

Challenges in building a 5G simulator

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NetSim

www.tetcos.com

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Outline

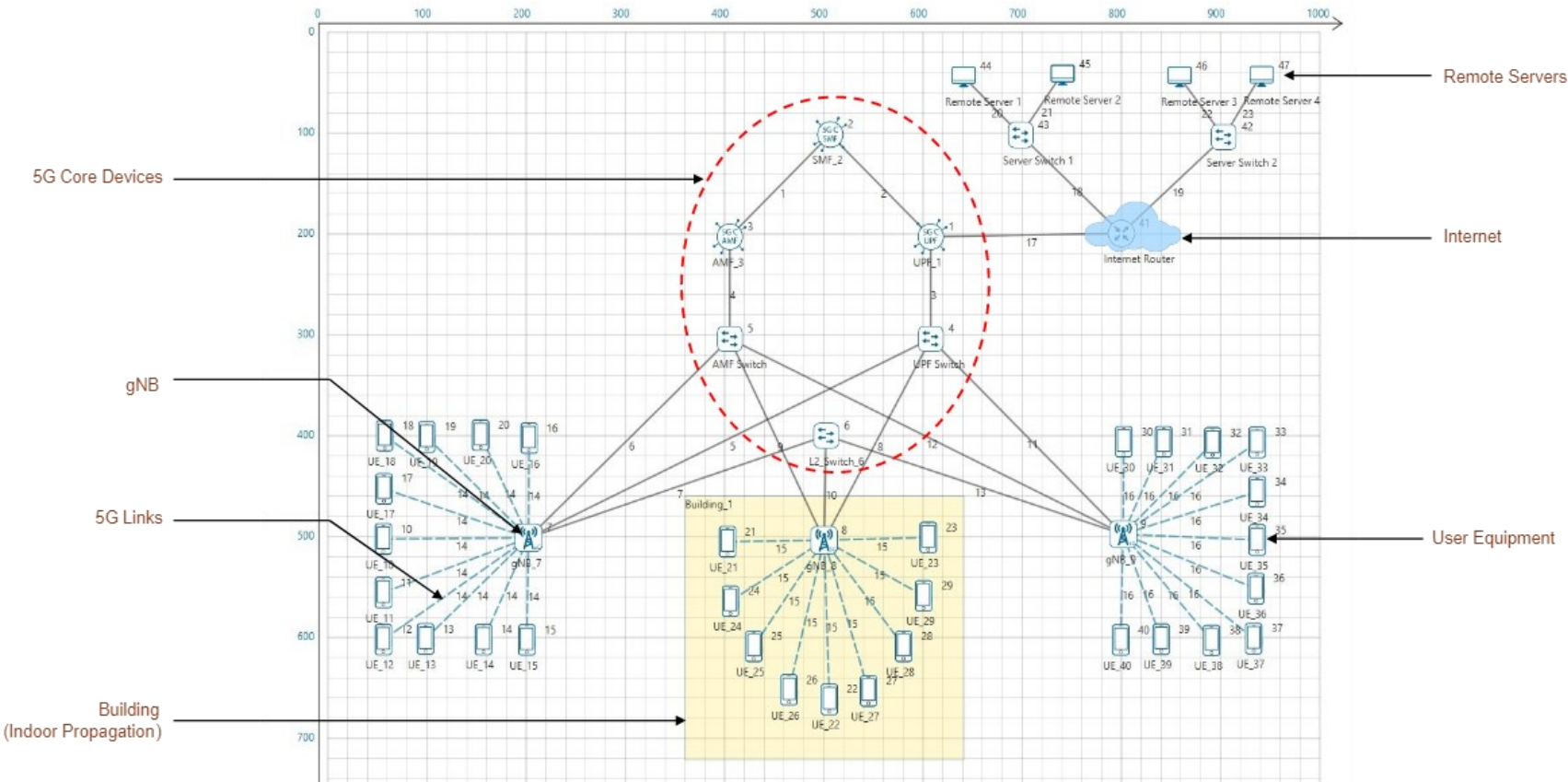
- NetSim 5G library
- Broad problems faced in:
 - Modeling and simulation
 - Testing
- Focus: Interference
 - Computational requirements
 - Results
- Focus: Outer loop links adaptation (OLLA)
 - Lack of published SINR BLER data
 - Building a proprietary link level simulator
 - Results
- Dev roadmap and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

NetSim 5G NR Design Window



Results

Tabular Output

Dynamic Metrics Plot

Source Data

Print

Reset Plot

Color Picker

Results Window

Packet & Event Trace

Log files

Plot Window

The screenshot shows the NetSim - Results interface with several components:

- Application_Metrics_Table** (Detailed View):

Application Name	Packet generated	Packet received	Throughput (Mbps)	Delay(microsec)
App1_CBR	3334	7	0.008176	109594.275714
App2_CBR	4281	1810	2.114080	496136.890486
App3_CBR	5000	1459	1.704332	3454587.691905
App4_CBR	4281	1926		
- TCP_Metrics_Table** (Detailed View):

Source	Destination	Segment Sent	Segment Received	Ack Sent	Ack Received	Duplicat
SERVER_1	ANY_DEVICE	0	0	0	0	0
SERVER_2	ANY_DEVICE	0	0	0	0	0
SERVER_3	ANY_DEVICE	0	0	0	0	0
- Link_Metrics_Table** (Detailed View):

Link_id	Link_throughput_plot	Packet_transmitted	Packet_received	Packet_drops
All	NA	35672	12709	42
1	Link throughput	20	10	0
2	Link throughput	5767	1479	8
3	Link throughput	4281	0	5
4	Link throughput	4272	0	10
5	Link throughput	1481	1479	2
6	Link throughput	4289	10	4
7	Link throughput	10055	1491	13
8	Link throughput	1919	1837	0
9	Link throughput	1556	4477	0
- NetSim - Plots** (Plot Settings):
 - Chart Title: Link_1_Throughput (Bi-directional)
 - X-Axis: Time (sec)
 - Y-Axis: Throughput (Mbps)
 - Grid Line:
 - Range: Auto Range
 - Plot Settings:
 - Instantaneous
 - Cumulative Moving Avg.
 - Time Avg.
- Link_1_Throughput (Bi-directional Aggregated)** Plot:

The plot shows throughput (Mbps) on the y-axis (0 to 10) and time (sec) on the x-axis (0 to 15). A green signal represents the instantaneous throughput, which starts at approximately 8 Mbps and rapidly decays to a noisy baseline around 4 Mbps. A red line represents the cumulative moving average, which smooths the signal and follows the same decay pattern.

Measurements and logs

Radio Measurements Log

Channels: PDSCH, PUSCH, SSB

UE-gNB Association, UE-gNB Distance

Propagation Loss, Pathloss, Shadow Fading

Rx Power, SINR, Interference Power, Beamforming Gain

CQI, MCS

UE ID	Channel	Association	Distance	Pathloss	SINR	Rx Power	Interference Power	Beamforming Gain	CQI	MCS
193014 UE_B	PDSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193017 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193020 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193023 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193026 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193029 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193032 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193035 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193038 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193041 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193044 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193047 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193050 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193053 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193056 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193059 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193062 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193065 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193068 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193071 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193074 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193077 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193080 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193083 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193086 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193089 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193092 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193095 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193098 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193101 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193104 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193107 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193110 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193113 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193116 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193119 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193122 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193125 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193128 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193131 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A
193134 UE_B	PUSCH	TRUE	1	108	N/A	-96.292206	7.5375	N/A	6.0206	N/A

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

NetSim 5G Data Files

NetSim 5G Data Files

Slot ID

gNB ID

Carrier ID

Available PRBs

UE ID

Allocated PRBs

Bits per PRB

PRB Allocation Log

Slot ID	gNB ID	Carrier ID	Available PRBs	UE ID	Allocated PRBs	Bits per PRB
20162	7	1	2	Downlink	116	1000.25
20163	7	1	2	Downlink	116	1000.25
20164	7	1	3	Uplink	46	1000.75
20165	7	1	3	Uplink	46	1000.5
20166	7	1	4	Uplink	46	1000.5
20167	7	2	3	Downlink	116	1000.5
20168	7	1	4	Downlink	43	1000.75
20169	7	2	4	Downlink	116	1000.75
20170	7	1	1	Uplink	46	1001
20171	7	1	1	Uplink	46	1001
20172	7	1	1	Uplink	46	1001
20173	7	2	1	Downlink	116	1001.25
20174	7	1	2	Downlink	43	1001.25
20175	7	2	2	Downlink	116	1001.25
20176	7	1	3	Uplink	46	1001.5
20177	7	1	3	Uplink	46	1001.5
20178	7	1	3	Uplink	46	1001.5
20179	7	2	3	Downlink	116	1001.5

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 event 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

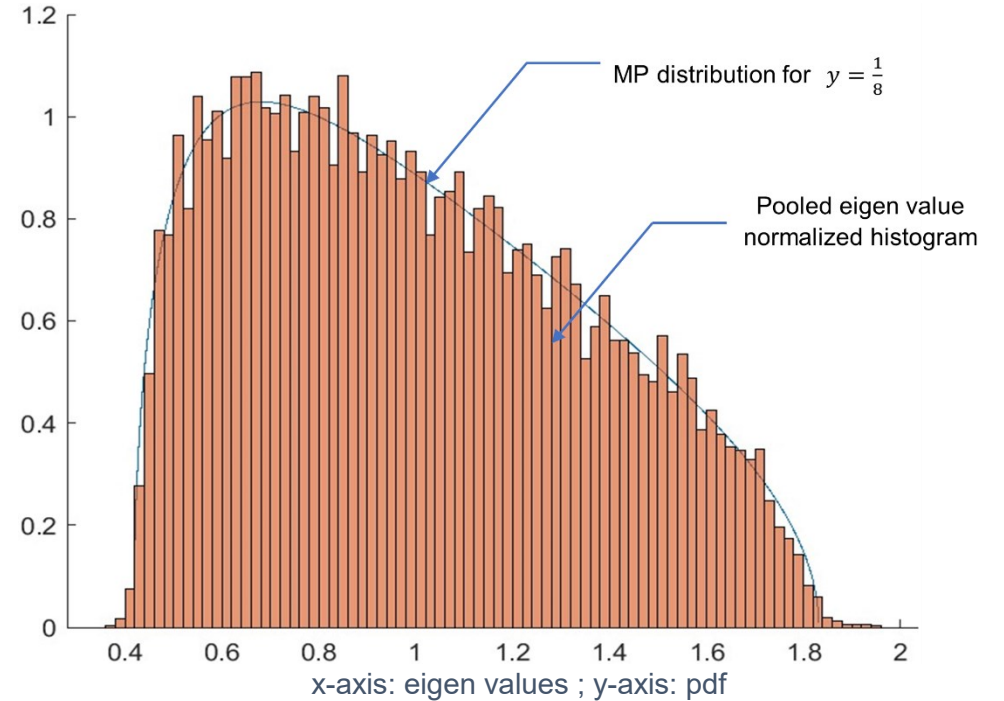
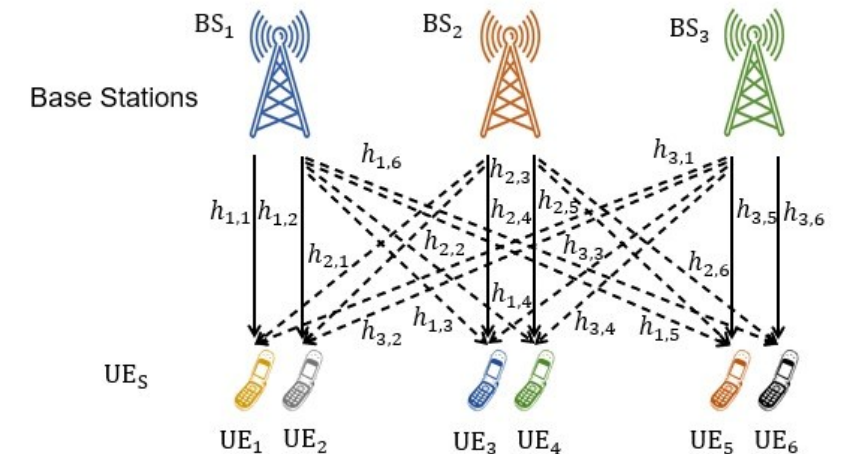


Fig: NetSim Results vs. Marchenko-Pastuer distribution for $N_r = 16$ and $N_t = 128$

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

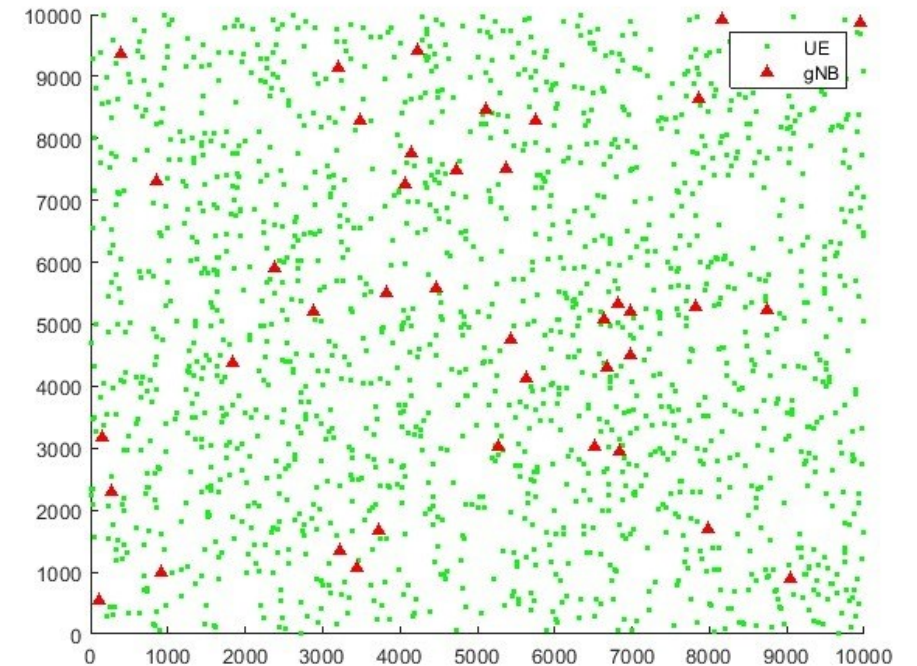
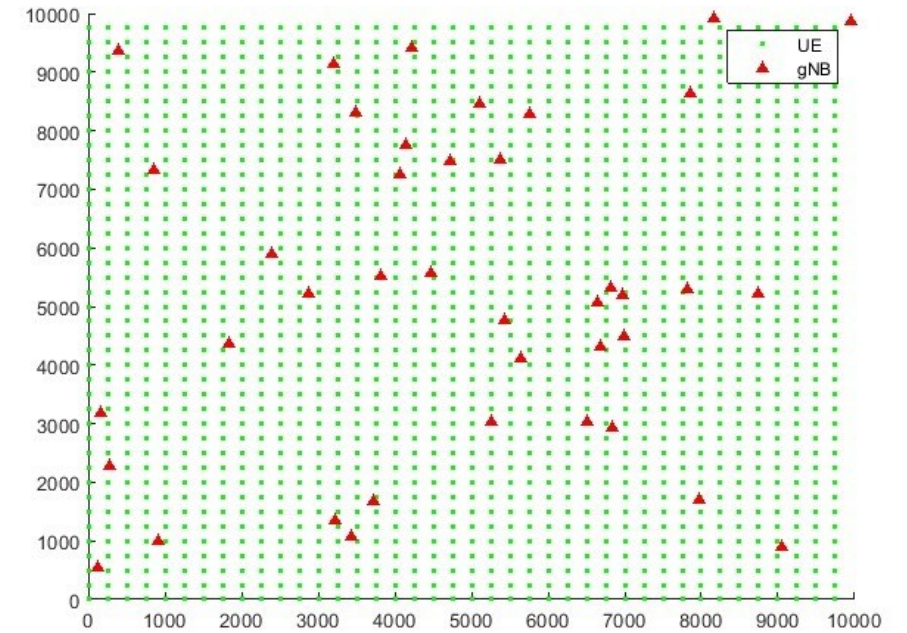
$$\text{SINR}_{ij} = \frac{\frac{P_{Tx}}{PL_{ij}} G_{ij}}{\sum_{k \neq i} \frac{P_{Tx}}{PL_{kj}} G_{kj} + BW \times N_0}$$



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

Interference results

Simulation Parameters	Values
Environment Size	10km × 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

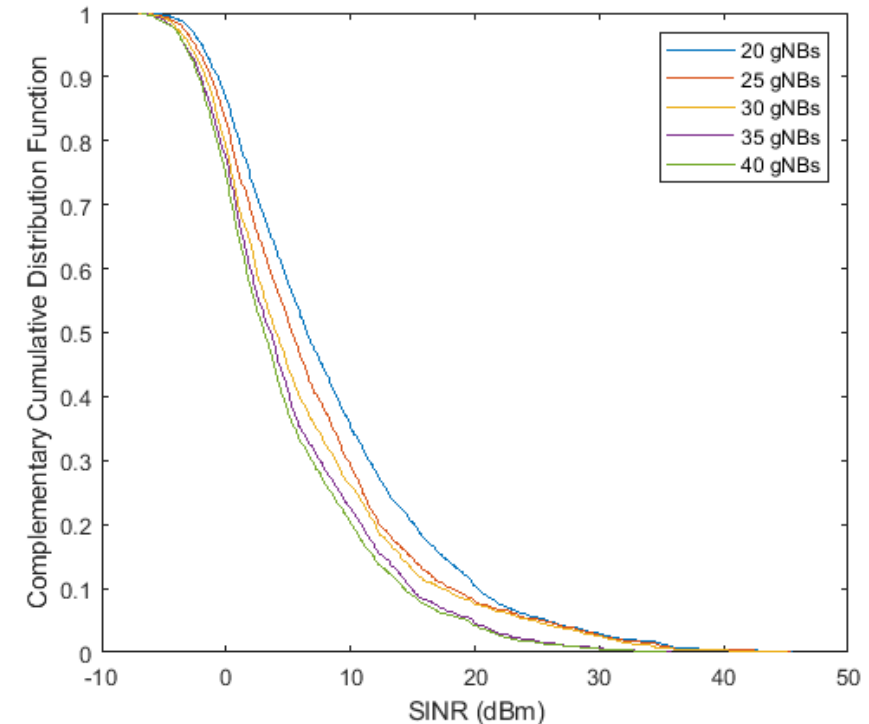
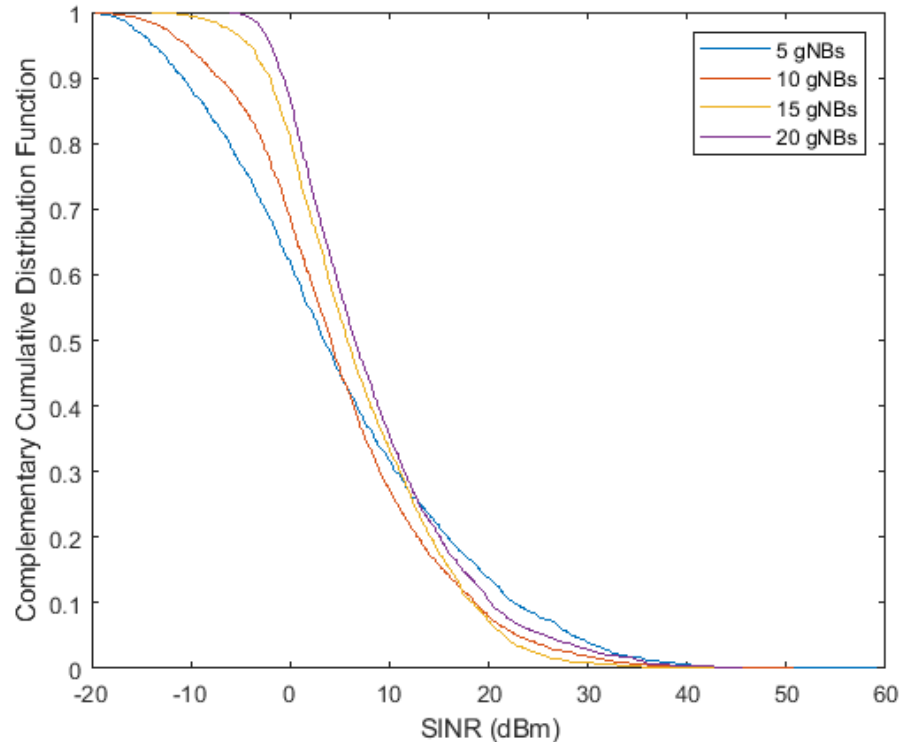


1600 UEs, 40 gNBs. Top: gNBs random, UEs uniform.

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)

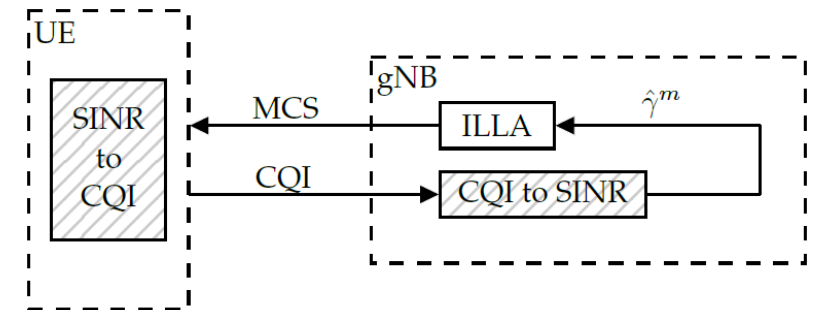
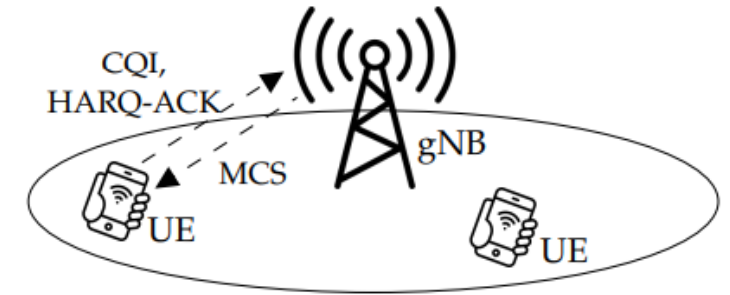


- Lesser gNBs give worse performance for lower SINR and better performance for higher SINR. This is due to very low interference
- As gNB count increases min SINR seen by UEs improve. However, Max SINR seen by UEs reduce. This is due to high interference

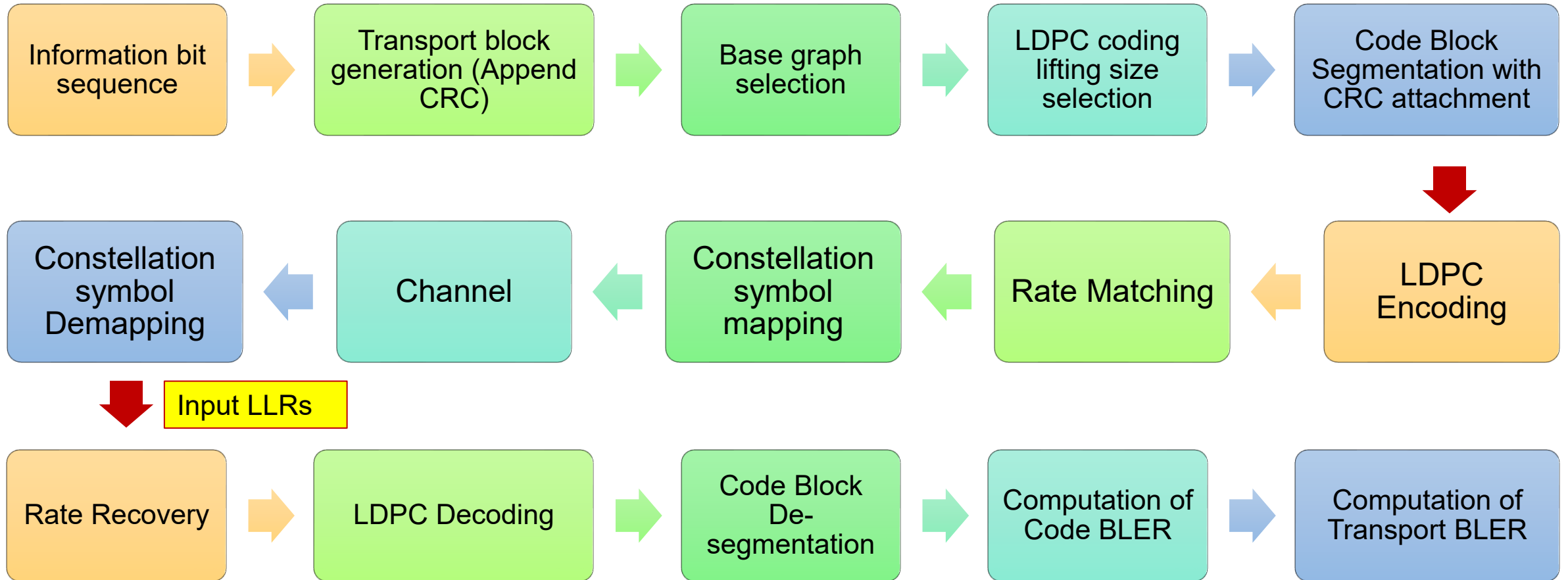
- Beyond 20 gNBs, increasing gNB count leads to performance degradation
- Min SINR, Max SINR and CCDF vs SINR falls as gNB count is increased
- gNB count should be optimized for coverage.
Maximizing will NOT lead to better coverage

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

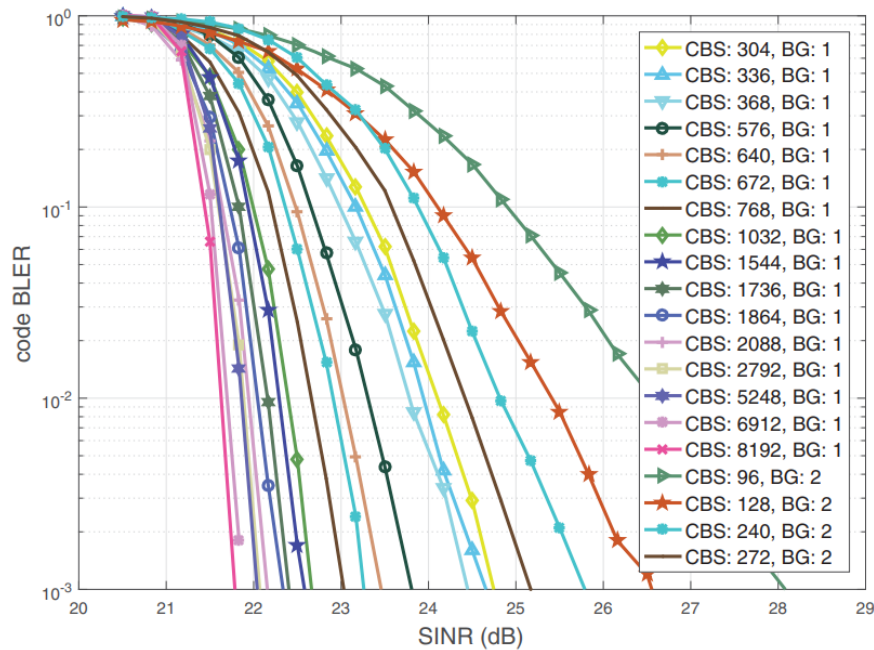


Generalized code for all tables and for all MCSs

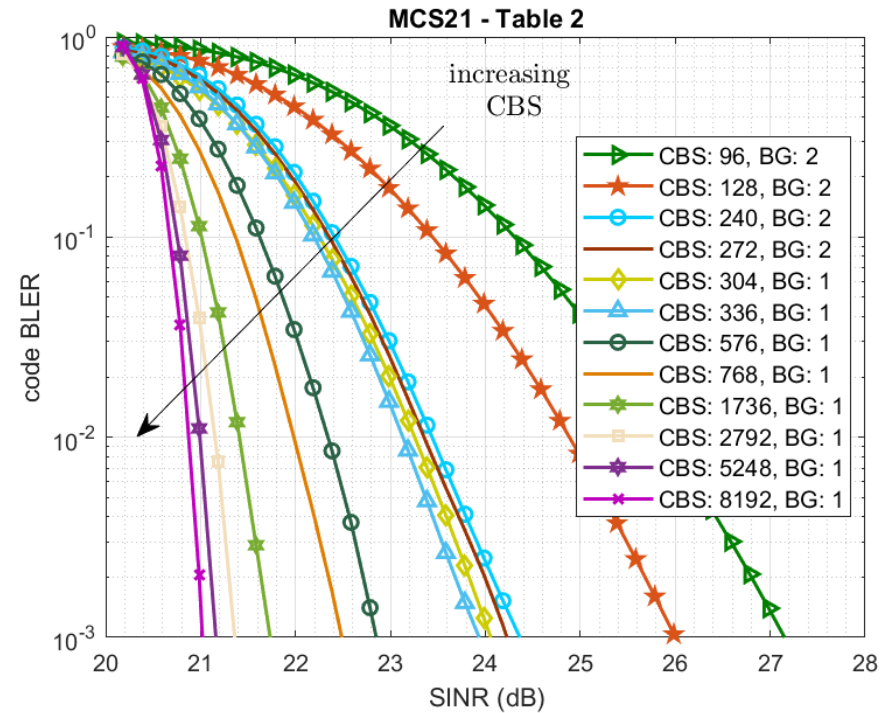
Simulator output

Code BLER vs SINR for MCS index 21 of Table 2

Results from “standard reference”



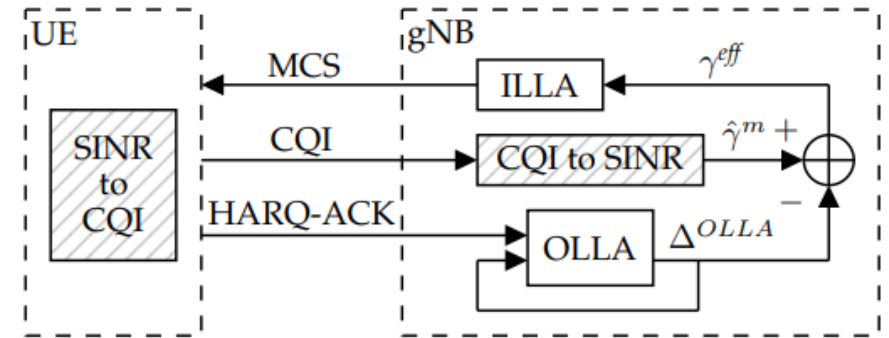
Results from “our program”



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 $28 \times 3 \times 2 = 168$ 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 $e(k)$ is an indicator variable whose value is 0 for ACK and 1 for NACK

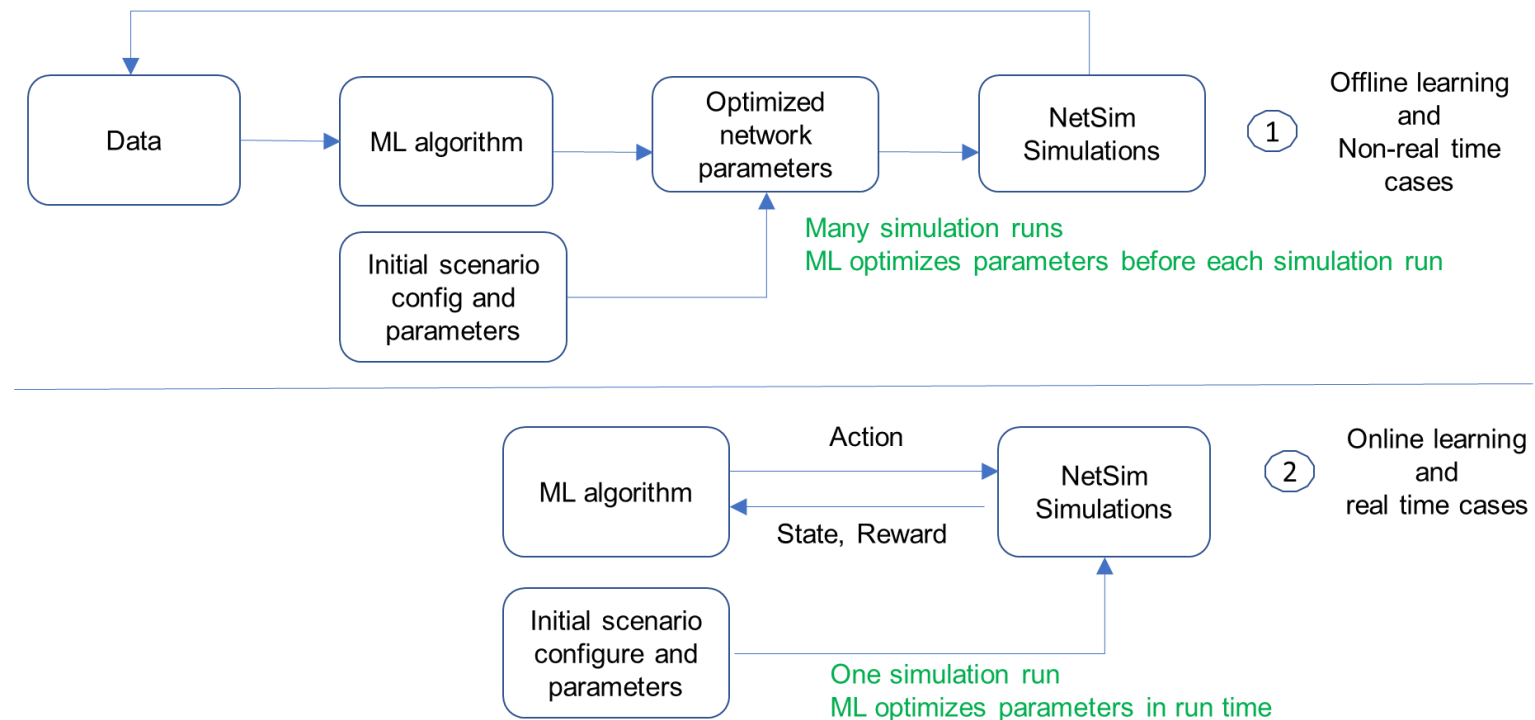
$$\gamma_{eff}(k, n) = \hat{\gamma}_m(k, a) - \Delta_{olla}(k, n)$$

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

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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