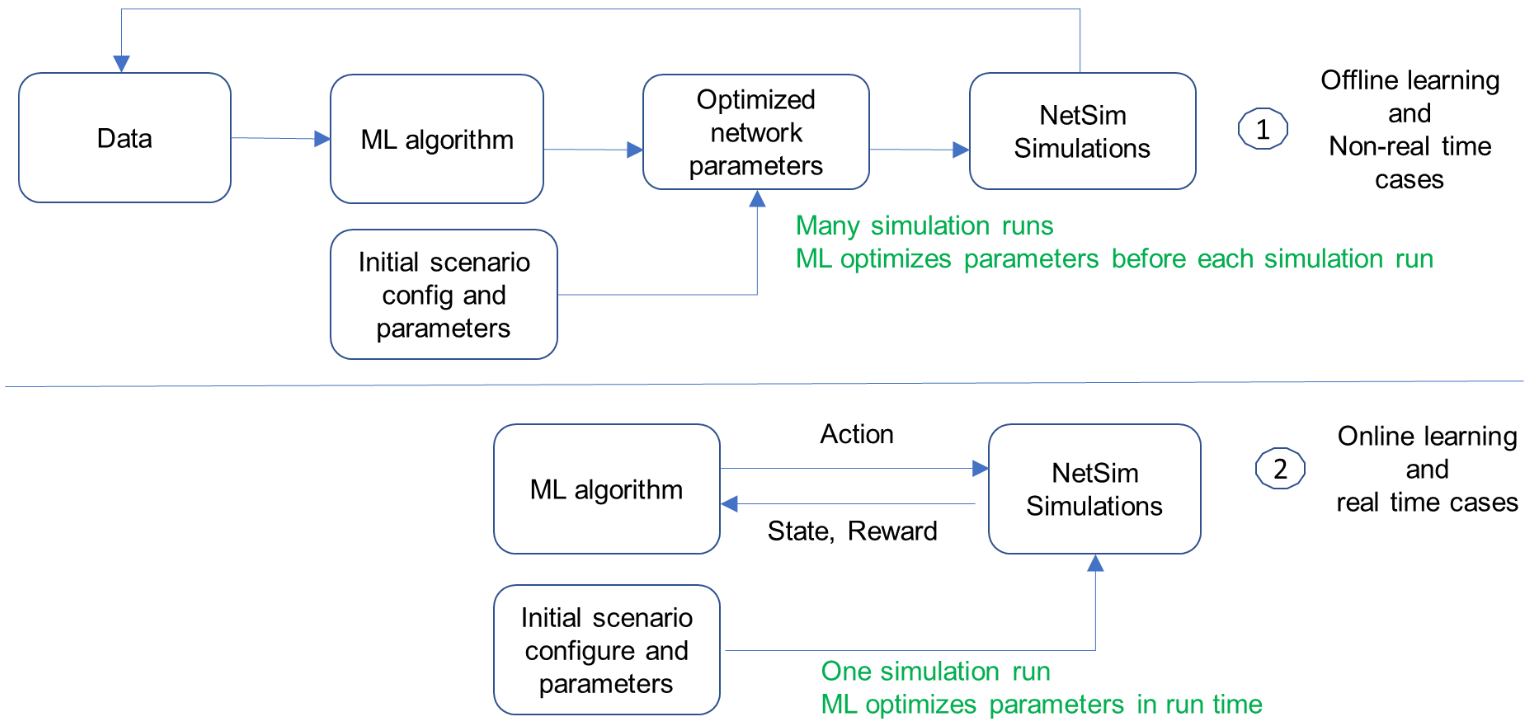
$$\gamma_{eff}(k,n) = \hat{\gamma}_m(k,a) - \Delta_{olla}(k,n)$$

$$BLER_T = \frac{1}{\left(1 + \frac{\Delta_{up}}{\Delta_{down}}\right)} \approx \frac{\Delta_{down}}{\Delta_{up}}$$

Convergence problems (i) non full buffer traffic (ii) high mobility

Dev roadmap and new challenges

- Network slicing
  - Dynamic slice configuration
- Uplink interference
- V2X
  - Sidelink, D2D
- ML: Simulator as a source of synthetic data for training real world algorithms
  - CSV data file for import using python keras or tf
  - Train DNN or GANs
- ML: Simulator as a test bed for validating your algorithm (see fig)
  - Online
  - Offline



Growing number of papers using ML with NetSim

Thank you

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