Predicting Interference in 5G Networks using NetSim

Objective

In this experiment, we will simulate and study the impact of downlink interference on the signal-to-interference ratio (SINR). We explore a simple case. A UE starts from BS_1 and moves in a straight line to BS_2. While the UE is attached to BS_1 it experiences interference from BS_2. Once it gets handed over to BS_2 the UE experiences interference from BS_1. There is always thus only one interferer, and we analyze the SINR as the UE moves a straight line from BS_1 to BS_2.

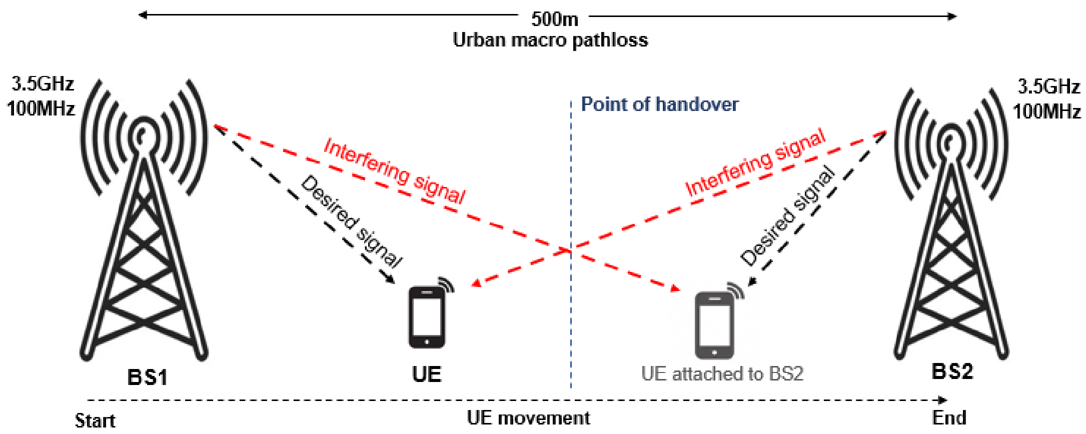


Fig 1: UE1 is initially attached to BS1. The signal from BS1 is the desired signal while the signal from BS2 is the interfering signal. Post-handover desired signal is transmitted from BS2 while signal from BS1 is the interfering signal. We assume omni-directional antennas at both BSs and consider cases when the UE is in line-of-sight (LOS) and in non-line-of-sight (NLOS)

Introduction[1]

Due to the scarcity of the wireless spectrum, it is not possible in 5G networks to separate concurrent transmissions completely in frequency. Some transmissions will necessarily occur at the same time in the same frequency band, separated only in space, and the signals from many undesired or interfering transmitters are added to the desired transmitter's signal at a receiver.

The main determinants of the interference are

- The network geometry i.e., the location of the receivers and the locations of the transmitters
- Base stations' (or gNBs') transmit power, and
- The path loss model (signal attenuation with distance).

The performance and coverage of a 5G network is critically depends on the signal-to-interference-and-noise ratios (SINRs) level at the receivers. This is defined as

$$SINR = \frac{P_r}{N_0 W + I}$$

[1] Some of the content in this section is from [1]

Where P_r is the received power of the desired signal, W is the bandwidth, N_0W is the thermal noise and I is the received power of interfering signals.

In 5G, the modulation and coding scheme (MCS) is computed from the SINR. Higher the SINR higher the MCS, and hence higher the date rate. Interference is therefore an important performance-limiting factor in wireless networks and hence it is crucial to exactly characterize interference.

Network setup: ISD = 500m, C Band, 100 MHz, Urban Macro.

In our network scenario, the inter-site distance (ISD) between BS_1 and BS_2 is 500m. Both base stations operate in the 3.5 GHz band, commonly called the C band, with a bandwidth of 100 MHz. The environment is assumed to be urban with signal attenuation per the 3G PP Urban Macro pathloss model. Shadow-fading and fast fading are turned off to avoid sources of randomness.

Case #1: No interference in both base stations with LOS

Procedure:

In this section we explain how users can run the simulation and obtain results that match those provided in the document

1. Use the following download Link to download the workspace https://github.com/NetSim-TETCOS/5G_Advanced_Experiments_v13_2_20/archive/refs/heads/main.zip
2. Go to NetSim Home window, go to Your Work and click on Import.

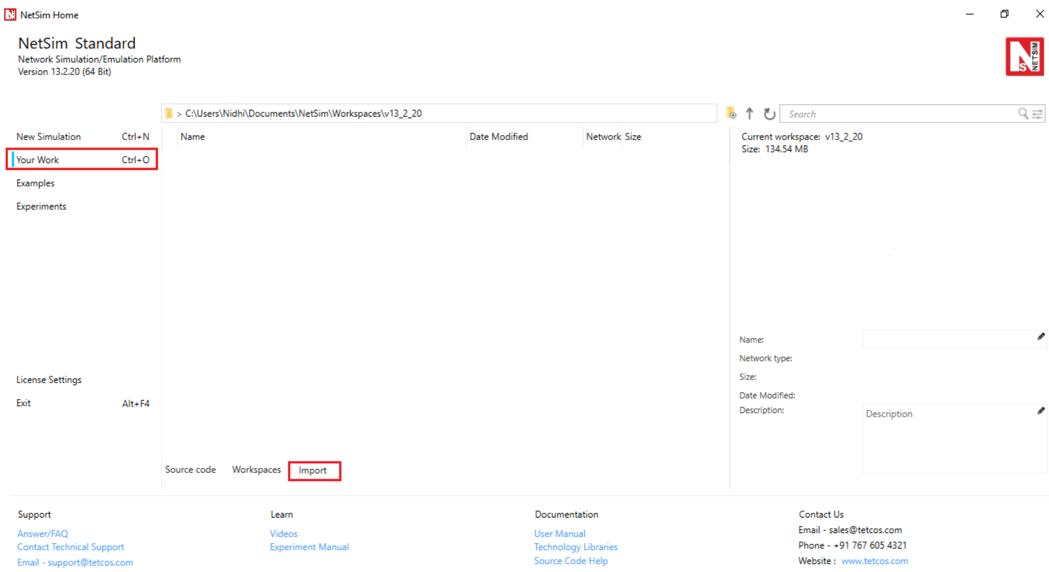


Fig 2: NetSim Home Window

3. In the Import Workspace Window, browse and select the Predicting_Interference_in_5G Networks_using_NetSim_v13.2.20.netsimexp file from the downloads. Click on create a new workspace option and browse to select a path in your system where you want to set up the workspace folder.
4. Choose a suitable name for the workspace of your choice. Click Import.

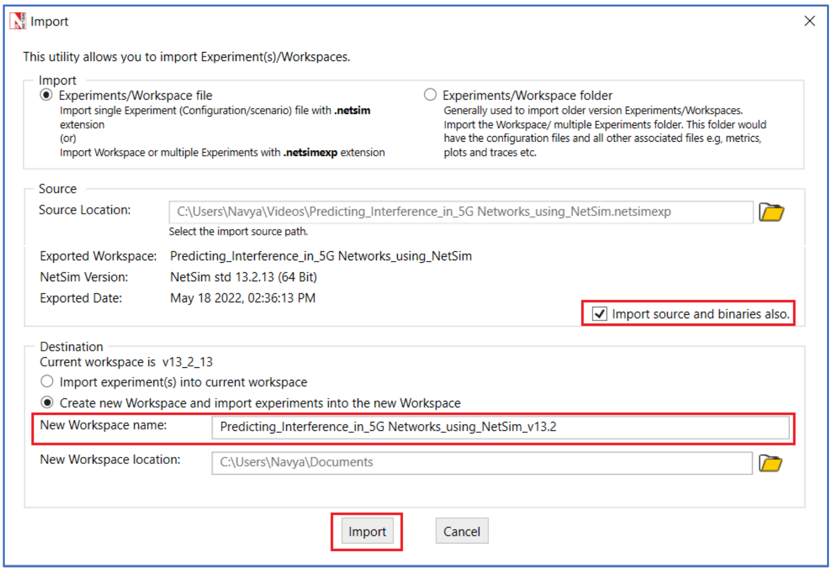


Fig 3: Import the downloaded workspace

5. The Imported Project workspace will automatically be set as the current workspace.
6. The list of experiments is now loaded onto the selected workspace.
7. The Experiments/ configuration files associated with the case mentioned above are available in the folder "ISD_500m_C-Band" inside the workspace.

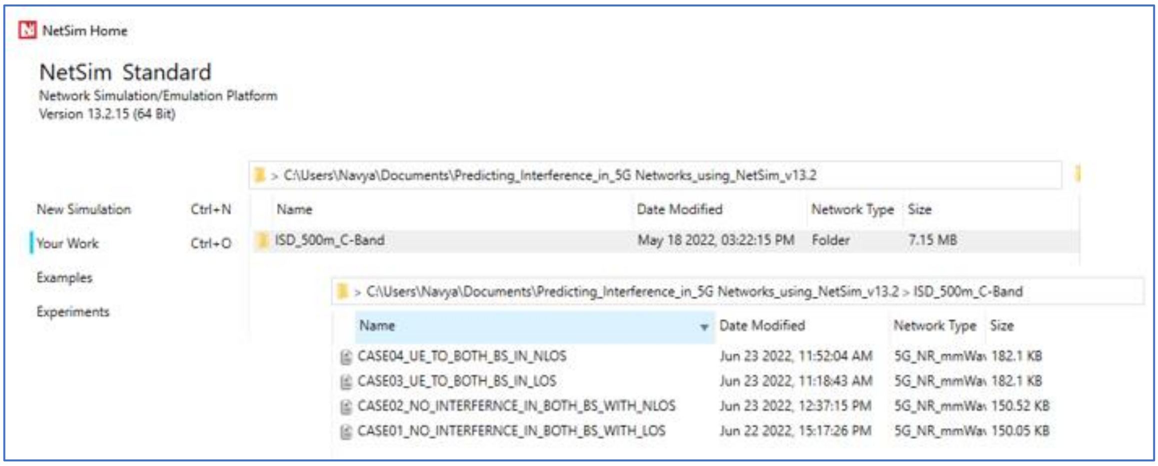


Fig 4: NetSim your work window with list of cases for ISD 500m C-band.

Network Scenario

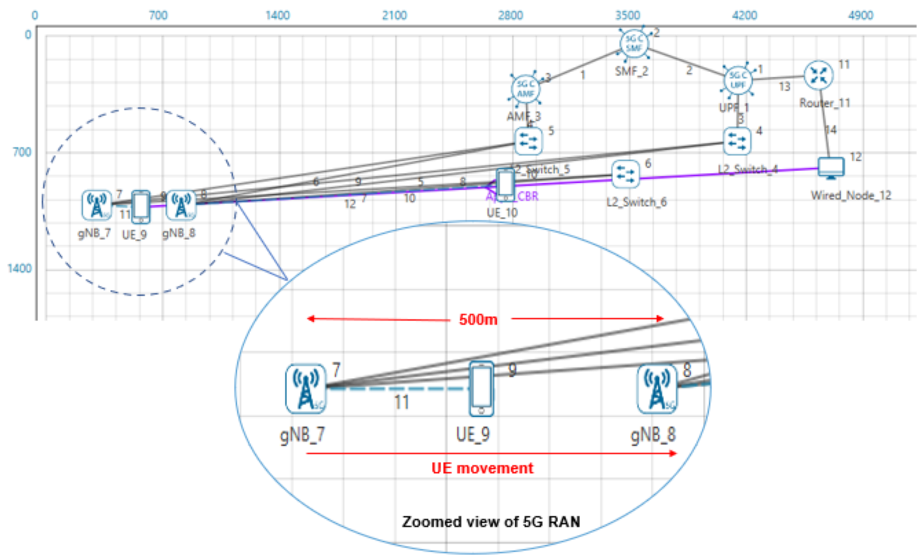


Fig 5: NetSim Scenario.

Simulation parameters:

Consider the grid environment as 7000m. Place the two gNBs on the grid environment. Distance between two gNBs is 500m.

Devices	X	Y
gNB_8	800	1000
gNB_7	300	1000
UE_9	300	1000
UE_10	300	1500

Table 1:Device Co-ordinates

Go to gNB properties. In the RAN interface set physical layer properties as shown in the below table. Similarly set the same properties in another gNB.

gnb> Interface 5G RAN	
gNB Height (m)	10
Tx Power (dBm)	40dBm
Tx Antenna Count	1
Rx Antenna Count	1
CA Type	Single Band
CA Configuration	n78 (C Band)
F_Low (MHz)	3300
F_High (MHz)	3800
DL: UL Ratio	4:1
Numerology	2
Channel Bandwidth (MHz)	100MHZ
MCS Table	QAM64
CQI Table	TABLE1
Outdoor Scenario	Urban Macro
Indoor Office Type	Mixed Office
Path loss Model	3GPPTR38.901-7.4.1
LOS Mode	User Defined
LOS probability	1

Shadow Fading Model	None
Fading and Beamforming	No Fading
O2I Building Penetration Model	None
Downlink interference model	No interference

Table 2: Values set for different parameters in simulation

Go to UE properties. In the RAN Interface set physical layer properties in both UE's as shown below.

UE > Interface 5G RAN	
UE Height	1.50
Tx Power	23 dBm
Tx Antenna Count	1
Rx Antenna Count	1

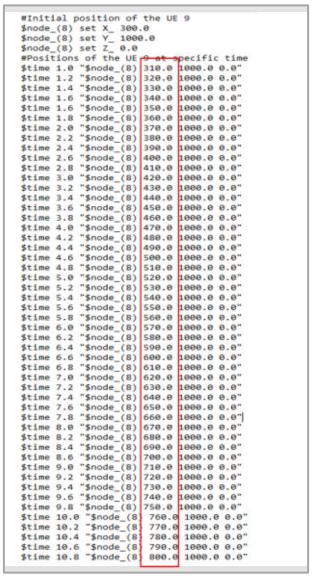
Table 3: Properties set for UE

In the General layer, set UE X and Y coordinates of gNB X and Y coordinates. The initial position of UE must be the position of gNB1.

Set the mobility model as file-based mobility and configure the mobility that UE needs to be travel straight towards to the gNB2. So, configure the mobility file according to the distance that UE needs to travel

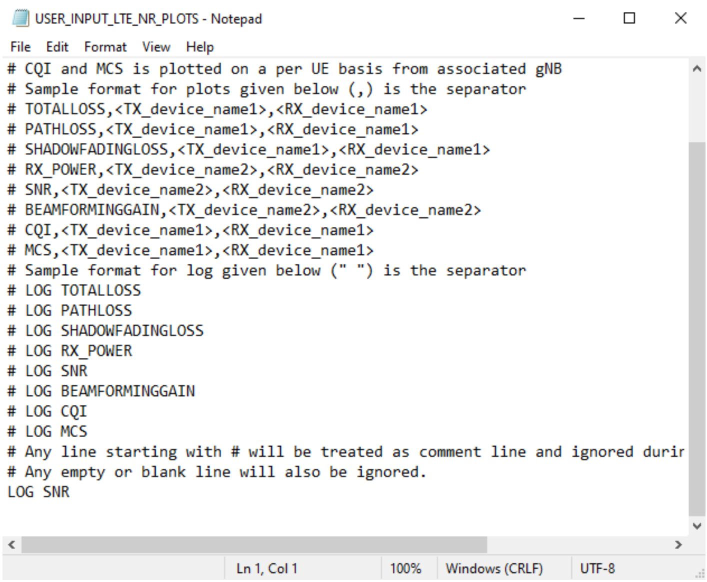
For example, in the above scenario 500m case, UE needs to travel 500m from gNB1 to gNB2 So, it is travelling straight towards to another gNB since it's Y coordinates is fixed.

Run the Simulation 12s. Upon running the simulation, a text file will open for the user to input the parameters and devices (tx-rx pair) for which parameters need to be logged and plotted. Give input as shown in **Error! Reference source not found.**



```
#Initial position of the UE 9
$node_(8) set X_ 300.0
$node_(8) set Y_ 1000.0
$node_(8) set Z_ 0.0
#Positions of the UE 9 at specific time
$time 1.0 "$node_(8) 310.0 1000.0 0.0"
$time 1.2 "$node_(8) 320.0 1000.0 0.0"
$time 1.4 "$node_(8) 330.0 1000.0 0.0"
$time 1.6 "$node_(8) 340.0 1000.0 0.0"
$time 1.6 "$node_(8) 350.0 1000.0 0.0"
$time 1.8 "$node_(8) 360.0 1000.0 0.0"
$time 2.0 "$node_(8) 370.0 1000.0 0.0"
$time 2.2 "$node_(8) 380.0 1000.0 0.0"
$time 2.4 "$node_(8) 390.0 1000.0 0.0"
$time 2.6 "$node_(8) 400.0 1000.0 0.0"
$time 2.8 "$node_(8) 410.0 1000.0 0.0"
$time 3.0 "$node_(8) 420.0 1000.0 0.0"
$time 3.2 "$node_(8) 430.0 1000.0 0.0"
$time 3.4 "$node_(8) 440.0 1000.0 0.0"
$time 3.6 "$node_(8) 450.0 1000.0 0.0"
$time 3.8 "$node_(8) 460.0 1000.0 0.0"
$time 4.0 "$node_(8) 470.0 1000.0 0.0"
$time 4.2 "$node_(8) 480.0 1000.0 0.0"
$time 4.4 "$node_(8) 490.0 1000.0 0.0"
$time 4.6 "$node_(8) 500.0 1000.0 0.0"
$time 4.8 "$node_(8) 510.0 1000.0 0.0"
$time 5.0 "$node_(8) 520.0 1000.0 0.0"
$time 5.2 "$node_(8) 530.0 1000.0 0.0"
$time 5.4 "$node_(8) 540.0 1000.0 0.0"
$time 5.6 "$node_(8) 550.0 1000.0 0.0"
$time 5.8 "$node_(8) 560.0 1000.0 0.0"
$time 6.0 "$node_(8) 570.0 1000.0 0.0"
$time 6.2 "$node_(8) 580.0 1000.0 0.0"
$time 6.4 "$node_(8) 590.0 1000.0 0.0"
$time 6.6 "$node_(8) 600.0 1000.0 0.0"
$time 6.8 "$node_(8) 610.0 1000.0 0.0"
$time 7.0 "$node_(8) 620.0 1000.0 0.0"
$time 7.2 "$node_(8) 630.0 1000.0 0.0"
$time 7.4 "$node_(8) 640.0 1000.0 0.0"
$time 7.6 "$node_(8) 650.0 1000.0 0.0"
$time 7.8 "$node_(8) 660.0 1000.0 0.0"
$time 8.0 "$node_(8) 670.0 1000.0 0.0"
$time 8.2 "$node_(8) 680.0 1000.0 0.0"
$time 8.4 "$node_(8) 690.0 1000.0 0.0"
$time 8.6 "$node_(8) 700.0 1000.0 0.0"
$time 9.0 "$node_(8) 710.0 1000.0 0.0"
$time 9.2 "$node_(8) 720.0 1000.0 0.0"
$time 9.4 "$node_(8) 730.0 1000.0 0.0"
$time 9.6 "$node_(8) 740.0 1000.0 0.0"
$time 9.8 "$node_(8) 750.0 1000.0 0.0"
$time 10.0 "$node_(8) 760.0 1000.0 0.0"
$time 10.2 "$node_(8) 770.0 1000.0 0.0"
$time 10.4 "$node_(8) 780.0 1000.0 0.0"
$time 10.6 "$node_(8) 790.0 1000.0 0.0"
$time 10.8 "$node_(8) 800.0 1000.0 0.0"
```

Fig 6: UE mobility file for 500m




```
# CQI and MCS is plotted on a per UE basis from associated gNB
# Sample format for plots given below (,) is the separator
# TOTALLOSS,<TX_device_name1>,<RX_device_name1>
# PATHLOSS,<TX_device_name1>,<RX_device_name1>
# SHADOWFADINGLOSS,<TX_device_name1>,<RX_device_name1>
# RX_POWER,<TX_device_name2>,<RX_device_name2>
# SNR,<TX_device_name2>,<RX_device_name2>
# BEAMFORMINGGAIN,<TX_device_name2>,<RX_device_name2>
# CQI,<TX_device_name1>,<RX_device_name1>
# MCS,<TX_device_name1>,<RX_device_name1>
# Sample format for log given below (" ") is the separator
# LOG TOTALLOSS
# LOG PATHLOSS
# LOG SHADOWFADINGLOSS
# LOG RX_POWER
# LOG SNR
# LOG BEAMFORMINGGAIN
# LOG CQI
# LOG MCS
# Any line starting with # will be treated as comment line and ignored durir
# Any empty or blank line will also be ignored.
LOG SNR
```

Fig 7: Input file for logging and plotting

After simulation, open 5G_Prameter_Log present under the Log files section in Result Dashboard.

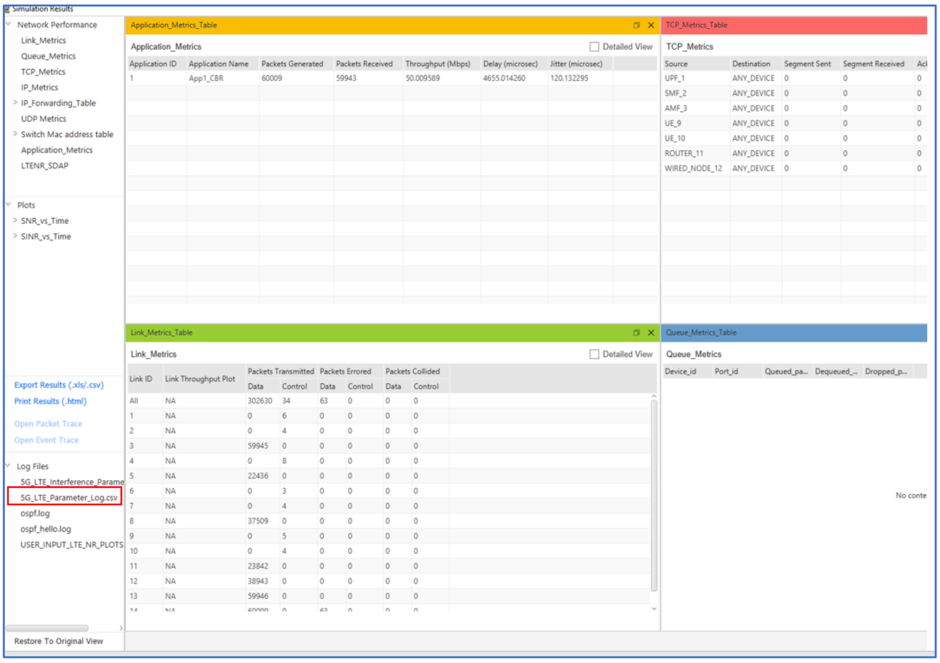
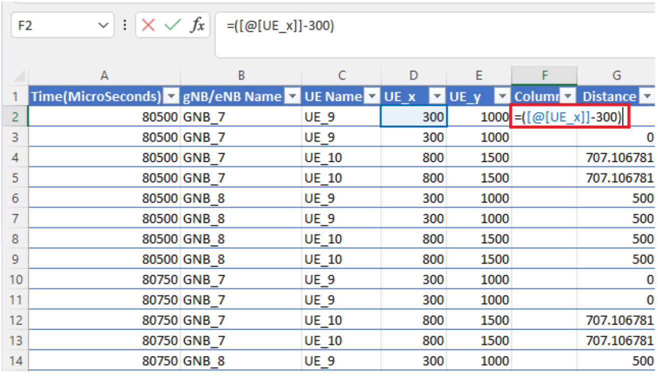


Fig 8: ISD 500m simulation result Dashboard

In the log file create one more column after UE_y column and enter the formula in first row of that log file as shown in **Error! Reference source not found.** and create a pivot table for this log file by clicking the pivot option present at the top of the ribbon under insert section as



F2 =([@[UE_x]]-300)

	Time(MicroSeconds)	gNB/eNB Name	UE Name	UE_x	UE_y	Columr	Distance
2	80500	GNB_7	UE_9	300	1000	=([@[UE_x]]-300)	
3	80500	GNB_7	UE_9	300	1000		0
4	80500	GNB_7	UE_10	800	1500		707.106781
5	80500	GNB_7	UE_10	800	1500		707.106781
6	80500	GNB_8	UE_9	300	1000		500
7	80500	GNB_8	UE_9	300	1000		500
8	80500	GNB_8	UE_10	800	1500		500
9	80500	GNB_8	UE_10	800	1500		500
10	80750	GNB_7	UE_9	300	1000		0
11	80750	GNB_7	UE_9	300	1000		0
12	80750	GNB_7	UE_10	800	1500		707.106781
13	80750	GNB_7	UE_10	800	1500		707.106781
14	80750	GNB_7	UE_9	300	1000		500

Fig 9: 5G LTE Parameter log file

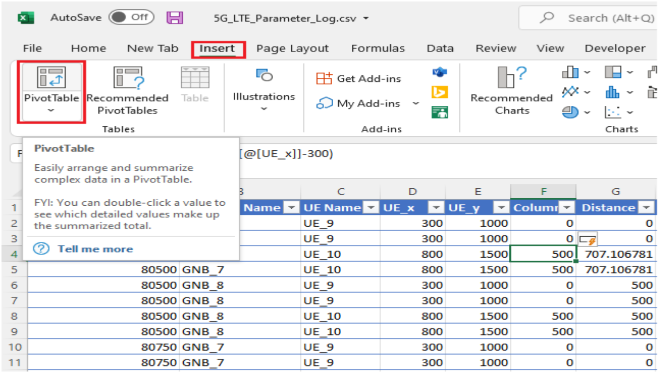


Fig 10: Inserting pivot table

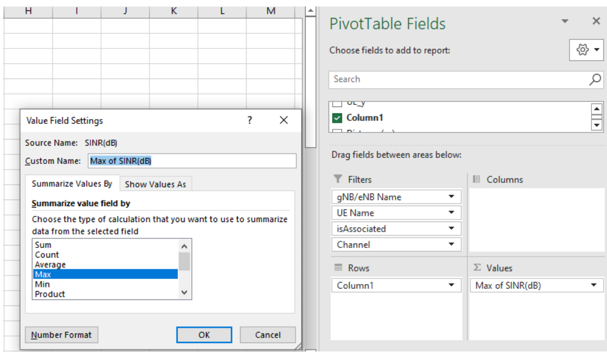


Fig 11: Creating pivot table

shown in **Error! Reference source not found.**

In the pivot table drop gNB/eNB Name, UE Name, Channel and IsAssociated field under filters area, drop column1 in Row area and drop SINR in Value area. set SINR values to max by clicking arrow icon present end of the field ->value filed setting->max as shown below as shown in **Error! Reference source not found.**

Now filter gNB as gNB7, UE name as UE_9, Channel as PDSCH and IsAssociated as TRUE as shown in **Error! Reference source not found.**.

Copy the values from 0 to 280 along with Row Labels and Max_SINR_dB header and paste it into another sheet. Similarly filter gNB/eNB name to GNB_8 and copy the row label value along with SINR and paste it into next to 280 in previously created new sheet as shown in **Error! Reference source not found.**.

gNB/eNB Name	GNB_7
UE Name	UE_9
isAssociated	TRUE
Channel	PDSCH

Row Labels	Max of SINR(dB)
0	70.225638
10	70.225638
20	65.407497
30	61.957832
50	57.309944
60	55.609134
70	54.161307
80	52.901781
90	51.787631
100	50.788998
110	49.88431
120	49.057492
130	48.296255
140	47.590995
150	46.934066
160	46.319286
170	45.741585
180	45.196753
190	44.681258
200	44.192108
210	43.726744

Fig 12: SINR values for 500m

Row Labels	Max of SINR(dB)
0	70.225638
10	70.225638
20	65.407497
30	61.957832
50	57.309944
60	55.609134
70	54.161307
80	52.901781
90	51.787631
100	50.788998
140	47.590995
150	46.934066
160	46.319286
240	41.521104
250	40.812806
260	40.132229
270	39.477287
280	38.846119
280	43.030578
290	43.726744
300	44.192108
340	46.319286
350	46.934066
480	65.407497
490	70.225638
500	70.225638

Fig 13: Downlink SINR results for ISD-500m

Case #2: No interference in both base stations with NLOS

gNB7 > Interface 5G RAN	
LOS Mode	User Defined
LOS probability	0
Downlink Interference	No Interference
gNB 8 > Interface 5G RAN	
LOS Mode	User Defined
LOS probability	0
Downlink interference	No Interference

Table 4: Properties set for Case02

Set the above property changes and simulate the scenario for 15 sec. Tabulate the results obtained from 5G_Prameter_Log in simulation metrics window.

Case #3: UE to Both Base stations is in LOS

gNB7 > Interface 5G RAN	
LOS Mode	User Defined
LOS probability	1
Downlink Interference	Exact geometric model
gNB 8 > Interface 5G RAN	
LOS Mode	User Defined
LOS probability	1
Downlink interference	Exact geometric model

Table 5: Properties set for Case03

Set the above property changes and simulate the scenario for 12 sec. Tabulate the results obtained from 5G_Prameter_Log in simulation metrics window.

Case #4: UE to Both Base stations is in NLOS

gNB7 > Interface 5G RAN	
LOS Mode	User Defined
LOS probability	0
Downlink Interference	Exact geometric model
gNB 8 > Interface 5G RAN	
LOS Mode	User Defined
LOS probability	0
Downlink interference	Exact geometric model

Table 6:Properties set for Case04

Set the above property changes and simulate the scenario for 12 sec. Tabulate the results obtained from 5G_Prameter_Log in simulation metrics window

Results. UE in LOS and NLOS

Distance	Case #2 DL SINR (dB)	Case #3 DL SINR (dB)	Case #4 DL SINR (dB)
0	65.59	41.44	60.27
10	65.59	41.09	60.03
20	57.03	35.91	51.21
30	50.90	32.10	44.82
50	42.65	26.7	35.99
60	39.62	24.61	32.67
70	37.05	22.76	29.79
80	34.82	21.09	27.22
90	32.84	19.56	24.90
100	31.06	18.13	22.77
110	29.46	16.79	20.80
120	27.99	15.51	18.95
130	26.63	14.29	17.20
140	25.38	13.11	15.53
150	24.21	11.96	13.93
160	23.12	10.84	12.39
170	22.10	9.75	10.90
180	21.13	8.67	9.45
190	20.21	7.6	8.03
200	19.34	6.54	6.63
210	18.52	5.49	5.26
220	17.73	4.18	3.90
230	16.98	2.78	2.56
240	16.25	1.39	1.22
250	15.56	0	-0.12
260	14.90	-1.39	-1.46
270	14.26	-2.78	-2.80
280	13.64	-4.18	-4.16
280	17.73	4.18	3.90
290	18.52	5.49	5.26
300	19.34	6.54	6.63
310	20.21	7.6	8.03
320	21.13	8.67	9.45
330	22.10	9.75	10.90
340	23.12	10.84	12.39
350	24.21	11.96	13.93
360	25.38	13.11	15.53
370	26.63	14.29	17.20
380	27.99	15.51	18.95
390	29.46	16.79	20.80
400	31.06	18.13	22.77
410	32.84	19.56	24.90
420	34.82	21.09	27.22

430	37.05	22.76	29.79	470	50.90	32.10	44.82
440	39.62	24.61	32.67	480	57.03	35.91	51.21
450	42.65	26.7	35.99	490	65.59	41.09	60.03
460	46.30	29.14	39.94	500	65.59	41.44	60.27

Table 7: Results for SINR vs. distance for ISD-500m downlink.

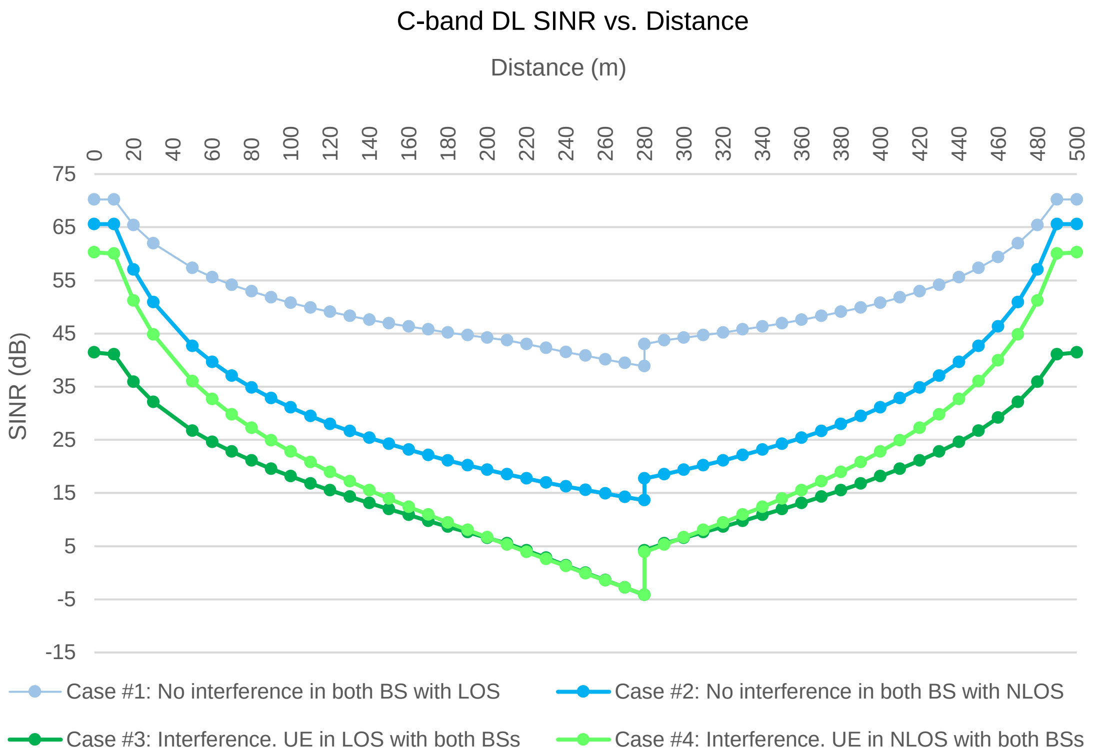


Fig 14: Downlink SINR vs. distance plot for C-band for different network configurations.

Discussion

Initially, the UE is attached to BS_1. In the scenario, the UE moves in a straight line towards BS_2 and at 280m it is handed over to BS_2. Till 280m the "desired" signal is from BS_1 while the "interfering" signal is from BS_2. Post-handover there is a reversal; the desired signal is from BS_2 while the interfering signal is from BS_1.

Signals from BS_1 and from BS_2 to the UE undergoes pathloss. If the transmit powers at both BSs are P_t then the $SINR$ comes out to be

$$SINR = \frac{P_t \times PL(d)}{N_0 \times W + P_t \times PL(d_{ISD} - d)}$$

Where $PL(d)$ is the pathloss loss (per the 3GPP pathloss models) at a distance of d. Since the distance between the two BSs is equal to d_{ISD}, the inter site distance, the UE is at a distance of $(d_{ISD} - d)$ from the interfering BS, and hence the $PL(d_{ISD} - d)$ term in the denominator.

With this background, let us look at **Error! Reference source not found.**.

- In all cases, we see a constant SINR till 10m because the pathloss equations defined in the standard take effect only from 10m.

- SINR. vs distance is plotted for four cases
  - Case #1: UE is LOS with both BSs and Interference is turned off
  - Case #2: UE is in NLOS with both BSs with interference is turned off
  - Case #3: UE is in LOS with both BSs with interference turned on
  - Case #4: UE is in NLOS with both BSs with interference turned on
- In case#1 and case #2, the term I in $SINR = \frac{P_r}{N_0W+I}$ is zero. Therefore $SINR = SNR = \frac{P_r}{N_0W}$. We see the SNR dropping as the UE moves away from BS_1. Then at 280m it gets handed over to BS_2, and we see the SNR increasing as the UE moves closer to BS_2. Why is there a "jump" at the handover point? This is because the standards specify that handover should occur only when target-gNB's SINR is offset (3dB) higher than serving-gNB's SINR. This condition is satisfied at 280m.
- Next, we observe that the NLOS curve (blue) is lower than the LOS curve (grey). This is because NLOS pathloss is higher than the LOS pathloss
- Case #3 and Case #4 (i.e., when interference is turned on) show counter intuitive behaviour. The SINR in LOS is lower than the SINR of the NLOS. This is the opposite of Case #1 and case #2. What could cause this behaviour? From the Table 8 below we observe that at 10m
  - The received signal strength P_r is higher for LOS than for NLOS
  - The interference power in LOS is higher than for NLOS. This happens because LOS pathloss is lower (than NLOS pathloss) from interfering BS to UE
  - Interference power difference between LOS and NLOS cases is much higher than pathloss difference.
  - Therefore, NLOS SINR is higher than LOS SINR (thermal noise = -94 dBm)

Case	**Pathloss from attached to BS (dB)**	**Received signal strength P_r(dBm)**	**Interference signal strength from interfering BS (dBm)**	**SINR (dB)**
UE in LOS (10m)	63.60	-23.60	-64.69	41.09
UE in LOS (270m)	94.35	-53.69	-51.56	-2.78
UE in NLOS (10m)	68.23	-28.23	-89.67	60.02
UE in NLOS (270m)	119.57	-79.57	-76.85	-2.80

Table 8: Radio measurements for the different cases

Advanced: Understanding the points of handoff

We investigate the point of hand-off for case #1 and case #2 where the interferences are assumed to be absent from the base-stations. This therefore represents a noise limited regime. In such a scenario, as the UE moves from BS 1 towards BS 1, the SNR seen by the car from BS 1 recedes, while the SNR seen from BS 2 grows gradually. Fig 15 shows a zoom of Fig 13 for case #1 and case #2 between distances of 260m to 280m. We clearly see that (unlike Fig 13) the point of handover is different for the NLOS and LOS cases. LOS handover is 272m while NLOS handover is at 280m. This is as expected because LOS and NLOS use different pathloss models (with different η, the pathloss exponent). Why then does Fig 13 show the handover points to be the same i.e., at 280m?

The answer lies in the fact that in NetSim, the pathloss calculations are not carried out on $continous$ distance but at *discrete* distances. The calculations are done every time a UE moves with the UE movement (in our example) dictated by a mobility file. The UE is assumed to instantaneously move to a point P at time t, and stay there till just before time $(t+1)$. At the moment, $(t+1)$, the UE instantaneously moves to point Q. Pathloss is computed at (t, P)

and at (t, Q). In the Fig 13 measurements were every 20m while in Fig 15 measurements are taken every 1m.

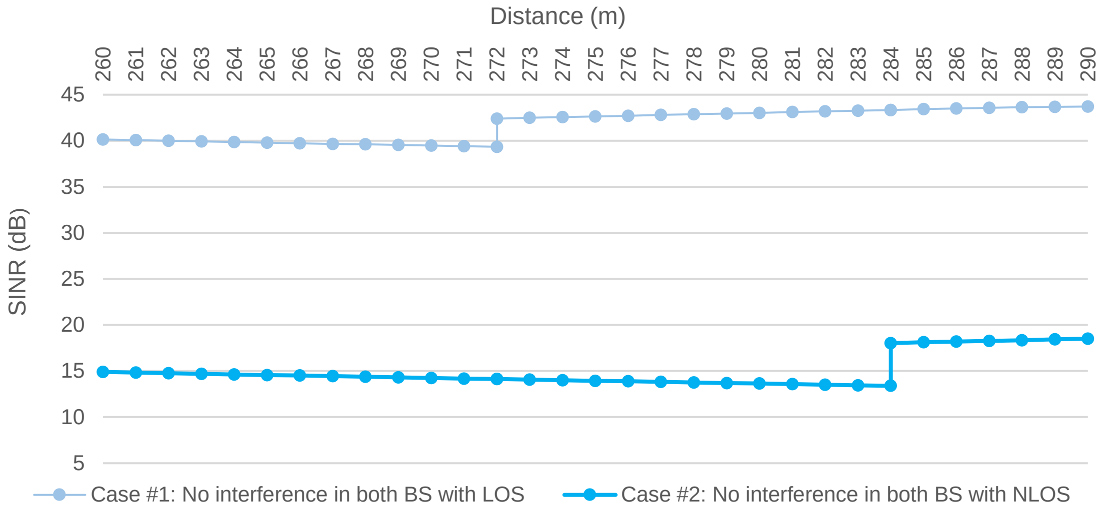


Fig 15: Handover point for case #1 (LOS, no interference) is 272m while for case #2 (NLOS, no interference) it is 280m

We leave it to the reader to carry out a similar exercise for cases #3 and #4.

Exercises

1. Perform a similar experiment using a different band (for example n5 or low band, 850 MHz)
2. Perform a similar experiment with 3 gNBs and the UE moving to a cell corner rather than the cell edge
3. (Advanced) Add on shadowing and observe possible ping-pong handovers
4. (Advanced) Change the handover "Offset" in NetSim code (from default 3 dB) and observe change in ping-pong handovers

References

[1] M. Haenggi and R. K. Ganti, "Interference in Large Wireless Networks," 2009.