NetSim®

Accelerate Network R & D

LTE and LTE-Advanced

A Network Simulation & Emulation Software

By

TETCOS LLP

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1 Introduction

NetSim's LTE library allows for full stack, system level simulation of 4G / 4.5G LTE networks and LTE based VANETs networks. Additionally, you can connect an LTE Network with Internetwork devices and run all the protocols supported in Internetworks. The LTE library is based on 3GPP 36.xxx series.

NetSim's protocol source C code shipped along with (standard / pro versions) is modular and customizable to help researchers to design and test their own LTE protocols.

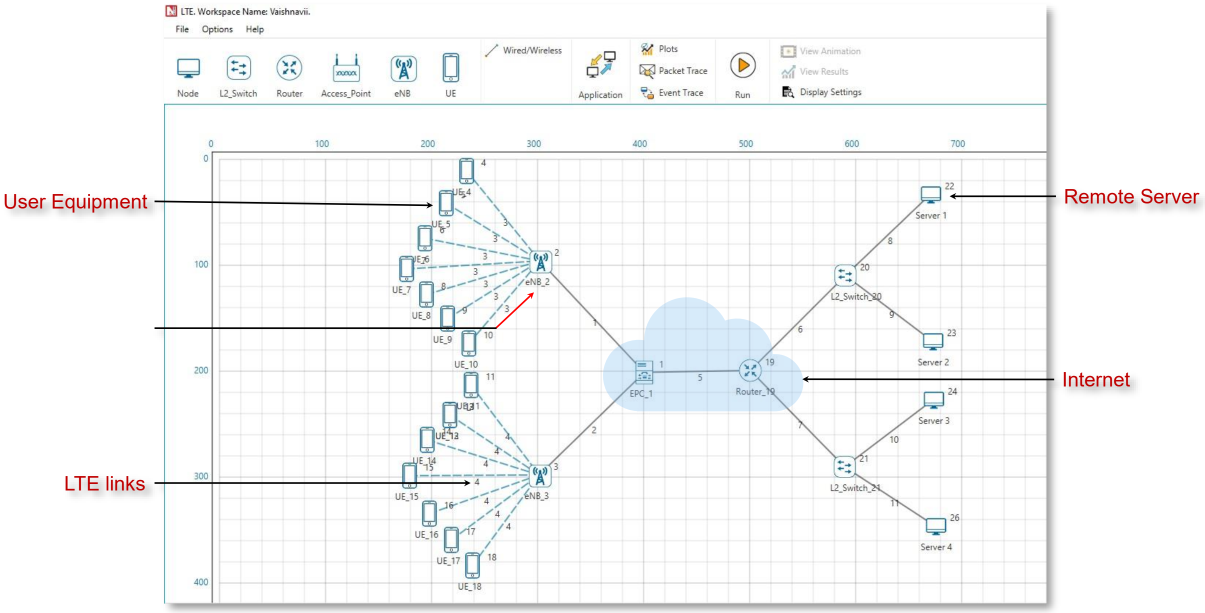


Figure 1-1: A typical LTE Network Scenario in NetSim

Figure 1-2: The Result dashboard and Plot window shown in NetSim after completion of simulation.

2 Simulation GUI

Open NetSim, Go to **New Simulation → LTE/LTE-A Networks**

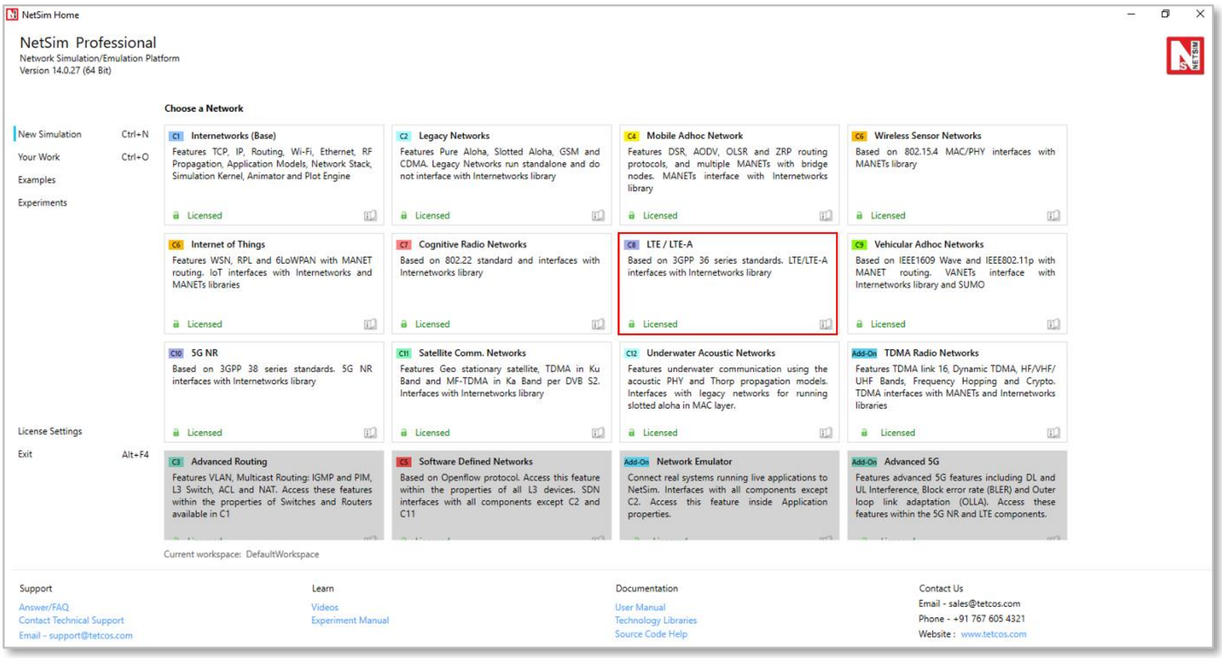


Figure 2-1: NetSim Home Screen

2.1 Create Scenario

LTE comes with a palette of various devices like Wired & Wireless Nodes, L2 Switch & Access Point, EPC (Evolved Packet Core) & Router, Macro Cell eNB and UE (User Equipment).

2.2 Devices specific to NetSim LTE Library

- **UE (LTE UE)** - User Equipment
- **Macro cell eNB** - Evolved NodeB
- **EPC (Evolved packet core)** – Provides end to end IP connectivity between NG (New Generation) core and eNB. This is the equivalent of MME in LTE and comprises of PGW, SGW and MME. EPC can connect to Routers in NG core which in turn can connect to Switches, APs, Servers etc.

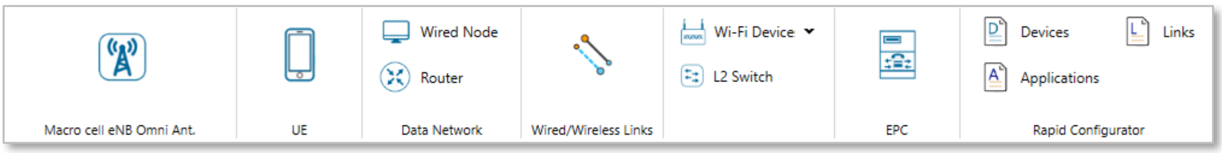


Figure 2-2: LTE Device Palette in GUI

a. Add a User Equipment (UE) – Click the UE icon on the toolbar and place the UE in the grid. The UE's are always assumed to be connected to one eNB. It can never be connected to more than one eNB, and neither can it be out-of-range of all eNBs.
b. Add an eNB – Click the **eNB** icon on the toolbar and place the eNB in the grid. eNBs can also be placed inside the building based on the network scenario created. Every eNB should be connected to at least one UE.
c. Add an EPC – EPC is automatically placed in grid. EPC must be connected to an eNB (connection between **eNB** and **EPC** is taken care by NetSim once user drops the eNB in GUI) or to a Router. NetSim LTE library currently supports only one EPC.
d. Add a Router – Click the **Router** icon on the toolbar, Select **Router** and place device in the grid.
e. Add an L2 Switch – Click the **L2_Switch** icon on the toolbar and place the device in the grid.
f. Access Point – Click the **Access_Point** icon on the toolbar and place the device in the grid.
g. Add a Wired Node and Wireless Node – Click **Wired_Node** icon or **Wireless_Node** icon on the toolbar and place the devices in the grid.
h. Configure an application as follows:
    i. Click on the Set Traffic tab in the top ribbon.
    ii. Select any application from the list and configure the traffic between source and destination.
    iii. Specify other application parameters per your model.

2.3 GUI Configuration of LTE

The LTE parameters can be accessed by right clicking on eNB or UE and selecting Interface (LTE) Properties → Datalink and Physical Layers as shown Table 2-1.

Macro Cell eNB Properties Interface (LTE) – Datalink Layer			
Parameter	**Type**	**Range**	**Description**
Scheduling Type	Local	Round Robin	The scheduler serves equal portion to each queue in circular order, handling all processes without priority.
	Local	Proportional Fair	Schedules in proportional to the CQI of the UEs
	Local	Max Throughput	Schedules to maximize the total throughput of the network by giving scheduling priority accordingly
EWMA Averaging Rate	Local	1.001 to 10000	EWMA Averaging Rate (α) determines how important the current observation is in the

			calculation of the EWMA. A lower alpha discounts older data faster thereby placing greater relevance on your more current data. EWMA(t) = (1 - 1/α) * EWMA(t-1) + (1/α)*r(t) 0 < 1/α <= 1.
SSB Periodicity (ms)	Local	The Range is 120 to 40960ms.	This is the time interval between two UE Measurement report.
RRC MIB Period (ms)	Local	80	The UE needs to first decode MIB for it to receive other system information. MIB is transmitted on the DL-SCH (logical channel: BCCH) with a periodicity of 80 ms and variable transmission repetition periodicity within 80 ms. MIB packets can be seen in the NetSim packet trace post simulation under Control Packet type
RRC SIB Period (ms)	Local	160	SIB1 also contains radio resource configuration information that is common for all UEs. SIB1 is transmitted on the DL-SCH (logical channel: BCCH) with a periodicity of 80 ms and variable transmission repetition periodicity within 80 ms. SIB1 is cell-specific SIB1 packets can be seen in the NetSim packet trace post simulation under Control Packet type.
PDCP Header Compression	Link Global	True / False	Header compression of IP data flows using the ROHC protocol, Compresses all the static and dynamic fields.
PDCP Discard Delay Timer	Link Global	50/150/300/500/750/ 1500	The discard Timer expires for a PDCP SDU, or the successful delivery of a PDCP SDU is confirmed by PDCP status report, the transmitting PDCP entity shall discard the PDCP SDU along with the corresponding PDCP Data PDU.
PDCP Out of Order Delivery	Link Global	True / False	Complete PDCP PDUs can be delivered out-of-order from RLC to PDCP. RLC delivers PDCP PDUs to PDCP after the PDU reassembling.
PDCP T Reordering Timer	Link Global	0-500ms	This timer is used by the receiving side of an AM RLC entity and receiving AM RLC entity in order to detect loss of RLC PDUs at lower layer.

RLC T Status Prohibit	Global	0-2400ms	This timer is used by the receiving side of an AM RLC entity in order to prohibit transmission of a STATUS PDU.
RLC T Reassembly	Link Global	0-200ms	This timer is used by the receiving side of an AM RLC entity and receiving UM RLC entity in order to detect loss of RLC PDUs at lower layer. If t-Reassembly is running, t-Reassembly shall not be started additionally, i.e. only one t-Reassembly per RLC entity is running at a given time.
RLC T Poll Retransmit	Link Global	5-4000ms	This is used by the transmitting side of an AM RLC entity in order to retransmit a poll.
RLC Poll Byte	Link Global	1kB-40mB	This parameter is used by the transmitting side of each AM RLC entity to trigger a poll for every pollByte bytes.
RLC Poll PDU	Link Global	p4-p65536 (in multiples of 8)	This parameter is used by the transmitting side of each AM RLC entity to trigger a poll for every pollPDU PDUs.
RLC Max Retx Threshold	Link Global	t1, t2, t3, t4, t6, t8, t16, t32	This parameter is used by the transmitting side of each AM RLC entity to limit the number of retransmissions of an AMD PDU.
Handover Interruption time	Link Global	0-100ms	The handover process in NetSim is based on event A3 i.e., the target signal strength is offset (3 dB) higher than the source signal strength. Handover interruption time (HIT) is added at the time of handover command is delivered to the UE. During this time there is no data plane traffic flow to the UE from the source/target.
Handover Margin	Global	0-10dB	The handover Margin is the offset in dB that is used as part of the event A3 handover process in NetSim. Handover is triggered when the target signal strength is offset higher than the source signal strength. Range for Handover margin is from 0.0 to 10.0 with 3.0 as default
Time to Trigger	Global	0-5120ms	With Time-to-Trigger, the handover is initiated only if the triggering requirement is fulfilled for a time interval specified by Time-to-Trigger

			(ms). This parameter can decrease the number of unnecessary handovers and effectively avoid Ping-Pong effects. 3GPP defines 16 valid values for time-to-trigger (all in milliseconds): 0, 40, 64, 80, 100, 128, 160, 256, 320, 480, 512, 640, 1024, 1280, 2560, and 5120. Users can enter any value between 0 to 5120 in milliseconds.
HARQ Mode	Local	TRUE, FALSE	Hybrid automatic repeat request (hybrid ARQ or HARQ) is a combination of re transmissions and error correction. The HARQ protocol runs in the MAC and PHY layers. In the 5G PHY, a code block group (CBG) is transmitted over the air by the transmitter to the receiver. If the CBG is successfully received the receiver sends back an ACK, else if the CBG is received in error the receiver sends back a NACK (negative ACK).If the transmitter receives an ACK, it sends the next CBG. However, if the transmitter receives a NACK, it re transmits the previously transmitted CBG. Large number packet errors can be observed in packet trace if HARQ is turned OFF.
HARQ Retry Limit	Local	0-4s	HARQ Retry Limit specifies the number of retransmissions attempts that will be made whenever a Code Block fails due to error.
MAX HARQ process count	Local	2,4,6,10,12,16	A HARQ entity is defined for each gNB-UE pair, separately for Uplink and Downlink and for each component carrier. The HARQ entity handles the HARQ processes. Max number of HARQ processes is 8 in 4G Max number of HARQ processes is 16 in 5G
Max CBG per TB	Local	2,4,6,8	Each Transport block is split into Code blocks (CBs) and CBs are grouped into Code Block Groups (CBGs). A Code Block group can have up to 2/4/6/8 CBs.
Interface (LTE) – Physical Layer			

Parameter	Type	Range	Description
Frame Duration (ms)	Fixed	10ms	Length of the frame.
Sub Frame Duration (ms)	Fixed	1ms	Length of the Sub-frame.
Subcarrier Number Per PRB	Fixed	12	NR defines physical resource block (PRB) where the number of subcarriers per PRB is the same for all numerologies.
eNB Height (meters)	Local	1 - 150 meters	Height of the gNB/eNB in meters By default, 10 meters
TX Power (dBm)	Local	-40dBm to 50dBm	It is the signal intensity of the transmitter. The higher the power radiated by the transmitter's antenna the greater the reliability of the communications system.
TX Antenna Count	Local	1/2/4	MIMO layer count for downlink.
RX Antenna Count	Local	1/2/4	MIMO layer count for uplink.
Duplex Mode	Fixed	TDD/ FDD	In TDD, the upstream and downstream transmissions occur at different times and share the same channel. In FDD, there are different frequency bands used uplink and downlink, The UL and DL transmission an occur simultaneously
CA Type	Local	INTER_BAND_CA INTRA_BAND_CONTIGUOUS_CA INTRA_BAND_NONCONTIGUOUS_CA SINGLE_BAND	Carrier Aggregation (CA) is used in LTE/5G in order to increase the bandwidth, and thereby increase the bitrate. CA options are intra-band (contiguous and non-contiguous) inter-band and single band. LTE Single Operating Band are referred from 3GPP 36101-h60
CA Configuration	Local	Depends on CA Type	Drop down provides the various bands available for the selected CA type (Eg: n78, n258, n261 etc)
CA Count	Fixed	Depends on CA Type	Single or multiple carriers depending on the CA_Type chosen
Slot Type	Local	Mixed, Downlink, Uplink,	Mixed supports DL and UL traffic Downlink supports only DL traffic Uplink supports only UL traffic
DL: UL Ratio	Local		Represents the ratio in which slots are assigned to downlink and uplink transmission
Frequency Range	Fixed	FR1	Frequency range for LTE is Frequency Range 1 (FR1) that includes sub-6 GHz, frequency bands.

Operating Band	Fixed		The LTE operates in different operating bands corresponding to CA configuration respectively
F Low (MHz)	Fixed		Lowest frequency of the Uplink/Downlink operating band.
F High (MHz)	Fixed		Highest frequency of the Uplink/Downlink operating band.
Numerology	Local	μ = 0	It is the numerology value which represents the subcarrier spacing.
Channel Bandwidth (MHz)	Local	5-20 MHz	The frequency range that constitutes the channel.
PRB Count	Local		PRB stands for physical resource block. The PRB count is determined automatically by NetSim as per the other inputs and cannot be edited in the GUI.
Guard Band (KHz)	Local		Guard band is the unused part of the radio spectrum between radio bands, for the purpose of preventing interference.
Subcarrier Spacing	Local	15 kHz	The LTE radio link is divided into three dimensions: frequency, time and space. The frequency dimension is divided into subcarriers with 15 kHz spacing in normal operation
Bandwidth PRB	Local	180 KHz	Physical Resource Block Bandwidth is a range of frequencies occupied by the radio communication signal to carry most of PRB energy.
Slot per Frame	Local	20	Slot within a frame is depending on the slot configuration.
Slot per Subframe	Local	2	Slot within a Subframe is depending on the slot configuration.
Slot Duration (us)	Local	500	Slot duration gets different depending on numerology. The general tendency is that slot duration gets shorter as subcarrier spacing gets wider.
Cyclic Prefix	Local	Normal	Cyclic prefix is used to reduce ISI(Inter Symbol Interference), If you completely turn off the signal during the gap, it would cause issues for an amplifier. To reduce this issue, we copy a part of a signal from the end and paste it into this gap. This copied portion prepended at the beginning is called 'Cyclic Prefix'.

Symbol per Slot	Local	7	The number of OFDM symbol per slot is 7 in normal cyclic prefix case
Symbol Duration (ms)	Local	71.43(ms)	Symbol duration is depending on the subcarrier spacing.
BWP	Local	Disable	A Bandwidth Part (BWP) is a contiguous set of physical resource blocks (PRBs) on a given carrier. These PRBs are selected from a contiguous subset of the common resource blocks for given numerology (u). This parameter was included in NetSim v13.1, as is reserved for future use. It therefore currently always set as disabled.
Overhead (%) per DL slot	Local	0.01-0.99, Default – 0.25	This represents the fraction of symbols in a slot used for control signaling. The remaining fraction is used for data transmission. In NetSim calculations are done over aggregated PRBs per the formula given below $Data\ PRB\ available = Total\ PRB\ available - Ceil(Total\ PRB\ available \times Overhead\ Fraction)$
Overhead (%) per UL slot	Local	0.01-0.99, Default – 0.25	This represents the fraction of symbols in a slot used for control signaling. The remaining fraction is used for data transmission. In NetSim calculations are done over aggregated PRBs per the formula given below $Data\ PRB\ available = Total\ PRB\ available - Ceil(Total\ PRB\ available \times Overhead\ Fraction)$
ANTENNA			
RX Antenna Count	Local	1,2,4	The number of receive antennas
TX Antenna Count	Local	1, 2, 4, 8, 16, 32, 64, 128 in gNB (1, 2, 4, 8, 16 in UE)	The number of transmit antennas. Power is split equally among the transmit antennas.
PDSCH CONFIG			
MCS Table	Local	QAM64LOWSE, QAM64, QAM256	MCS (Modulation Coding Scheme) is related to Modulation Order.
X Overhead	Local	XOH0	Accounts for overhead from CSI-RS, CORESET, etc. If the xOverhead in PDSCH-ServingCellconfig is not configured (a value from 0), N_oh^PRB the is set to 0

PUSCH CONFIG			
Transform Precoding	Local	Enable	Transform Precoding is the first step to create DFT-s-OFDM waveform. Transform Precoding is to spread UL data in a special way to reduce PAPR(Peak-to-Average Power Ratio) of the waveform. In terms of mathematics, Transform Precoding is just a form of DFT(Digital Fourier Transform).
MCS Table	Local	QAM64LOWSE, QAM64, QAM256	MCS (Modulation Coding Scheme) is related to Modulation Order. This is based on 3GPP 38.214-Table 5.1.3.1-1, 5.1.3.1-2 and 5.1.3.1-3 Users must set the MCS and CQI tables in the following combination QAM64: CQI Table 1 QAM 256: CQI Table 2 QAM 64 LOWSE: CQI Table 3
CSIREPORT CONFIG			
MCS Table	Local	QAM64LOWSE, QAM64, QAM256	MCS (Modulation Coding Scheme) is related to Modulation Order. This is based on 3GPP 38.214-Table 5.1.3.1-1, 5.1.3.1-2 and 5.1.3.1-3 Users must set the MCS and CQI tables in the following combination QAM64: CQI Table 1 QAM 256: CQI Table 2 QAM 64 LOWSE: CQI Table 3
CHANNEL MODEL			
Pathloss Model	Local	3GPPTR38.901-7.4.1 LOG DISTANCE NONE	None represents an ideal channel with no pathloss. TR 38.901_Standard Table 7.4.2-1 means pathloss will be calculated per the formulas in this standard
Outdoor Scenario	Local	Rural Macro (RMa)	For RMa, we need to specify the Building Height and Street Width. Buildings can be used in the scenario. UEs can be inside/outside buildings but eNBs can only be outside buildings.
Outdoor Scenario Building Height	Local	Urban Macro (UMa)	Buildings can be used in the scenario. UEs can be inside/outside buildings but eNBs can only be outside buildings.
	Local	Urban Micro (UMi)	Buildings can be used in the scenario. UEs can be

			inside/outside buildings but eNBs can only be outside buildings.
	Local	5-50m	It is the height of the building in meters.
Street Width	Local	5-50m	It is the width of the street in meters.
Indoor Scenario	Fixed	Indoor Office	Automatically chosen by NetSim in case the UE is within an indoor building.
Indoor Office Type	Local	Mixed-Office Open- Office	The pathloss will be per the chosen option when the UE is within a building
LOS_NLOS Selection	Fixed	3GPPTR38.901-Table 7.4.2-1 USER_DEFINED	This choice determines how NetSim decides if the eNB-UE communication is Line-of-sight or Non-Line-of-Sight. In case of USE_DEFINED the LOS probability is user defined. Else it is standards defined.
LOS Probability	Local	0 to 1	If LOS Probability =1, the LOS mode is set to Line-of-Sight and if the LOS Probability =0, the LOS mode as set to Non-Line-of-Sight. For a value in between the LOS is determined probabilistically. By default, value is set to 1.
Shadow Fading Model	Local	NONE LOG_NORMAL	Select NONE to Disable Shadowing Select LOG_NORMAL to Enable Shadowing Model, and the Std dev would be per 3GPP TR38.901-Table 7.4.1-1
Fading and Beamforming	Local	NO_FADING_MIMO_UNIT_GAIN, NO_FADING_MIMO_ARRAY_GAIN	RAYLEIGH WITH EIGEN BEAMFORMING: When fading and beamforming is enabled, NetSim uses the rich scattering in the channel to form spatial channels. The number of spatial channels is equal to the number of layers (in turn equal to Min (Nt, Nr)). The beamforming gains in the spatial channel is equal to the eigen values of the channel covariance (wishart) matrix. NO FADING: To disable the fading and beamforming.
O2I Building Penetration Model	Local	None, Low Loss Model, High Loss Model,	The composition of low and high loss is a simulation parameter that should be determined by the user of the channel models and is dependent on the buildings and the deployment scenarios. None to disable O2I Loss. Low-loss model is applicable to RMa.

			High-loss model is applicable to UMa and UMi.
Additional Loss Model	Local	NONE, MATLAB	Additional Loss model can be set to None or MATLAB, if set to MATLAB then MATLAB will be automatically called by NetSim during execution.
Path Loss Exponent (n)	Local	2 to 5	Path loss exponent indicates the rate at which the path loss increases with distance. The value depends on the specific propagation environment. Set any value between 2 to 5.
Shadowing Model	Local	Constant Log Normal	**Constant**: A shadowing model is used to represent the signal attenuation caused by obstructions along the propagation path. The constant shadowing model is suitable for the scenarios without mobility where the obstructions along the propagation paths remain unchanged. **Log Normal**: The lognormal shadowing model is suitable for a scenario with mobility and obstructions within the propagation environment. In this model, the shadowing value follows a log-normal distribution with a user specified standard deviation. In general, this value should be in the range of 5 to 12 dB depending on the density of obstructions within the propagation environment.
Standard Deviation (dB)	Local	5 to 12 dB	Shadowing is caused mainly by terrain features of the radio propagation environment. The mathematical model for shadowing is a log-normal distribution with standard deviation of 5 to 12 dB. Set any value between 5 to 12 dB.
INTERFERENCE MODEL			
Downlink Interference Model	Global	NO_INTERFERENCE, GRADED_DISTANCE_BASED_WYNER_MODEL, EXACT_GEOMETRIC_MODEL	DL interference options are No interference, Graded Distance based Wyner model and Exact geometric models. If no interference is chosen then in the SINR calculations, the values of I is set to zero. Wyner and geometric models compute interference. Wyner is an approximate model used by the research community while the geometric model is

			exact. Technical details of the two models are provided in the 5G/LTE NR manual.
Uplink Interference Model	Global	NO_INTERFERENCE, INTERFERNEC_OVER_THERMAL	NetSim uses Interference-over-thermal (IoT), to model co-channel uplink interference.
IoT value (dB)	Global	0 to 20	The Uplink IoT (dB) value is used to compute the SINR, and Interference power based on the following equations: $SINR\ (dB) = SNR(dB) - IoT(dB)$ The interference power (dBm units), logged in the radio measurements file will be given as I (dBm) = 10 * log_10 ((N * (10^(IOT (dB)-1)) where N is thermal noise and is equal to k*T*B.
ERROR MODEL AND MCS SELECTION			
MCS Selection Model	Global	IDEAL_SHANNON_THEOREM_BASED_RATE, SHANNON_RATE_WITH_ATTENUATION_FACTOR	MCS Selection Model determines how modulation and coding scheme is determined in 5G and LTE. The following Models are supported: Ideal Shannon Theorem-Based Rate: Spectral Efficiency is computed as SpectralEfficiency = log(1+SINR) Shannon Rate with Attenuation Factor (α): Spectral Efficiency is computed as SpectralEfficiency = α x log(1+SINR) Spectral Efficiency - MCS Table is looked up to select the MCS.
Attenuation Factor	Global	0.5-1	Attenuation factor (α) takes value between 0.5 and 1 with the default value of 0.75.
BLER Model	Global	ZERO_BLER BLER_ENABLE	Block Error Rate Model (BLER) is used to decide code block and transport block error in 5G and LTE.
Outer loop link adaption	Global	TRUE FALSE	The Outer Loop Link Adaptation (OLLA) technique, if enabled can improve the channel quality estimation by adjusting the value of SINR by an offset dependent on whether previous transmissions were decoded successfully or not, as captured by Hybrid Automatic Repeat Request (HARQ) feedback

Target BLER	Global	0-1	Target BLER plays an important role in 5G link adaptation. The BLER target is usually around 10% based on specifications but it can be varied depending on the characteristics of the cell. Range: 0 to 1
UE Properties			
Interface _1 (LTE) – Physical Layer			
Parameter	**Type**	**Range**	**Description**
UE Height (meters)	Local	1 to 22.5	Height of the UE in meters
TX Power (dBM)	Local	-40dBM to 50dBM	It is the signal intensity of the transmitter. The higher the power radiated by the transmitter's antenna the greater the reliability of the communications system.
Tx Antenna Count	Local	1/2	Number of transmit antennas. NetSim uses this parameter in MIMO operations.
Rx Antenna Count	Local	1/2/4	Number of receive antennas. NetSim uses this parameter in MIMO operations.

Table 2-1: Datalink layer and Physical properties for eNB and UE

3 Model Features

3.1 LTE Stack

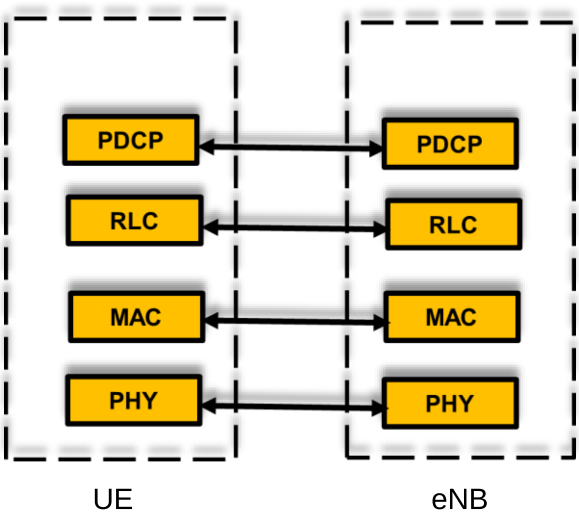


Figure 3-1: User Plane Protocol Stack

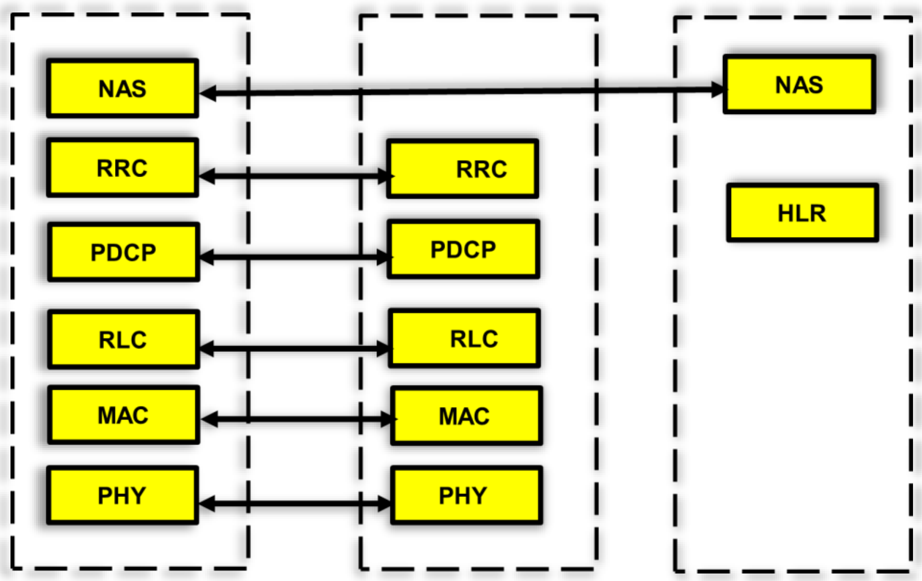


Figure 3-2: Control Plane Protocol Stack

3.2 RRC

The Radio Resource Control (RRC) protocol is used in the air Interface. The major functions of the RRC protocol include connection establishment and release functions, broadcast of system information, radio bearer establishment, reconfiguration and release, RRC connection mobility procedures, paging notification and release and outer loop power control. By means of the signaling functions, the RRC configures the user and control planes according to the network status and allows for Radio Resource Management strategies to be implemented. In NetSim RRC protocol includes the functionality related connection establishment, broadcast of system information, radio bearer establishment, reconfiguration, RRC connection mobility procedures, paging notification.

The RRC code is available in the following C files*, LTENR_RRC.c, LTENR_GNBRRC.c, and LTENR_NAS.c (RRC connection mobility and Handover procedures).*

A UE can move to RRC Idle mode from RRC connected/RRC Active or RRC Inactive state.

3.2.1 System information acquisition

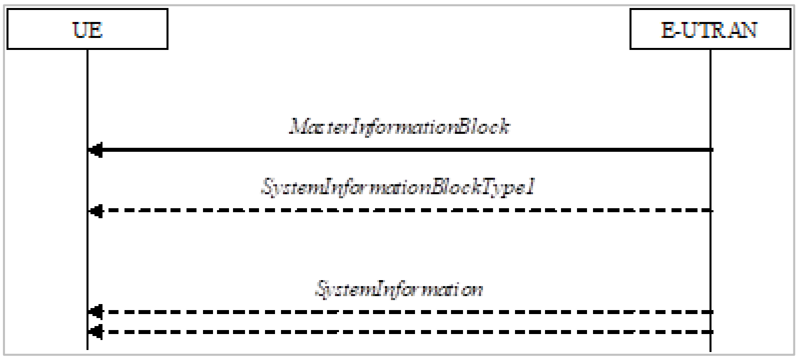


Figure 3-3 : System information acquisition

The system information is divided into the Master Information Block (MIB) and System Information Block 1.

3.2.1.1 Master Information Block (MIB)

MIB is the broadcast information transmitted by eNodeB at periodically. UE have the information of Physical cell ID and not it can descramble the further information which Master information Block, which will provide the System bandwidth, System frame number etc.

The UE needs to first decode MIB in order for it to receive other system information. MIB is transmitted on the DL-SCH (logical channel: BCCH) with a periodicity of 80 ms and variable transmission repetition periodicity within 40 ms.

Bits and Bytes of Master information blocks:

- Logical Channel – BCCH (Broadcast common control Channel)
- Transport Channel – BCH (Broadcast Channel)
- Physical Channel – PBCH (Physical Broadcast channel)
- RLC Mode – (Transparent Mode)

3.2.1.2 System Information Block 1 (SIB1)

SIB is the carries the most critical information required for the UE to access the cell e.g., random access parameters.

SIB1 includes information regarding the availability and scheduling of other SIBs e.g. mapping of SIBs to SI message, periodicity, SI-window size etc.

SIB1 also indicates whether one or more SIBs are only provided on-demand, in which case, it may also provide PRACH configuration needed by the UE to request for the required SI.

SIB1 also contains radio resource configuration information that is common for all UEs and cell barring information applied to the unified access control. SIB1 is transmitted on the DL-

SCH (logical channel: BCCH) with a periodicity of 80 ms and variable transmission repetition periodicity within 80 ms. SIB1 is cell-specific SIB.

- Logical Channel – BCCH (Broadcast common control Channel)
- Transport Channel – BCH (Broadcast Channel)
- Physical Channel – PBCH (Physical Broadcast channel)
- RLC Mode – (Transparent Mode)

3.2.2 RRC connection establishment

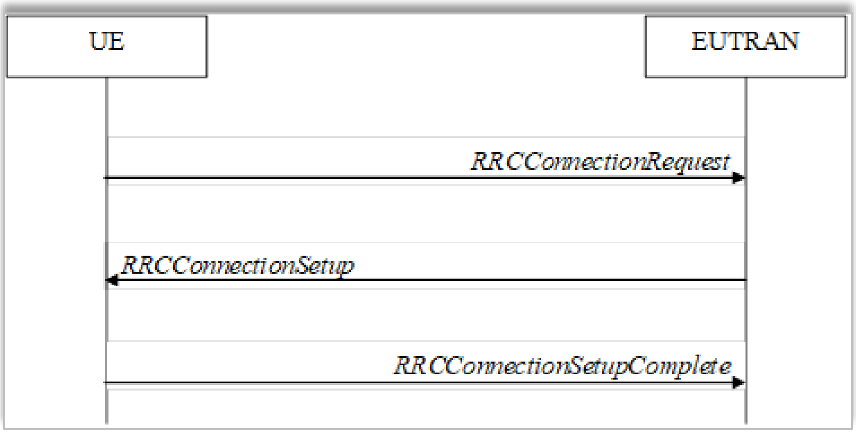


Figure 3-4 : RRC connection establishment

RRC connection establishment starts with UE sends the RRC connection request to EUTRAN (eNB). RRC connection setup as a response sends back from the EUTRAN to UE. The sends back the RRC connection setup complete and the RRC connection will establish between UE and EUTRAN (eNB).

3.3 PDCP

The PDCP layer receives a packet (data/control) from the upper layer, executes the PDCP functions and then transmits it to a lower layer. PDCP layer code related files *LTENR_PDCP.c.* PDCP Entity: The PDCP entities are located in the PDCP sublayer. NetSim currently implements one PDCP entity per UE (users can add more by modifying the code). The same PDCP entity is associated with both the control and the user plane.

The PDCP functionality supported is,

- Transmit PDCP SDU- It transmit the data between RLC and higher U-Plane interface
  - Sets the PDCP Sequence Number.
  - Adds RLC Header.
  - Calls RLC service primitive.
- ROHC (Robust Header Compression)

- ROHC is a kind of algorithm to compress the header of various IP packets. In case of IPv4, the size of uncompressed IP header is 40 bytes.

- PDCP Association
  - This call back function is invoked when the UE associates/dissociates from a eNB.
- Maintenance of PDCP sequence numbers (to know more check the PDCP entity structure)
- Discard Timer:
  - When the discardTimer expires for a PDCP SDU, or the successful delivery of a PDCP SDU is confirmed by PDCP status report, the transmitting PDCP entity shall discard the PDCP SDU along with the corresponding PDCP Data PDU.
  - Discarding a PDCP SDU already associated with a PDCP SN causes a SN gap in the transmitted PDCP Data PDUs, which increases PDCP reordering delay in the receiving PDCP entity.
- Duplicate Discard:
  - PDCP maintain the sequence number, if the PDCP receives the duplicate sequence number, discard the PDCP SDU along with the corresponding PDCP Data PDU.

3.4 RLC

Flow of TM, UM, and AM mode between RLC upper and lower layer as shown in Figure 3-5.

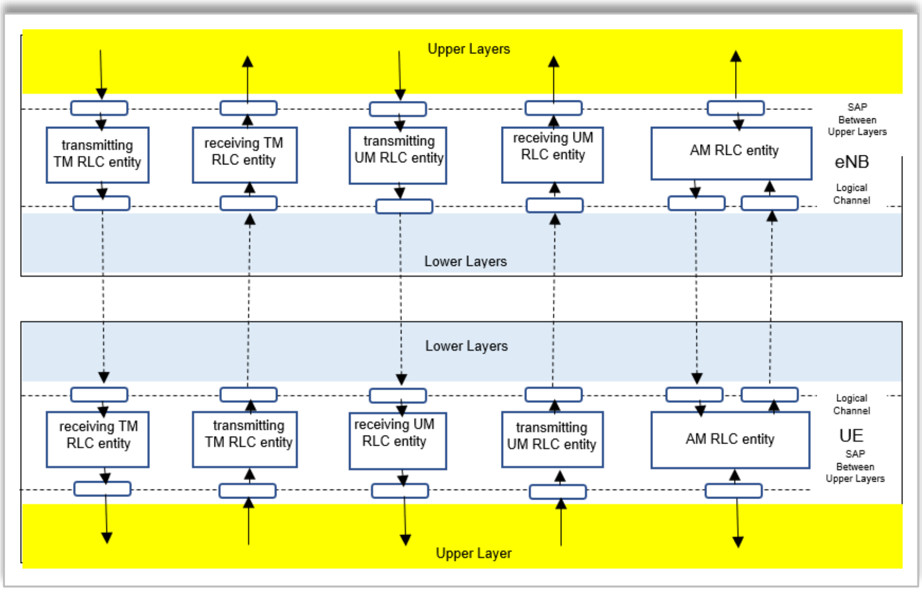


Figure 3-5: Overview Model of RLC sub layer

3.4.1 TM Mode (Transparent Mode)

The operation being done in TM mode is a buffering operation. It keeps the input data for a certain amount of time or until next input data come in, it just discard it if it does not get transmitted within a certain time frame.

As you see in the Figure 3-6, BCCH, PCCH, CCCH goes through this type of RLC process. In WCDMA, Voice call traffic used this RLC mode as well. It means that even some type of DTCH (voice traffic) uses this mode in WCDMA. However it is technically possible to use TM mode for DTCH as well. RLC TM mode code related file *LTENR_RLC.c.*

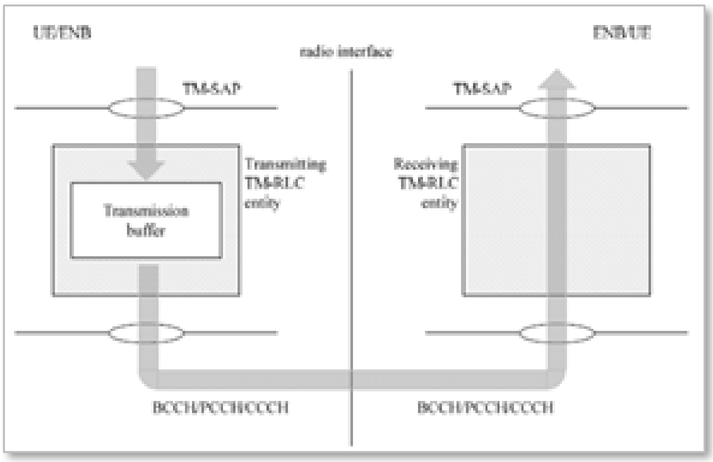


Figure 3-6: Model of two transparent mode peer entities

3.4.2 UM Mode (Unacknowledged Mode)

The following operation done in RLC UM transmission and reception.

RLC UM Data Flow (Transmission):

At the time of RLC UM transmission, It receives the SDU (Data) from the higher layers (PDCP or RRC) and put the SDU into the transmission buffer. When the MAC permits the transmission, it segment or concatenate the SDU into RLC PDU and add the RLC header to the RLC PDU. Then the RLC SDU sent to the next layer (MAC layer).

RLC UM Data Flow (Reception):

The MAC layer passes the received RLC PDU to the RLC layer. RLC layer removes RLC header from the RLC PDU, then the RLC layer assemble PDUs into the upper layer SDU and it passes the assembled SDUs to the higher layers (PDCP or RRC).

As you see in *Figure 3-7*, DTCH, MTCH. MCCH use this type of RLC process. Again, this is also a matter of choice. You can use AM or UM mode for DTCH. RLC UM mode code related file *LTENR_RLC_UM.c.*

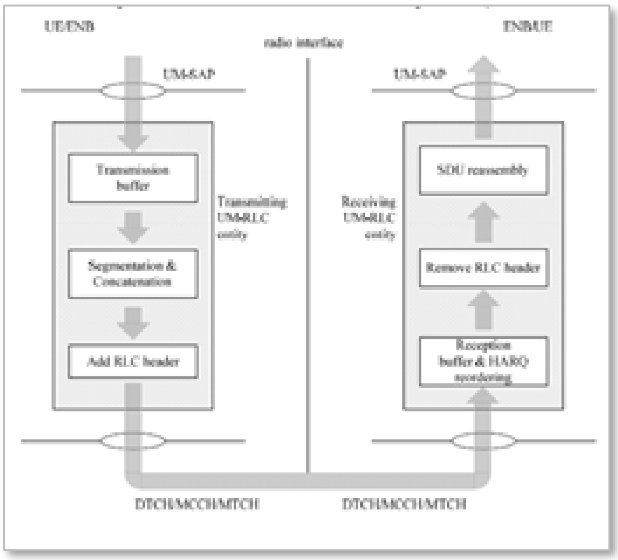


Figure 3-7: Model of two unacknowledged mode peer entities

3.4.3 AM Mode (Acknowledge Mode)

The following operation done in RLC AM transmission and reception.

RLC AM Data Flow (Transmission):

At the time of RLC AM transmission, It receives the SDU (Data) from the higher layers (PDCP or RRC) and put the SDU into the transmission buffer. When the MAC permits the transmission, it segment or concatenate the SDU into RLC PDU and add the RLC header to the RLC PDU and make the copy of the transmission buffer for the possible retransmission. Then the RLC SDU sent to the next layer (MAC layer).

RLC AM Data Flow (Reception):

The MAC layer passes the received RLC PDU to the RLC layer. RLC layer removes RLC header from the RLC PDU. If the received RLC PDU does not have any problem, mark it as positive ACK. Then the RLC layer assemble PDUs into the upper layer SDU and it passes the assembled SDUs to the higher layers (PDCP or RRC). RLC AM mode code related file *LTENR_RLC_AM.c.*

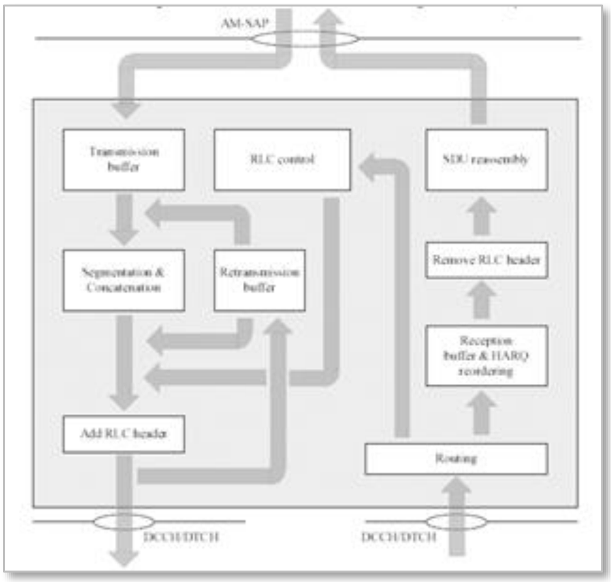


Figure 3-8: Model of an acknowledged mode entity

3.5 MAC Scheduler

At each eNB the MAC Scheduler decides the PRB allocation, in a slot, for each carrier. The max schedulers work as follows:

- Round Robin - It divides the available PRBs among the active flows, i.e., those logical channels which have a non-empty RLC queue. The MCS for each user is calculated according to the received CQIs.
- Proportional fair - It allocates PRBs in proportion to the channel quality in the active flows.
- Max throughput - It allocates PRBs to the active flow(s) to maximize the achievable rate.

Note that these are MAC scheduling algorithms, and they aren't based on the QoS set in the Application.

3.6 PHY Layer

3.6.1 Physical Speed of the LTE Air Interface

One Resource Block (RB) in LTE has 12 carriers (each carrier is 15 KHz) in frequency domain and 0.5 milliseconds (7 symbols) in time domain.

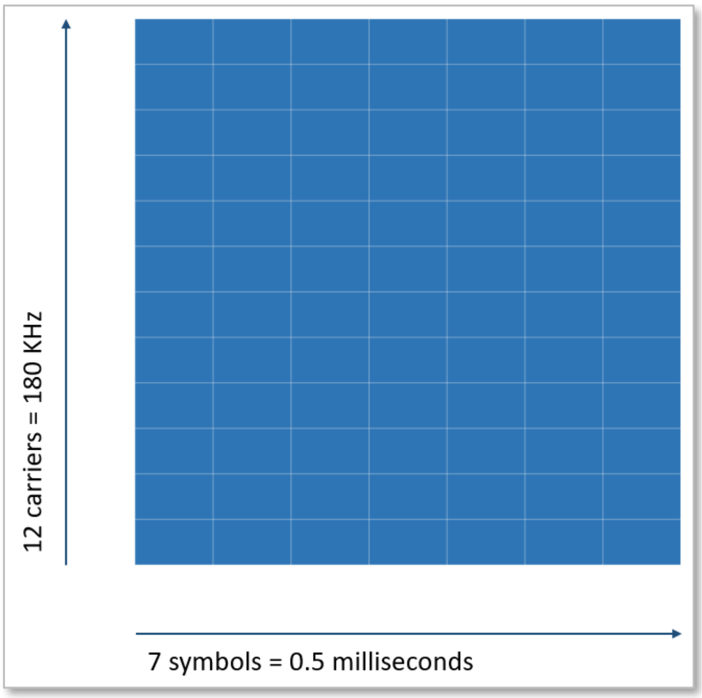


Figure 3-9: Physical Speed of the LTE Air Interface

$$So, the\ total\ number\ of\ symbols\ in\ a\ Resource\ block = 12\ \times 7 = 84$$

A symbol accommodates a specific number of bits depending on the modulation scheme. The following table lists the number of bits for different modulation schemes as shown Table 3-1.

Modulation scheme	# of bits per symbol
QPSK	2
16-QAM	4
64-QAM	6

Table 3-1: Modulation scheme vs. number of bits

The following table lists the number of Resource blocks, carriers, and the bandwidth available for different LTE channel bandwidths as shown Table 3-2.

Channel bandwidth (MHz)	5	10	15	20
Resource blocks	25	50	75	100
Number of carriers	300	600	900	1200
Occupied bandwidth (MHz)	4.5	9	13.5	18

Table 3-2: Resource blocks, carriers and the bandwidth

NOTE: ***In an LTE network, 10% of total bandwidth is used for the guard band. For example, if the channel bandwidth is 20 MHz, then 2 MHz is used for the guard band. So, if 180 KHz has 1 RB, 18 MHz has 100 RBs***.

3.6.2 LTE and LTE-A Operating Bands

The following table lists the details of the LTE and LTE-A frequency bands defined by 3GPP. NetSim uses these bands to let you simulate LTE-A networks.

NOTE: NetSim supports both TDD and FDD.

LTE band #	Uplink (MHz)	Downlink (MHz)	Width (MHz)	Duplex spacing	Band gap
1	1920 – 1980	2110 – 2170	60	190	130
2	1850 – 1910	1930 – 1990	60	80	20
3	1710 – 1785	1805 -1880	75	95	20
4	1710 – 1755	2110 – 2155	45	400	355
5	824 – 849	869 – 894	25	45	20
7	2500 – 2570	2620 – 2690	70	120	50
8	880 – 915	925 – 960	35	45	10
11	1427.9 - 1447.9	1475.9 - 1495.9	20	48	28
12	699 – 716	729 – 746	18	30	12
13	777 – 787	746 – 756	10	-31	41
17	704 – 716	734 – 746	12	30	18
18	815 – 830	860 – 875	15	45	30
19	830 – 845	875 – 890	15	45	30
20	832 – 862	791 – 821	30	-41	71
21	1447.9 - 1462.9	1495.9 - 1510.9	15	48	33
23	2000 – 2020	2180 – 2200	20	180	160
25	1850 – 1915	1930 – 1995	65	80	15
26	814 – 849	859 – 894	30	40	10
27	807 – 824	852 – 869	17	45	28
28	703 – 748	758 – 803	45	55	10

Table 3-3: LTE and LTE-A frequency bands

3.6.2.1 LTE Single Bands

The following list of specified frequency bands of LTE single bands are referred from 3GPP 36101-h60.

E UTRA	Uplink (UL) operating band			Downlink (DL) operating			Duplex
	FUL_low		**FUL_high**	**FDL_low**		**FDL_high**	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6	830 MHz	–	840MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9	1844.9	–	1879.9	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1447.9	1475.9	–	1495.9	FDD
12	699 MHz	–	716 MHz	729 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz	FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	FDD
20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	FDD

21	1447.9 MHz	–	1462.9	1495.9	–	1510.9	FDD
22	3410 MHz	–	3490 MHz	3510 MHz	–	3590 MHz	FDD
23	2000 MHz	–	2020 MHz	2180 MHz	–	2200 MHz	FDD
24	1626.5 MHz	–	1660.5	1525 MHz	–	1559 MHz	FDD
25	1850 MHz	–	1915 MHz	1930 MHz	–	1995 MHz	FDD
26	814 MHz	–	849 MHz	859 MHz	–	894 MHz	FDD
27	807 MHz	–	824 MHz	852 MHz	–	869 MHz	FDD
28	703 MHz	–	748 MHz	758 MHz	–	803 MHz	FDD
30	2305 MHz	–	2315 MHz	2350 MHz	–	2360 MHz	FDD
31	452.5 MHz	–	457.5 MHz	462.5 MHz	–	467.5 MHz	FDD
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD
41	2496 MHz		2690 MHz	2496 MHz		2690 MHz	TDD
42	3400 MHz	–	3600 MHz	3400 MHz	–	3600 MHz	TDD
43	3600 MHz	–	3800 MHz	3600 MHz	–	3800 MHz	TDD
44	703 MHz	–	803 MHz	703 MHz	–	803 MHz	TDD
45	1447 MHz	–	1467 MHz	1447 MHz	–	1467 MHz	TDD
46	5150 MHz	–	5925 MHz	5150 MHz	–	5925 MHz	TDD8
47	5855 MHz	–	5925 MHz	5855 MHz	–	5925 MHz	TDD11
48	3550 MHz	–	3700 MHz	3550 MHz	–	3700 MHz	TDD
49	3550 MHz	–	3700 MHz	3550 MHz	–	3700 MHz	TDD16
50	1432 MHz	-	1517 MHz	1432 MHz	-	1517 MHz	TDD13
51	1427 MHz	-	1432 MHz	1427 MHz	-	1432 MHz	TDD13
52	3300 MHz	-	3400 MHz	3300 MHz	-	3400 MHz	TDD
53	2483.5 MHz	-	2495 MHz	2483.5	-	2495 MHz	TDD
65	1920 MHz	–	2010 MHz	2110 MHz	–	2200 MHz	FDD
66	1710 MHz	–	1780 MHz	2110 MHz	–	2200 MHz	FDD4
68	698 MHz	–	728 MHz	753 MHz	–	783 MHz	FDD
70	1695 MHz	–	1710 MHz	1995 MHz	–	2020 MHz	FDD10
71	663 MHz	–	698 MHz	617 MHz	–	652 MHz	FDD
72	451 MHz	–	456 MHz	461 MHz	–	466 MHz	FDD
73	450 MHz	–	455 MHz	460 MHz	–	465 MHz	FDD
74	1427 MHz	–	1470 MHz	1475 MHz	–	1518 MHz	FDD
85	698 MHz	–	716 MHz	728 MHz	–	746 MHz	FDD
87	410 MHz	–	415 MHz	420 MHz	–	425 MHz	FDD
88	412 MHz	–	417 MHz	422 MHz	–	427 MHz	FDD
103	787 MHz	–	788 MHz	757 MHz	–	758 MHz	FDD

Table 3-4: LTE Single Bands

3.6.4 LTE and LTE-A Transmission Modes

NetSim supports the following LTE Transmission modes:

- Transmission Mode 1 – SISO, by using of a single antenna at eNodeB. Because of Round-robin scheduling, all applications see equal throughput.
- Transmission Mode 2 – MIMO and Transmit Diversity (TxD). Sends copies of same information via multiple antennas. This leads to higher reliability, but the throughput remains the same as Mode 1 .
- Transmission Mode 3, SU – MIMO Spatial Multiplexity, Open Loop. This is used to achieve high data rates. The data is divided and sent via various antennas. The throughput increases.
- Transmission Mode 4, MU-MIMO Spatial Multiplexing, Per the LTE standard. With a multi-user setup, multiple antennas are used to send and receive data. The data throughput further increases.
- Transmission mode 5 – MU-MIMO, where the number of receive, antennas is fixed to 2.

3.6.5 LTE and LTE-A PHY Layer Parameters

The following table lists the details of the parameters of the PHY layer in LTE as shown Table 3-5.

Channel bandwidth (MHz)	1.4	3	5	10	15	20
Number of Resource blocks (NRB)	6	15	25	50	75	100
Number of occupied carriers	73	181	301	601	901	1201
IFFT(Tx) /FFT size (Rx)	128	256	512	1024	1536	2048
Sampling frequency (Sampling rate)	1.92	3.84	7.68	15.36	23.04	30.72
Samples per slot	960	1920	3840	7680	11520	15360
Guard Band	160	150	250	500	750	1000

Table 3-5: LTE and LTE-A PHY Layer Parameters

IFFT = Inverse Fast Fourier Transform and FFT = Fast Fourier Transform

3.6.6 HARQ

3.6.6.1 Introduction

We start with a brief and simplistic explanation of the HARQ mechanism.

1. Hybrid automatic repeat request (hybrid ARQ or HARQ) is a combination of retransmissions and error correction. The HARQ protocol runs in the MAC and PHY layers.
2. In the 5G PHY, a code block group (CBG) is transmitted over the air by the transmitter to the receiver. If the CBG is successfully received the receiver sends back an ACK, else if the CBG is received in error the receiver sends back a NACK (negative ACK).

3. If the transmitter receives an ACK, it sends the next CBG. However, if the transmitter receives a NACK, it retransmits the previously transmitted CBG.
4. In 5G/LTE, the incorrectly received CBG is not discarded but stored at the receiver. When the re-transmitted CBG is received, the two CBGs are combined. This is called Hybrid ARQ with chase-combining (HARQ-CC).

3.6.6.2 Implementation in NetSim

1. HARQ is implemented in 4G (Macro Cell eNB) and in 5G (Macro Cell gNB) in both downlink and uplink.
2. A HARQ entity is defined for each eNB-UE pair, separately for Uplink and Downlink and for each component carrier. The HARQ entity handles the HARQ processes.
   a. Max number of HARQ processes is 8 in 4G.
   b. Max number of HARQ processes is 16 in 5G.
3. Each HARQ process transmits one Transport Block (TB) at any time
4. When operating in MIMO, each layer handles a different TB. This means that one TB is not transmitted across multiple layers.
5. Each TB is split into Code blocks (CBs) and CBs are grouped into Code Block Groups (CBGs).
6. At the receiver the CBGs are given to a multiplexer which combines the CBGs into a TB.
7. CBGs are always retransmitted at the same MCS as the first transmission. This restriction comes from the specification of the rate matcher in the 3GPP TS 38.212 standard.

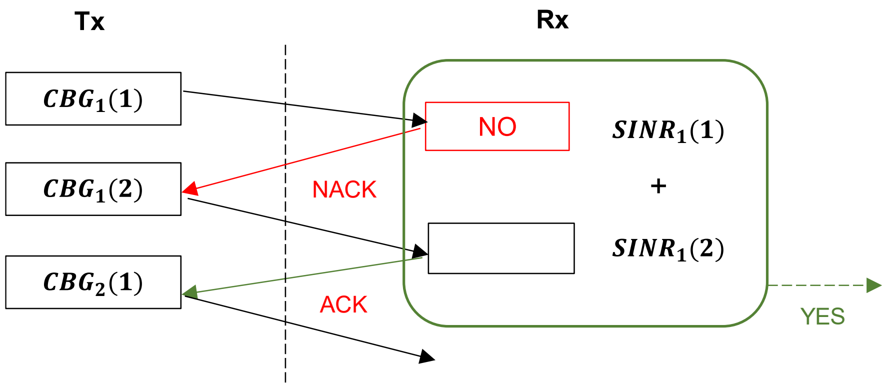


Figure 3-10: We see the HARQ transmission process. The transmitter sends CBG1 which is errored. Therefore, the receiver sends a NACK. CBG1 is then retransmitted (transmission attempt 2). The receiver then soft combines the first and second transmissions, which is successful and hence sends back an ACK.

8. In HARQ-CC, every retransmission contains the same coded bits (information and coding bits). We abstract soft combining and model it by summing (in linear scale) the SINRs of transmitted and retransmitted CBGs. The BLER is then looked up for the combined SINR.

9. The New Data Indicator (NDI) flag is set (both in UL and DL) true for transmission of a new TB.
10. HARQ entity is terminated during handover-triggered de-association from a eNB and re-created at the new eNB after the handover procedure is completed.
11. HARQ retransmissions have priority over new data transmissions. Within a HARQ process, new data transmissions are not taken up when retransmission data is in the queue.
12. HARQ processes are multiplexed in time (slots) in a round robin fashion. For example, if we had a case with 4 HARQ processes then:

    Slot 1 – HARQ Process 1 > Success
    Slot 2 – HARQ Process 2 > Success
    Slot 3 – HARQ Process 3 > Error
    Slot 4 – HARQ Process 4 > Success
    Slot 5 – HARQ Process 1 > Success
    Slot 6 – HARQ Process 2 > Success
    Slot 7 – HARQ Process 3 > Retransmission Success
    ... and so on

3.6.6.3 Assumptions and limitations

1. The HARQ ACK/NACK is sent out-of-band by the receiver immediately after receipt ($\Delta t \to 0^+$). It is then instantaneously and correctly received at the transmitter. The ACK/NACKs are not logged.

2. If DL/UL transmission can occur, then reverse direction (UL/DL respectively) ACK/NACK will be successful. Specifically, even if the UL data link is in outage, ACK/NACK transmitted in the UL will be correctly received by the eNB.

3.6.6.4 Transmission flow

1. Packets are either split or combined into transport blocks (TBs) depending on the packet size and the TB size. It is the TB that needs to be transmitted over the air.

    a. Users can set the application layer packet size in NetSim GUI > Application properties. The packet size at the MAC is the application packet size plus transport layer and IP layer overheads. Users can obtain the MAC layer packet size from the packet trace.

    b. The TB size is determined by the LTE and 5G NR protocol running in the MAC/PHY. Users can obtain the TB size from the code block log file.

2. TB are then split to Code blocks (CBs). The code block size calculation and TB segmentation is explained in section 3.6.7 Below.
3. CBs are grouped into code block groups (CBGs).
    a. The max number of CBGs per TB can be set in the NetSim GUI (based on RRC parameter MAX_CBG_PER_TB in the NetSim GUI)
4. TBs are transmitted by transmitting CBGs, which is in turn comprises of CBs
5. BLER is applied upon CBG reception at the receiver
6. If any CB is in error, the transmitter retransmits the entire CBG to which that CB is a part of.
7. The receiver then soft combines the first transmission and all subsequent retransmissions
    a. Soft combining is modelled by adding their SINRs in the linear scale. For example, if there were 2 retransmissions, then the combined SINR would be given by

$$CombinedSINR_3^{Tx} = SINR_3^{Tx} + SINR_2^{Tx} + SINR_1^{Tx}$$

8. BLER is applied on the improved (combined) SINR by tossing a biased coin
9. If any CB is in error, go to step 6, subject to transmit limit of 4 (retransmit limit of 3).
    a. The transmit limit is user settable in NetSim, and by default is set to 4.
10. If all CBGs (in a TB) are successful, then at the receiver, the TB is sent up to the RLC
11. Else, the entire TB is dropped.

3.6.6.5 Special cases

1. If there is a retransmission scheduled in a multi-layer scenario, then the scheduler cannot retransmit data in one layer and transmit new data in another layer to the same UE. Hence during retransmissions, the scheduler allows other UEs to use the resources. The reason is: the next TB can only be sent after receiving a successful ACK or if the current TB is dropped. Therefore, another TB (to the same UE) cannot be scheduled on the remaining resources. For example, if Max-throughput scheduling is used, when a CBG is received in error the NDI flag is false. When the NDI flag is false, the UE is not passed through the scheduler function; only the CB that needs to be transmitted is Hence remaining PRBs left - after retransmitting the errored CBG - must be allocated to a not Max-SINR UE. Also note that, the not Max-SINR UE’s CBGs may also be errored in which case those CBGs need to be retransmitted. This above complicated factor leads to a break down in the general belief that Max-throughput scheduler leads to Max-SINR UE getting all throughput with other UEs getting NIL throughput.

2. Again, consider a multi-layer scenario with CBG errors in 2 or more layers. How many PRBs should then be allocated for retransmissions and how many for new data from different UEs? In such cases NetSim calculates the PRBs required for retransmission as the max of PRBs required for retransmission in each layer.

3.6.6.6 Logging

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Time (ms)	gNBId	gNBIf	UEId	UEIf	Channel	CA	FrameId	Sub	SlotId	LayerId	ProcessId	Re	TBS	Modulation	CodeI	CBS	CBS_	SINR(Combined	BLE	CBG	CBI(	NDI	Tra
13000.5	10	4	12	1	PDSCH	0	1301	1	2	1	1		888	256QAM	711	968	888	43.169552	0	1	1	TRUE	(
13000.5	10	4	12	1	PDSCH	0	1301	1	2	2	1		888	256QAM	711	968	888	50.511929	0	1	1	TRUE	(
13000.5	10	4	12	1	PDSCH	0	1301	1	2	3	1		888	256QAM	711	968	888	56.157132	0	1	1	TRUE	(
13000.5	10	4	12	1	PDSCH	0	1301	1	2	4	1		888	256QAM	711	968	888	58.955028	0	1	1	TRUE	(
13001.5	10	4	12	1	PUSCH	0	1301	2	2	1	1		888	256QAM	711	968	888	51.730194	0	1	1	TRUE	(
13003	10	4	12	1	PDSCH	0	1301	4	1	1	1		888	256QAM	711	968	888	43.169552	0	1	1	TRUE	(
13003	10	4	12	1	PDSCH	0	1301	4	1	2	1		888	256QAM	711	968	888	50.511929	0	1	1	TRUE	(
13003	10	4	12	1	PDSCH	0	1301	4	1	3	1		888	256QAM	711	968	888	56.157132	0	1	1	TRUE	(
13003	10	4	12	1	PDSCH	0	1301	4	1	4	1		888	256QAM	711	968	888	58.955028	0	1	1	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	1	1		80808	256QAM	711	8448	8112	43.169552	0	1	1	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	1	1		80808	256QAM	711	8448	8112	43.169552	0	1	2	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	1	1		80808	256QAM	711	8448	8112	43.169552	0	2	1	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	1	1		80808	256QAM	711	8448	8112	43.169552	0	2	2	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	1	1		80808	256QAM	711	8448	8112	43.169552	0	3	1	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	1	1		80808	256QAM	711	8448	8112	43.169552	0	4	1	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	1	1		80808	256QAM	711	8448	8112	43.169552	0	5	1	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	1	1		80808	256QAM	711	8448	8112	43.169552	0	6	1	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	1	1		80808	256QAM	711	8448	8112	43.169552	0	7	1	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	1	1		80808	256QAM	711	8448	8112	43.169552	0	8	1	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	2	1		80808	256QAM	711	8448	8112	50.511929	0	1	1	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	2	1		80808	256QAM	711	8448	8112	50.511929	0	1	2	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	2	1		80808	256QAM	711	8448	8112	50.511929	0	2	1	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	2	1		80808	256QAM	711	8448	8112	50.511929	0	2	2	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	2	1		80808	256QAM	711	8448	8112	50.511929	0	3	1	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	2	1		80808	256QAM	711	8448	8112	50.511929	0	4	1	TRUE	(
13005.5	10	4	12	1	PDSCH	0	1301	6	2	2	1		80808	256QAM	711	8448	8112	50.511929	0	5	1	TRUE	(

Figure 3-11: HARQ log file showing code block transmission. Here CBS_ represents the information bits within a code block (CBS column).

1. Transmission attempts 1, 2, 3 and 4 are indexed as 0, 1, 2, 3. If the 4th attempt is errored, the CBG is dropped.
2. Packet trace only logs "packet" flow, and does not log flow of TBs, CBGs etc. Therefore, the packet trace logs a packet in the MAC OUT of the transmitter and subsequently if received successfully at the MAC IN of the receiver. If the packet errored, it is also marked in the packet trace.
3. Note that if a TB is in error than all the packets that were part of the TB will be marked as error.
4. The transmission/re-transmission of CBs is logged in the Code Block logfile.
5. The remarks column would have messages for HARQ preparation and would be blank for actual transmissions.
6. TBS is always logged on a per layer basis.
7. CBGID is also on a per layer basis.
8. SINR reported in the CBG log is the post-soft combining SINR.

Time (ms)	gNBId	gNBIf	UEId	UEIf	Channel	CA	FrameId	Sub	SlotId	LayerId	ProcessId	Re	TBS	Modulation	Code	CBS	CBS_	SINR(Combined	BL
160.999	9	4	11	1		0	17	1	2	0	N/A	HARQ entity created							
160.999	9	4	13	1		0	17	1	2	0	N/A	HARQ entity created							
160.999	10	4	12	1		0	17	1	2	0	N/A	HARQ entity created							
160.999	10	4	14	1		0	17	1	2	0	N/A	HARQ entity created							
161	9	4	11	1	PUSCH	0	17	2	1	0	1	Process number = 1, NDI = True, Transmission number = 0							
161	9	4	13	1	PUSCH	0	17	2	1	0	1	Process number = 1, NDI = True, Transmission number = 0							
161	9	4	11	1	PUSCH	0	17	2	1	0	1	Allocated PRBs for new data = 0							
161	9	4	13	1	PUSCH	0	17	2	1	0	1	Allocated PRBs for new data = 0							
161	10	4	12	1	PUSCH	0	17	2	1	0	1	Process number = 1, NDI = True, Transmission number = 0							
161	10	4	14	1	PUSCH	0	17	2	1	0	1	Process number = 1, NDI = True, Transmission number = 0							
161	10	4	12	1	PUSCH	0	17	2	1	0	1	Allocated PRBs for new data = 0							
161	10	4	14	1	PUSCH	0	17	2	1	0	1	Allocated PRBs for new data = 0							
161.5	9	4	11	1	PUSCH	0	17	2	2	0	1	Process number = 1, NDI = True, Transmission number = 0							
161.5	9	4	13	1	PUSCH	0	17	2	2	0	1	Process number = 1, NDI = True, Transmission number = 0							
161.5	9	4	11	1	PUSCH	0	17	2	2	0	1	Allocated PRBs for new data = 0							
161.5	9	4	13	1	PUSCH	0	17	2	2	0	1	Allocated PRBs for new data = 0							
161.5	10	4	12	1	PUSCH	0	17	2	2	0	1	Process number = 1, NDI = True, Transmission number = 0							
161.5	10	4	14	1	PUSCH	0	17	2	2	0	1	Process number = 1, NDI = True, Transmission number = 0							
161.5	10	4	12	1	PUSCH	0	17	2	2	0	1	Allocated PRBs for new data = 0							
161.5	10	4	14	1	PUSCH	0	17	2	2	0	1	Allocated PRBs for new data = 0							
162	9	4	11	1	PUSCH	0	17	3	1	0	1	Process number = 1, NDI = True, Transmission number = 0							
162	9	4	13	1	PUSCH	0	17	3	1	0	1	Process number = 1, NDI = True, Transmission number = 0							
162	9	4	11	1	PUSCH	0	17	3	1	0	1	Allocated PRBs for new data = 0							
162	9	4	13	1	PUSCH	0	17	3	1	0	1	Allocated PRBs for new data = 0							
162	10	4	12	1	PUSCH	0	17	3	1	0	1	Process number = 1, NDI = True, Transmission number = 0							
162	10	4	14	1	PUSCH	0	17	3	1	0	1	Process number = 1, NDI = True, Transmission number = 0							

Figure 3-12: HARQ log showing HARQ working via information provided in the Remarks columns.

3.6.6.7 HARQ turn off

There are ongoing discussions of abandoning of HARQ for the 1 ms end-to-end latency use case of URLLC. This decision implies that the code rate had to be lowered such that a single shot transmission, i.e., no retransmissions and no feedback, achieves the required BLER.

NetSim allows users to turn HARQ OFF via the GUI. Note that the code block log will continue to be written. Users will notice that errored CBGs are not retransmitted if HARQ is turned OFF. Since the CB/CBG is in error, that entire TB to which it belongs will be in error.

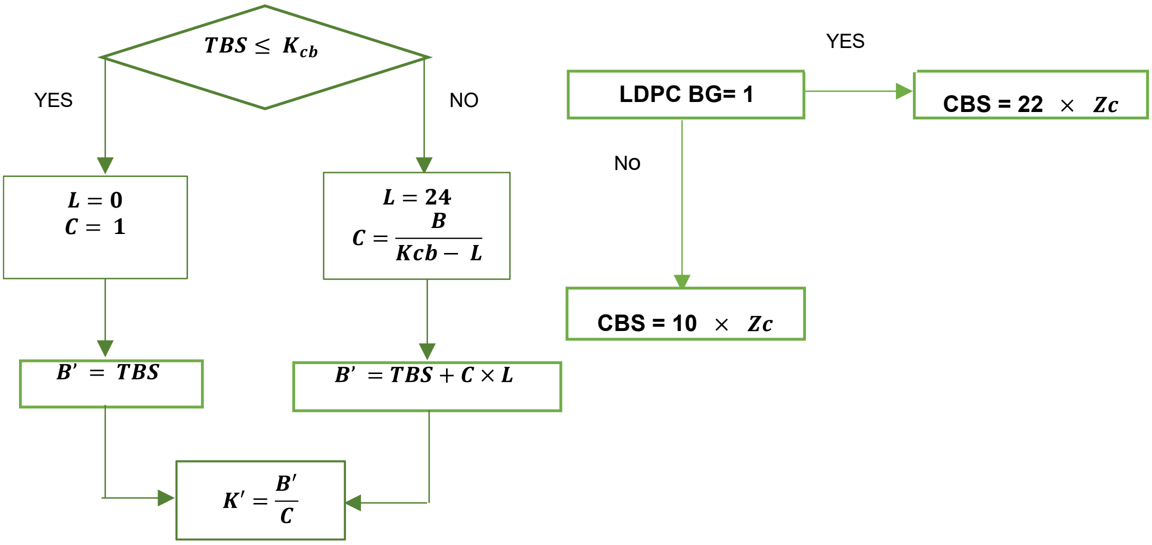
Users can inspect the packet trace and will see large numbers of packets errors if HARQ is turned OFF and if the UE is seeing a high BLER.

3.6.7 Segmentation of transport block into code blocks

1. If the transport block size is larger than 3824, a 16-bit CRC is added at the end of the transport block or 24-bit CRC is added.
2. The transport block is divided into multiple equal size code blocks when the transport block size exceeds a threshold.
3. For quasi-cyclic low-density parity-check code (QC-LDPC) base graph 1, the threshold is equal to 8448.
4. For QC-LDPC base graph 2, the threshold is equal to 3840. In 5G NR, the maximum code block size number is 8448.
5. An additional 24-bit CRC is added at the end of each code block when there is a segmentation.
6. A CBG can have up to 2/4/6/8 CBs.

7. Maximum transport block size - 1,277,992.

LDPC BG 1, CBS Max, (K_{cb}) = 8448, LDPC BG 2, CBS Max, (K_{cb}) = 3840



L = Extra CRC bits, C = Number of Code blocks, TBS = Size of Transport block, K' = Information bits in code block. The base matrix expansion factor Zc is calculated by selecting minimum Zc in all sets of lifting size tables, such that: $K_b \times Zc \geq K$. K_b denotes the number of information bit columns for the lifting size Zc.

3.6.8 BLER and MCS selection

NetSim GUI allows users to set the BLER, via the BLER drop down option. This option has two settings, and each setting in turn has different options for MCS selection. Both BLER and MCS selection are global options and will apply to all Macro Cell eNBs and UEs in both DL and UL in the network scenario.

1. Zero BLER
   - MCS Selection: Ideal Shannon theorem-based rate
     - Spectral efficiency is calculated assuming ideal Shannon rate whereby

$$SpectralEfficiency = \log_2(1 + SINR)$$

     - Spectral Efficiency - MCS Table 7.2.3-1 (4-bit CQI Table) of standard 36.213 is looked up to select the MCS.
     - Data is transmitted at this MCS with zero BLER
   - MCS Selection: Shannon rate with attenuation factor
     - Spectral efficiency is calculated per the following expression provided in TR 36.942:

$$SpectralEfficiency = \alpha \times \log_2(1 + SINR)$$

- α is the attenuation factor and generally $0.5 \leq \alpha \leq 1.00$. Default: 0.75Spectral Efficiency - MCS Table 7.2.3-1 (4-bit CQI Table) of standard 36.213 is looked up to select the MCS.
- Data is transmitted at this MCS with zero BLER

2. BLER Enable: Within this, users can set outer loop link adaptation (OLLA) to True or False
   - OLLA False: The MCS is chosen in the same way as described in the Zero BLER case. Data is, however, transmitted at the chosen MCS, with BLER. The BLER is looked up from NetSim's proprietary BLER-MCS-SINR curves.
   - OLLA True: In this case, the user needs to set a target BLER (t-BLER), for example 10%. Based upon the set t-BLER an initial MCS is "guessed". Subsequently, the MCS is dynamically adjusted based on an outer-loop link adaptation algorithm that uses HARQ ACK-NACK messages. Note that the t-BLER is based on initial transmission and not after a re-transmission.

3.6.9 PHY measurements

All PHY measurements, downlink and uplink, are done on the actual transmitted data on the data channel. The measurements are not done using control the control channels.

The measurements are wideband i.e., a single value of channel state that is deemed representative of all RBs in use. This assumes that the PHY layer that the channel is flat across all the RBs. Such an assumption ensures acceptable accuracy for a system level simulation while keeping the computational complexity manageable.

The SNR in downlink (received by a UE from a eNB/gNB) and in the uplink (received by an eNB/gNB from a UE). The SNR is calculated at every slot and thereafter the SNR gets averaged after every "Average_SNR_Window" time frame to go forward and compute the AMC (Modulation & coding) information, and for each carrier as:

- SNR = Received power / Thermal Noise.
- Interference from other UEs / eNBs are not considered.
- The received power is transmit power less propagation loss.
- The MCS values are chosen based on the received SNR.

3.6.10 Carrier Aggregation

Carrier aggregation is a feature that LTE-A uses to increase the bandwidth, and the bitrate. An aggregated carrier is known as a component carrier (CC). The component carrier can have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz and a maximum of five component carriers can be aggregated. So, the maximum aggregated bandwidth is 100 MHz.

Carrier aggregation can be used: Frequency Division Duplex (FDD) and Time Division Duplex (TDD). The following figure illustrates the use of FDD.

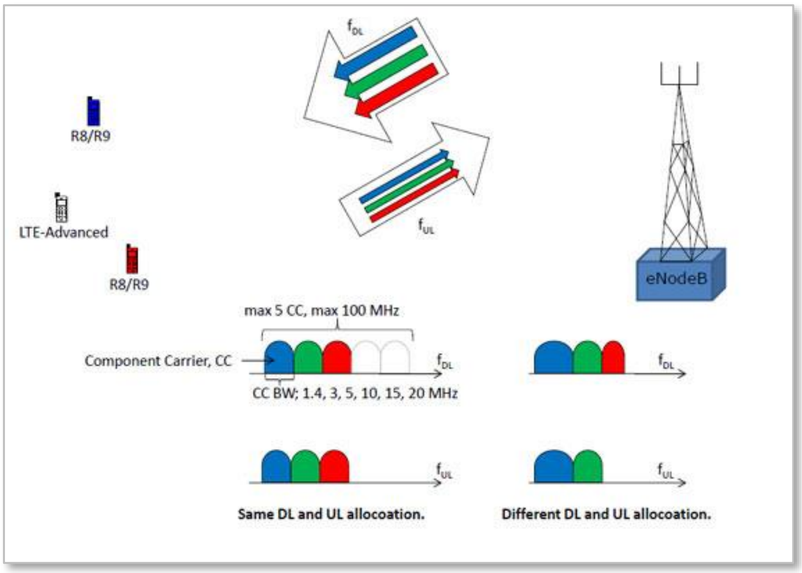


Figure 3-13: Illustrates the Carrier aggregation

FDD can use different number of component carriers in the Downlink (DL) and Uplink (UL). But, the number of UL component carriers must always be equal to or lower than the number of DL component carriers. Also, the individual component carriers can use different bandwidths.

TDD uses the same number of component carriers with identical bandwidths for DL and UL.

3.6.10.1 CA Configurations

CA can be configured into intra-band (contiguous and non-contiguous) and inter-band non-contiguous. Intra-band contiguous and inter-band combinations, that aggregate two Component Carriers (CCs) in downlink, are specified from Release 10.

The Intra-band contiguous CA configuration refers to contiguous carriers aggregated in the same operating band.

The Intra-band non-contiguous CA configuration refers to non-contiguous carriers aggregated in the same operating band.

The Inter-band CA configuration refers to aggregation of component carriers in different operating bands, where the carriers aggregated in each band can be contiguous or non-contiguous.

The following figure illustrates the CA configurations.

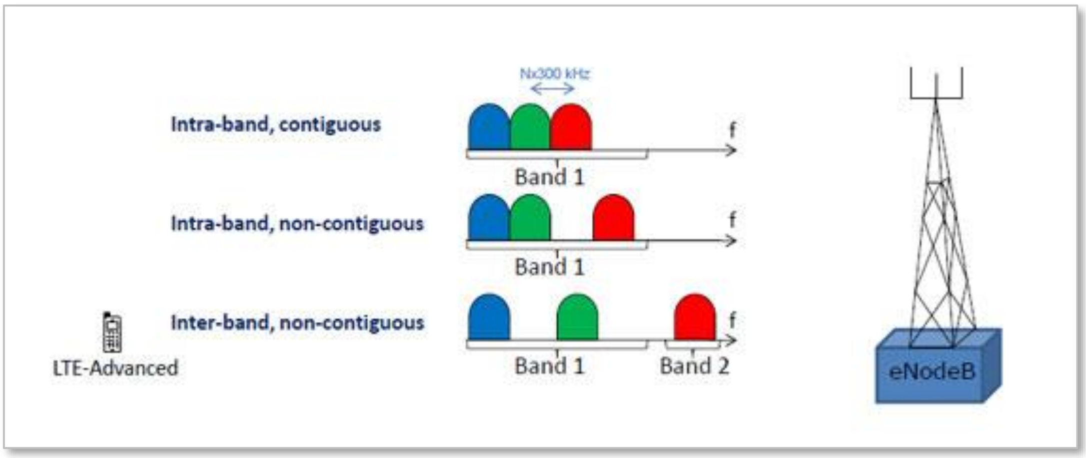


Figure 3-14: Illustrates the CA configurations

3.6.10.2 CA Bandwidth Classes

The following table lists the details of the Carrier Aggregation Bandwidth classes in terms of the total number of Resource blocks used by the CC.

For example, Bandwidth class A specifies N_RB,agg <= 100. This means that the Number of the aggregated RBs within the fully allocated Aggregated Channel bandwidth (NRB,agg) should be less than 100 and the aggregated Tx Bandwidth for class A cannot exceed 20 MHz, and limits to 1 CC in the band.

NOTE: NetSim currently supports CA Bandwidth classes A, B and C only.

Class	Aggregated Transmission Bandwidth		Maximum number of CC
	NRB,agg	Maximum Tx	
A	N <= 100	20	1
B	25 < N <=	20	2
C	100 < N <=	40	2
D	200 < N <=	60	3
E	300 < N <=	80	4
F	400 < N <=	100	5
I	700 < N <=	160	8

Table 3-6: CA Bandwidth classes

3.6.10.3 CA Configuration Naming Conventions

To understand the naming conventions in a CA configuration and the bandwidth combination set usage, let us see the CA_1C configuration. This CA configuration states that the UE can operate on Band 1, with two continuous CCs and with a maximum of 200 RBs. The bandwidth combination set states that the allocation of those 200 RBs can be either 75 RBs on both CCs or 100RBs on both CCs.

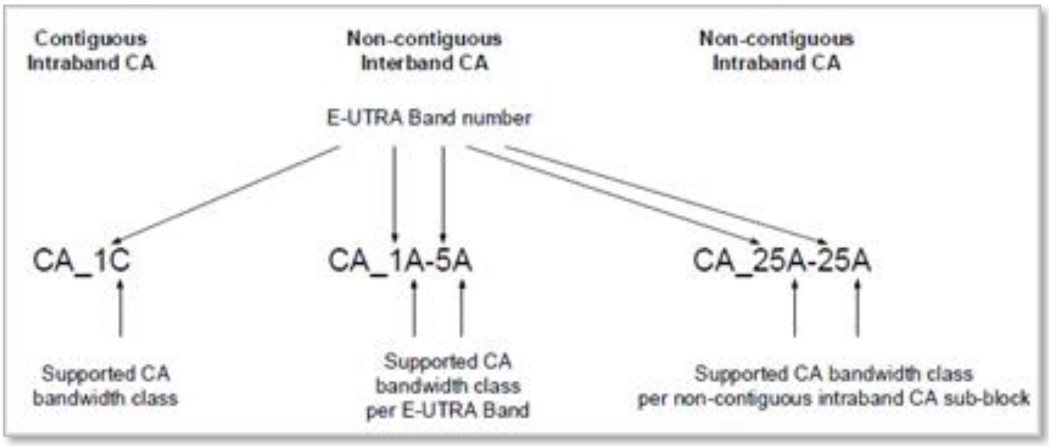


Figure 3-15: CA Configuration Naming Conventions

For more information about Carrier Aggregation, see

https://www.3gpp.org/technologies/keywords-acronyms/101-carrier-aggregation-explained.

3.6.10.4 CA Configuration Table (based on TR 36 716 01-01)

Carrier aggregation can be configured in the Macro cell eNB's Physical layer properties. Following are the various configuration options that are available as shown Table 3-7 and Table 3-8.

FDD Bands:

CA Configuration Table							
CA Configuration	**CA Count**	**CA Type**	**Frequency Range**	**Uplink Low (MHz)**	**Uplink High (MHz)**	**Downlink Low (MHz)**	**Downlink High (MHz)**
INTER_BAND_CA							
CA_1A_3A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1920, 1710	1980, 1785	2110, 1805	2170, 1880
CA_3A_7A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 2500	1785, 2570	1805, 2620	1880, 2690
CA_3A_20A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 832	1785, 862	1805, 791	1880, 821
CA_3A_28A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 703	1785, 748	1805, 758	1880, 803
CA_3A_8A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 880	1785, 915	1805, 925	1880, 960
CA_7A_20A	2	CA1_UL, CA1_DL,	FR1	2500, 832	2570, 862	2620, 791	2690, 821

		CA2_UL, CA2_DL					
CA_7A_28A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	2500, 703	2570, 748	2620, 758	2690, 803
CA_28A_32A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	703, 1452	748, 1496	758, 1452	803, 1496
CA_1A_3A_7A	3	CA1_UL, CA1_DL, CA2_UL, CA2_DL, CA3_UL, CA3_DL	FR1	1920, 1710, 2500	1980, 1785, 2570	2110, 1805, 2620	2170, 1880, 2690
CA_3A_7A_20A	3	CA1_UL, CA1_DL, CA2_UL, CA2_DL, CA3_UL, CA3_DL	FR1	1710, 2500, 832	1785, 2570, 862	1805, 2620, 791	1880, 2690, 821
INTRA_BAND_CONTIGUOUS_CA							
CA_1C	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1920, 1920	1980, 1980	2110, 2110	2170, 2170
CA_2C	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1850, 1850	1910, 1910	1930, 1930	1990, 1990
CA_3B	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 1710	1785, 1785	1805, 1805	1880, 1880
CA_3C	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 1710	1785, 1785	1805, 1805	1880, 1880
CA_5B	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	824, 824	849, 849	869, 869	894, 894
CA_7B	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	2500, 2500	2570, 2570	2620, 2620	2690, 2690
CA_7C	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	2500, 2500	2570, 2570	2620, 2620	2690, 2690
CA_8B	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	880, 880	915, 915	925, 925	960, 960
CA_12B	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	699, 699	716, 716	729, 729	746, 746

CA_27B	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	807, 807	824, 824	852, 852	869, 869
CA_28C	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	703, 703	748, 748	758, 758	803, 803
CA_66B	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 1710	1780, 1780	2110, 2110	2200, 2200
CA_66C	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 1710	1780, 1780	2110, 2110	2200, 2200
CA_66D	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 1710	1780, 1780	2110, 2110	2200, 2200
CA_70C	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1695, 1695	1710, 1710	1995, 1995	2020, 2020
INTRA_BAND_NONCONTIGUOUS_CA							
CA_1A_1A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1920, 1920	1980, 1980	2110, 2110	2170, 2170
CA_2A_2A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1850, 1850	1910, 1910	1930, 1930	1990, 1990
CA_3A_3A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 1710	1785, 1785	1805, 1805	1880, 1880
CA_4A_4A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 1710	1755, 1755	2110, 2110	2155, 2155
CA_5A_5A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	824, 824	849, 849	869, 869	894, 894
CA_7A_7A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	2500, 2500	2570, 2570	2620, 2620	2690, 2690
CA_12A_12A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	699, 699	716, 716	729, 729	746, 746
CA_23A_23A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	2000, 2000	2020, 2020	2180, 2180	2200, 2200

CA_25A_25A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1850, 1850	1915, 1915	1930, 1930	1995, 1995
CA_66A_66A	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 1710	1780, 1780	2110, 2110	2200, 2200
CA_66A_66B	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 1710	1780, 1780	2110, 2110	2200, 2200
CA_66A_66C	2	CA1_UL, CA1_DL, CA2_UL, CA2_DL	FR1	1710, 1710	1780, 1780	2110, 2110	2200, 2200
CA_25A_25A_25A	3	CA1_UL, CA1_DL, CA2_UL, CA2_DL, CA3_UL, CA3_DL	FR1	1850, 1850, 1850	1915, 1915, 1915	1930, 1930, 1930	1995, 1995, 1995
CA_66A_66A_66A	3	CA1_UL, CA1_DL, CA2_UL, CA2_DL, CA3_UL, CA3_DL	FR1	1710, 1710, 1710	1780, 1780, 1780	2110, 2110, 2110	2200, 2200, 2200
SINGLE_BAND							
BAND_1	1	CA1	FR1	1920	1980	2110	2170
BAND_2	1	CA1	FR1	1850	1910	1930	1990
BAND_3	1	CA1	FR1	1710	1785	1805	1880
BAND_4	1	CA1	FR1	1710	1755	2110	2155
BAND_5	1	CA1	FR1	824	849	869	894
BAND_6	1	CA1	FR1	830	840	875	885
BAND_7	1	CA1	FR1	2500	2570	2620	2690
BAND_8	1	CA1	FR1	880	915	925	960
BAND_9	1	CA1	FR1	1749.9	1784.9	1844.9	1879.9
BAND_10	1	CA1	FR1	1710	1770	2110	2170
BAND_11	1	CA1	FR1	1427.9	1447.9	1475.9	1495.9
BAND_12	1	CA1	FR1	699	716	729	746
BAND_13	1	CA1	FR1	777	787	746	756
BAND_14	1	CA1	FR1	788	798	758	768
BAND_17	1	CA1	FR1	704	716	734	746
BAND_18	1	CA1	FR1	815	830	860	875
BAND_19	1	CA1	FR1	830	845	875	890
BAND_20	1	CA1	FR1	832	862	791	821
BAND_21	1	CA1	FR1	1447.9	1462.9	1495.9	1510.9
BAND_22	1	CA1	FR1	3410	3490	3510	3590
BAND_23	1	CA1	FR1	2000	2020	2180	2200
BAND_24	1	CA1	FR1	1626.5	1660.5	1525	1559
BAND_25	1	CA1	FR1	1850	1915	1930	1995
BAND_26	1	CA1	FR1	814	849	859	894

BAND_27	1	CA1	FR1	807	824	852	869
BAND_28	1	CA1	FR1	703	748	758	803
BAND_30	1	CA1	FR1	2305	2315	2350	2360
BAND_31	1	CA1	FR1	452.5	457.5	462.5	467.5
BAND_65	1	CA1	FR1	1920	2010	2110	2200
BAND_66	1	CA1	FR1	1710	1780	2110	2200
BAND_68	1	CA1	FR1	698	728	753	783
BAND_70	1	CA1	FR1	1695	1710	1995	2020
BAND_71	1	CA1	FR1	663	698	617	652
BAND_72	1	CA1	FR1	451	456	461	466
BAND_73	1	CA1	FR1	450	455	460	465
BAND_74	1	CA1	FR1	1427	1470	1475	1518
BAND_85	1	CA1	FR1	698	716	728	746
BAND_87	1	CA1	FR1	410	415	420	425
BAND_88	1	CA1	FR1	412	417	422	427

Table 3-7: CA Configuration Table for FDD bands

TDD Bands:

CA Configuration	CA Count	CA Type	Frequency Range	Uplink Low (MHz)	Uplink High (MHz)
INTER_BAND_CA					
DL_2A-48A_UL_2A-48A_BCS0	2	CA1, CA2	FR1	3550, 3550	3700, 3700
DL_2A-48A-48A_UL_2A-48A_BCS0	2	CA1, CA2	FR1	3550, 3550	3700, 3700
DL_2A-48A-48C_UL_2A-48A_BCS0	2	CA1, CA2	FR1	3550, 3550	3700, 3700
DL_2A-48C_UL_2A-48A_BCS0	2	CA1, CA2	FR1	3550, 3550	3700, 3700
DL_2A-48D_UL_2A-48A_BCS0	2	CA1, CA2	FR1	3550, 3550	3700, 3700
DL_2A-48A-48D_UL_2A-48A_BCS0	2	CA1, CA2	FR1	3550, 3550	3700, 3700
DL_2A-48E_UL_2A-48A_BCS0	2	CA1, CA2	FR1	3550, 3550	3700, 3700
DL_2A-48A-48E_UL_2A-48A_BCS0	2	CA1, CA2	FR1	3550, 3550	3700, 3700
INTRA_BAND_CONTIGUOUS_CA					
CA_3DL_41D_3UL_41D_BCS0	3	CA1, CA2, CA3	FR1	2496, 2496, 2496	2690, 2690, 2690
CA_4DL_41E_3UL_41D_BCS0	4	CA1, CA2, CA3, CA4	FR1	2496, 2496, 2496, 2496	2690, 2690, 2690, 2690
CA_5DL_41F_3UL_41D_BCS0	5	CA1, CA2, CA3, CA4, CA5	FR1	2496, 2496, 2496, 2496, 2496	2690, 2690, 2690, 2690, 2690
2DL_48C_2UL_48C_BCS0	2	CA1, CA2	FR1	3550, 3550	3700, 3700

3DL_48D_2UL_48C_BCS0	3	CA1, CA2, CA3	FR1	3550, 3550, 3550	3700, 3700, 3700
4DL_48E_2UL_48C_BCS0	4	CA1, CA2, CA3, CA4	FR1	3550, 3550, 3550, 3550	3700, 3700, 3700, 3700
CA_48A_48B	2	CA1, CA2	FR1	3550, 3550	3700, 3700
CA_48B_48B	2	CA1, CA2	FR1	3550, 3550	3700, 3700
CA_48B_48C	2	CA1, CA2	FR1	3550, 3550	3700, 3700
CA_48B_48D	2	CA1, CA2	FR1	3550, 3550	3700, 3700
CA_48B_48E	2	CA1, CA2	FR1	3550, 3550	3700, 3700
INTRA_BAND_NONCONTIGUOUS_CA					
CA_2DL_42A-42A_1UL_BCS1	2	CA1, CA2	FR1	3400, 3400	3600, 3600
CA_3DL_42A-42C_2UL_42C_BCS1	3	CA1, CA2, CA3	FR1	3400, 3400, 3400	3600, 3600, 3600
CA_4DL_42C-42C_2UL_42C_BCS1	4	CA1, CA2, CA3, CA4	FR1	3400, 3400, 3400, 3400	3600, 3600, 3600, 3600
3DL_48A-48C_2UL_48C_BCS0	3	CA1, CA2, CA3	FR1	3550, 3550, 3550	3700, 3700, 3700
4DL_48C-48C_2UL_48C_BCS0	4	CA1, CA2, CA3, CA4	FR1	3550, 3550, 3550, 3550	3700, 3700, 3700, 3700
SINGLE_BAND					
BAND_33	1	CA1	FR1	1900	1920
BAND_34	1	CA1	FR1	2010	2025
BAND_35	1	CA1	FR1	1850	1910
BAND_36	1	CA1	FR1	1930	1990
BAND_37	1	CA1	FR1	1910	1930
BAND_38	1	CA1	FR1	2570	2620
BAND_39	1	CA1	FR1	1880	1920
BAND_40	1	CA1	FR1	2300	2400
BAND_41	1	CA1	FR1	2496	2690
BAND_42	1	CA1	FR1	3400	3600
BAND_43	1	CA1	FR1	3600	3800
BAND_44	1	CA1	FR1	703	803
BAND_45	1	CA1	FR1	1447	1467
BAND_46	1	CA1	FR1	5150	5925
BAND_47	1	CA1	FR1	5855	5925
BAND_48	1	CA1	FR1	3550	3700
BAND_49	1	CA1	FR1	3550	3700
BAND_50	1	CA1	FR1	1432	1517
BAND_51	1	CA1	FR1	1427	1432

BAND_52	1	CA1	FR1	3300	3400
BAND_53	1	CA1	FR1	2483.5	2495

Table 3-8: CA Configuration Table for TDD bands

3.6.11 Downlink Interference Model

3.6.11.1 Configuration

Downlink Interference Model can be configured in the eNB's LTE interface properties under Interference model section of Physical Layer as shown below:

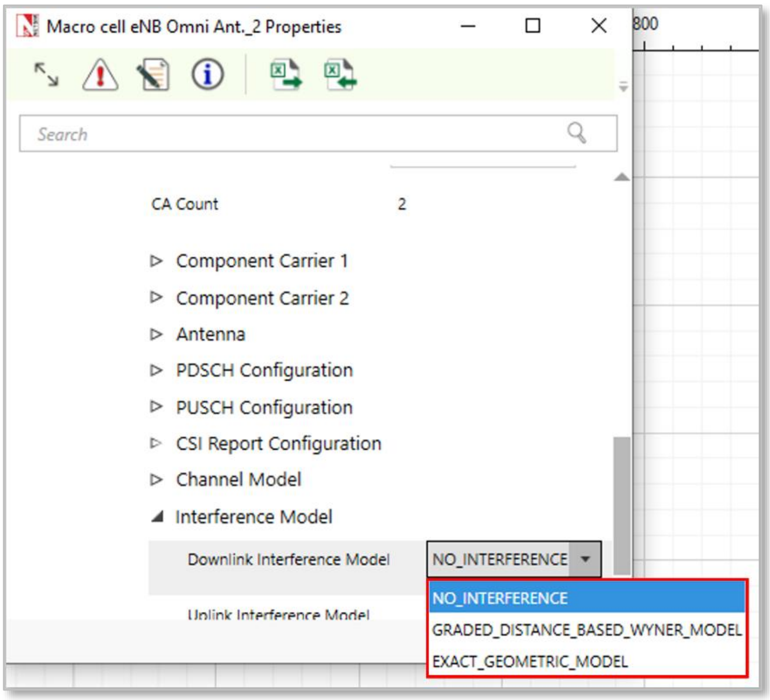


Figure 3-16: eNB >Interface (LTE) >Physical layer properties

Downlink Interference Model is set to NO_INTERFERENCE by default.

3.6.11.2 Graded distance-based Wyner model

The Wyner model is widely used to model and analyze cellular networks due to its simplicity and analytical tractability. In this model:

- Only interference from (two) adjacent cells is considered.
- Random user locations and path loss variations are ignored, and
- The interference intensity from each neighboring base station (BS) is characterized by a single fixed parameter $0 \leq \alpha \leq 1$). The channel gain between BS and its home user is 1 and the intercell interference intensity is α. Thus, a user sees a constant interference irrespective of its location.

These three simplifications lose a lot of information. We alter the Wyner model to address these flaws by:

- Considering interference from arbitrary number of BSs
- Factoring in the user location. The UEs distance from the interfering BS is an obvious factor that determines the interference intensity since the amount of interference caused depends on the signal attenuation with distance, the path loss law. Since the Wyner model uses relative interference, the ratio of a UEs distance from serving and interfering BSs is used as one of the interference parameters.
- Using a graded interference intensity model, whereby a UE will see a different value of α at different locations, thereby modelling the effect of interference more accurately.

3.6.11.2.1 Technical description

- We model DL interference from any number of interfering BSs. Let BS_i be the serving BS to UE_k. Let BS_j be any other BS ($j \neq i$). Then the distance between UE_k and BS_i is denoted as $D_{UE_k}^{BS_i}$, while the distance between UE and BS_j is denoted as $D_{UE_k}^{BS_j}$.
- A UE sees interference if $\frac{\left(D_{UE_K}^{BS_j} - D_{UE_K}^{BS_i}\right)}{D_{UE_K}^{BS_j}}$ is within a user defined threshold (for example, 20%). This ratio is also equal to $1 - \frac{D_{UE_k}^{BS_i}}{D_{UE_K}^{BS_j}}$. When $D_{UE_K}^{BS_i} \le D_{UE_K}^{BS_j}$, we see that $0 \le \frac{\left(D_{UE_K}^{BS_j} - D_{UE_K}^{BS_i}\right)}{D_{UE_K}^{BS_j}} \le 1$. The ratio is 0 when $D_{UE_K}^{BS_i} = D_{UE_K}^{BS_j}$ and is 1 when $D_{UE_K}^{BS_i} = 0$. When $D_{UE_K}^{BS_i} = D_{UE_K}^{BS_j}$ the UE is equidistant from both BS i.e., at the cell edge. When $D_{UE_K}^{BS_i} = 0$, the UE is at the centre of the serving BS, BS_i.
- Users at the cell-edge will see out of cell interference; as the user moves closer to the cell centre, it sees lesser interference.
- We call this user defined threshold as differential distance ratio threshold and denote it by DDR_{th}. The DDR threshold is used to define K thresholds, which are in turn used to determine the out of cell interference experienced by UE_k, as explained below. First, we bin the DDR_{th}, conditional on $D_{UE_K}^{BS_i} \le D_{UE_K}^{BS_j}$, into K steps, as follows:

$$0 \le \frac{\left(D_{UE_K}^{BS_j} - D_{UE_K}^{BS_i}\right)}{D_{UE_K}^{BS_j}} < \left(\frac{DDR_{th}}{K}\right) \times 1$$

$$\left(\frac{DDR_{th}}{K}\right) \times 1 \le \frac{\left(D_{UE_K}^{BS_j} - D_{UE_K}^{BS_i}\right)}{D_{UE_K}^{BS_j}} < \left(\frac{DDR_{th}}{K}\right) \times 2$$

...

...

$$\left(\frac{DDR_{th}}{K}\right) \times (K-1) \leq \frac{\left(D_{UE_K}^{BS_j} - D_{UE_K}^{BS_i}\right)}{D_{UE_K}^{BS_j}} < \left(\frac{DDR_{th}}{K}\right) \times K$$

$$\left(\frac{DDR_{th}}{K}\right) \times K \leq \frac{\left(D_{UE_K}^{BS_j} - D_{UE_K}^{BS_i}\right)}{D_{UE_K}^{BS_j}}$$

Where DDR_{th}, is a user input varying from 0.00 to 1.00 (default is 0.1 or 10%), and K, the number of steps, is a user input varying from 1 to 4 (default is 1).

- The relative interference for each of these steps would be I_n $(0 \leq n \leq K)$ where K is the number of steps and n represents each individual step ($n = p$ if the p^{th} inequality in the above is satisfied, counting the first inequality as the zeroth inequality).
- We specify the interference power relative to the power received from BS_i. Therefore, given the value of I_n, interference power is calculated as the received power from BS_i (excluding beamforming gain) less I_n. Thus

  $$InterferencePowerfromBS_j\ (dB) = \ ReceivedPowerfromBS_i(dBm) - I_n^j(dB)$$

  Therefore, we have $I_n^i(dB) = \ P_{serving}^{BS}(dBm) - \ P_{Interfering}^{BS}(dBm)$. This is equivalent to the Wyner model with $\alpha = \frac{P_{Interfering}^{BS}}{P_{serving}^{BS}}$ in the linear scale; however, note that in our interference model, α depends on the UE's location, because I_n depends on the distance.
- This interference powers (linear) from all interfering BSs are added to the noise power (in linear scale) and then

  $$SINR = \frac{Received\ power\ from\ BS_i + BeamFormingGain}{NoisePower + \sum InterferencePower}$$

- Each I_n is a user input. It is subject to the limits $0 \leq I_n \leq 20\ dB$. NetSim will enforce the sanity check $20 \geq\ I_K \geq\ I_{K-1} \geq\ ... \geq\ I_0 \geq 0$. Here I_K is the relative interference seen when the UE is near BS_i and I_0 is the relative interference seen when the UE is nearly equidistant from its two nearest BSs (and hence far from BS_i).
- In an ideal case, when the user is at the cell edge, the received power from BS_i will be roughly equal to the received power from BS_j (since it is equidistant from the two BSs), and so $SINR_{CellEdge}$ will necessarily be less than 0 dB.
- As the UE moves away from the cell edge and towards BS_i, the received power from BS_i increases and that from BS_j decreases, and so the SINR improves. For this reason,

we have the limits on I_n as $0\ dB \leq I_n \leq 20\ dB$. If the user sets I_n to a large value, it will be equivalent to having no inter-cell interference.

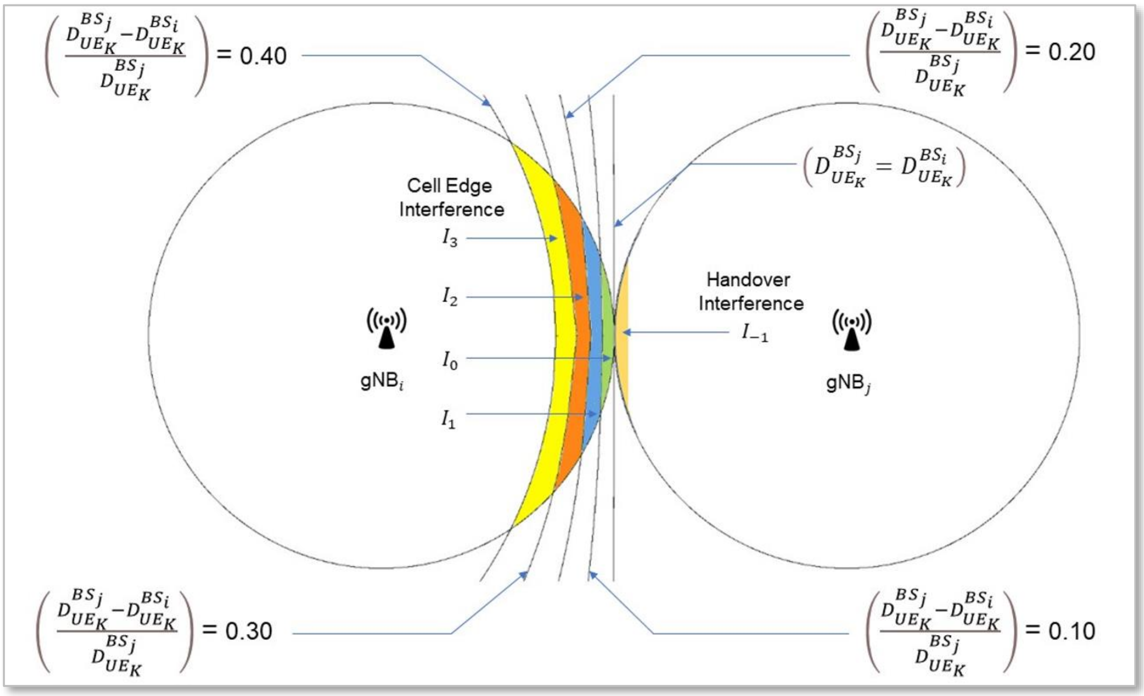


Figure 3-17: Interference zones are the regions within the four curves and the cell boundary of $\boldsymbol{gNB_i}$. This example is for a case involving just 2 BSs with $\boldsymbol{DDR = 0.4}$ and $\boldsymbol{K = 4}$. The four curves are therefore the equations where $\frac{\left(D_{UE_K}^{BS_j} - D_{UE_K}^{BS_i}\right)}{D_{UE_K}^{BS_j}}$ is equal to $\frac{k}{4} = \boldsymbol{0.1}$, $\frac{2k}{4} = \boldsymbol{0.2}$, $\frac{3k}{4} = \boldsymbol{0.3}$, and $\frac{4k}{4} = \boldsymbol{0.4}$. The handover interference region is also shown.

- In case $\frac{\left(D_{UE_K}^{BS_j} - D_{UE_K}^{BS_i}\right)}{D_{UE_K}^{BS_j}} > DDR_{th}$, the out of cell interference seen at the UE is set to I_K. The default value of I_K is 0, i.e., cell centre users do not see any out of cell interference. The default values of I_k for $k = 1, 2, \ldots, K-1$ is 10 dB.
- In NetSim, handover is triggered when the signal strength from BS_j is offset (3dB by default) higher than signal strength from BS_i. A handover is not triggered when UE_k is equidistant from both BSs but only when it is slightly nearer to BS_j. Therefore, the short time when $D_{UE_K}^{BS_i} \geq D_{UE_K}^{BS_j}$ is a special case requiring a different interference power. We term this interference as "Handover interference" and is a separate user input. Handover interference is denoted as I_{-1} and $-3dB \leq I_{-1} \leq 0\ dB$.

3.6.11.4 Exact Geometric Model

NetSim supports various 3GPP propagation models. These models are used to calculate the pathloss between every BS (eNB) and UE. One the parameters in the pathloss equations is the distance between the BS and the UE. Some of the other user settable parameters used in the 3GPP models are (i) Centre frequency (chosen from the band selected) (ii) Rural or Urban environments (iii) UE-BS channel is in LOS or NLOS (iv) Shadow-fading in the UE-BS channel (v) Indoor or outdoor UE location, etc., are also supported in NetSim.

Let BS_i be the serving BS to UE_k. Let BS_j be any other BS ($j \neq i$). UE_k communicates with BS_i while all other BSs ($j \neq i$) act as interferers.

The distance between UE_k and BS_i is denoted as $D_{UE_k}^{BS_i}$, while the distance between UE and BS_j is denoted as $D_{UE_k}^{BS_j}$. The power of the interfering signal from any BS_j at any UE_k depends on (i) the transmit power of the interfering BS and (ii) pathloss between the interfering BS and the UE. It can therefore be expressed as

$$I_{UE_k}^{BS_j} = P^{BS_j} - PL_{UE_k}^{BS_j}$$

where P^{BS_j} is the transmit power of BS_j, $PL_{UE_k}^{BS_j}$ represents the 3GPP model based pathloss between BS_j and UE_k. This pathloss is dependent on $D_{UE_k}^{BS_j}$ and the channel between BS_j and UE_k. The interference powers (linear) from all interfering BSs (i.e., apart from the serving BS) are added to the noise power (in linear scale) and we get the expression

$$SINR_{UE_k} = \frac{Received\ power\ from\ BS_i + BeamFormingGain}{NoisePower + \sum_j I_{UE_k}^{BS_j}}$$

The Wyner model is approximate but is computationally faster; the geometric model is precise but computationally slower due to the calculations involved.

3.6.11.5 Interference modeling in OFDM in NetSim

NetSim doesn’t model the allocation of specific subcarriers to individual users. The aggregate resources are divided amongst the UEs per UEs’ requirements and the scheduling algorithm.

- The received power at UE_k from BS_i, with transmit power P_i is given (in the linear scale) as

$$P_{UE_k}^{BS_i} = \left(\frac{P_i}{PL_{UE_k}^{BS_i}}\right)$$

- I_{ik}^{j} or the interference in linear scale at a UE_k (associated with BS_i) from BS_j

- To normalize the power should we further multiply by the ratio given below

$$I_{ik} = \Sigma_j \, I_{ik}^{j} \times \left(\frac{RB_{UE_k}^{slot}}{RB_{total}^{slot}} \right)$$

- Assumptions:

A1. The above formula assumes the interference seen by UE_k is proportional to the number of RBs allotted to UE_k

A2. Fast fading is not accounted for in the interference calculations since it would require too much computational time, given that it needs to be re-calculated every coherence time.

- The total noise seen will be

$$k \times T \times \; RB_{UE_k}^{slot}$$

- The signal power $P_{UE_k}^{BS_i} \times \left(\frac{RB_{UE_k}^{slot}}{RB_{total}^{slot}} \right)$

Therefore,

$$SINR = \frac{P_{UE_k}^{BS_i} \times \left(\frac{RB_{UE_k}^{slot}}{RB_{total}^{slot}} \right)}{k \times T \times \; RB_{UE_k}^{slot} + \; \Sigma_j \, I_{ik}^{j} \times \left(\frac{RB_{UE_k}^{slot}}{RB_{total}^{slot}} \right)} = \frac{P_{UE_k}^{BS_i}}{k \times T \times \; RB_{total}^{slot} + \; \Sigma_j \, I_{ik}^{j}}$$

3.6.11.5.1 Interference in MIMO

- If UE_k is receiving from BS_i in multiple layers, the interference power I_{ik}^{j} is the same for all layers.

$$SINR_L = \frac{P_{UE_k}^{BS_i} \times \lambda_L}{k \times T \times \; RB_{total}^{slot} + \; \Sigma_j \, I_{ik}^{j}}$$

Where L represents a MIMO layer.

- Note that neither the noise nor the interference is divided by the layer count, because the combining vector has unit norm.

3.6.11.5.2 Limitations

- In the above interference formula NetSim assumes that all interfering BSs transmit data in that slot.
- The calculations need to be done for each slot. Enabling interference in the UI will slow down the simulation.

3.7 Data rate calculation

For NR, the approximate data rate for a given number of aggregated carriers in a band or band combination is computed as follows.

$$\text{Data rate (in Mbps)} = 10^{-6} \cdot \sum_{j=1}^{J} \left(v_{Layers}^{(j)} \cdot Q_m^{(j)} \cdot f^{(j)} \cdot R_{max} \cdot \frac{N_{PRB}^{BW(j),\mu} \cdot 12}{T_s^{\mu}} \cdot \left(1 - OH^{(j)}\right) \right)$$

wherein

J is the number of aggregated component carriers in a band or band combination.

R_{max} = 948/1024

For the j-th CC,

$v_{Layers}^{(j)}$ is the maximum number of supported layers given by higher layer parameter maxNumberMIMO-LayersPDSCH for downlink and maximum of higher layer parameters maxNumberMIMO-LayersCB-PUSCH and maxNumberMIMO-LayersNonCB-PUSCH for uplink.

$Q_m^{(j)}$ is the maximum supported modulation order given by higher layer parameter supportedModulationOrderDL for downlink and higher layer parameter supportedModulationOrderUL for uplink.

$f^{(j)}$ is the scaling factor given by higher layer parameter scalingFactor and can take the values 1.

μ is the numerology (value is always 0)

T_s^{μ} is the average OFDM symbol duration in a subframe for numerology μ, i.e. $T_s^{\mu} = \frac{10^{-3}}{14 \times 2^{\mu}}$. Note that normal cyclic prefix is assumed.

$N_{PRB}^{BW(j),\mu}$ is the maximum RB allocation in bandwidth $BW^{(j)}$ with numerology μ

$OH^{(j)}$ is the overhead and takes the following values.

0.14, for frequency range for DL

0.08, for frequency range for UL

NOTE: Only one of the UL or SUL carriers (the one with the higher data rate) is counted for a cell operating SUL.

3.8 LTE Metrics

3.8.1 LTE Packet trace

The LTE packet trace file has in its column the field CONTROL_PACKET_TYPE. This field has control and data packets information, this field contains control packets related RRC connection (RRC_MIB, RRC_SIB1, RRC_SETUP_REQUEST, RRC_SETUP_COMPLETE, RRC_SETUP), UE_MEASUREMENT_REPORT, and STATUSPDU.

PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	MAC_LAYER_ARRIVAL_TIME(US)	PHY
0	N/A	Control_Packet	RRC_MIB	ENB-1	Broadcast-0	80000	
0	N/A	Control_Packet	RRC_MIB	ENB-1	Broadcast-0	80000	
0	N/A	Control_Packet	RRC_SIB1	ENB-1	Broadcast-0	160000	
0	N/A	Control_Packet	RRC_SIB1	ENB-1	Broadcast-0	160000	
0	N/A	Control_Packet	RRC_MIB	ENB-1	Broadcast-0	160000	
0	N/A	Control_Packet	RRC_MIB	ENB-1	Broadcast-0	160000	
0	N/A	Control_Packet	RRC_SI	ENB-1	UE-2	159999.5	
0	N/A	Control_Packet	RRC_SI	ENB-1	UE-3	159999.5	
0	N/A	Control_Packet	RRC_SETUP_REQUEST	UE-2	ENB-1	161999.5	
0	N/A	Control_Packet	RRC_SETUP_REQUEST	UE-3	ENB-1	161999.5	
0	N/A	Control_Packet	RRC_SETUP	ENB-1	UE-2	162999.5	
0	N/A	Control_Packet	RRC_SETUP	ENB-1	UE-3	162999.5	
0	N/A	Control_Packet	RRC_SETUP_COMPLETE	UE-2	ENB-1	163999.5	
0	N/A	Control_Packet	RRC_SETUP_COMPLETE	UE-3	ENB-1	163999.5	
0	N/A	Control_Packet	UE_MEASUREMENT_REPORT	UE-2	ENB-1	164999.5	
0	N/A	Control_Packet	UE_MEASUREMENT_REPORT	UE-3	ENB-1	164999.5	
10	0	CBR	App1_CBR	UE-2	UE-3	180000	
10	0	CBR	App1_CBR	UE-2	UE-3	180000	
10	0	CBR	App1_CBR	UE-2	UE-3	180000	
10	0	CBR	App1_CBR	UE-2	UE-3	180000	
10	0	CBR	App1_CBR	UE-2	UE-3	180000	
10	0	CBR	App1_CBR	UE-2	UE-3	180000	
0	N/A	Control_Packet	STATUSPDU	ENB-1	UE-2	185999.5	

Figure 3-18: Packet trace

3.8.2 Limitations

NetSim’s LTE module has been developed a special case of the 5G NR library operating in the FR1 band with $\mu = 0$. Hence some output metrics of 5G NR such as the SDAP metrics would appear in the LTE results. These can be ignored.

4 Featured Examples

NetSim contains some example configuration files to simulate and understand how LTE and LTE-A work.

To simulate these examples, click **Examples** > **LTE-and-LTE-A** in the NetSim Home Screen.

You can change the default values of the parameters in these examples and see how they impact the LTE and LTE-A network.

4.1 LTE MIMO

You simulate the example configuration for MIMO in an LTE network Energy model to understand the impact of SISO and MIMO Transmission modes on the throughput of the applications transferred in SISO and MIMO Transmission modes.

The LTE network you model from the example configuration file meets the following specifications:

- A network with 1 Macro cell eNB, 1EPC, 1 UEs, 1 router, 1 wired node, and 1 unicast application running on the wired node.
- Set Transport Protocol to UDP in Application icon present in the top ribbon/toolbar.

NetSim uses the following defaults for this example:

- Each one the unicast applications transmit data at a constant bit-rate from Wired_Node_5 to the UEs.
- Simulation runs for 2 seconds.

To simulate the example for SISO and MIMO in an LTE network in NetSim:

Open NetSim and Select Examples > **LTE and LTE-A** > **LTE MIMO** then click on the tile in the middle panel to load the example as shown in below screenshot Figure 4-1.

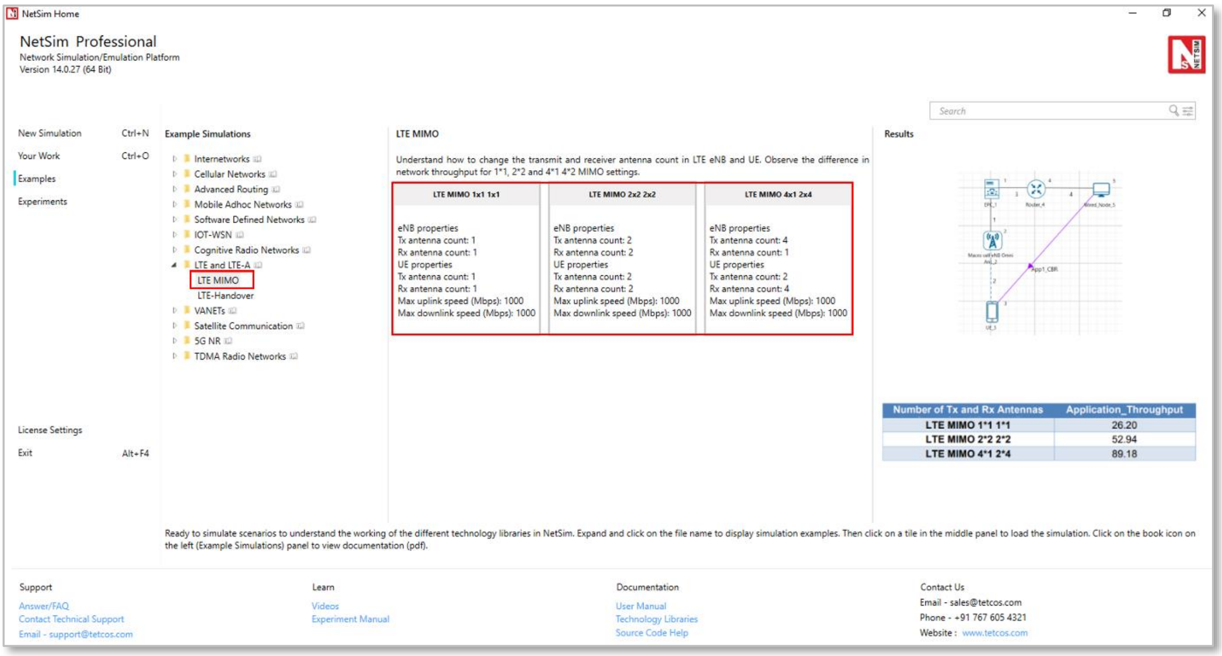


Figure 4-1: List of scenarios for the example of LTE MIMO

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file as shown Figure 4-2.

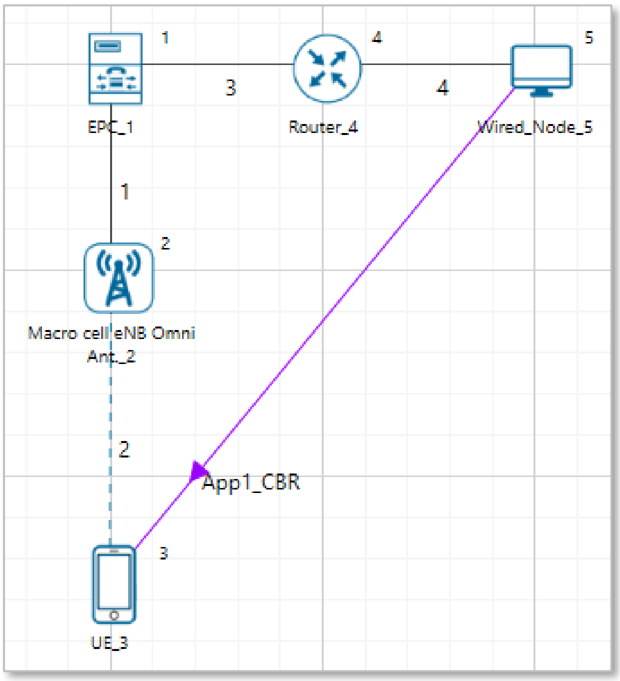


Figure 4-2: Network set up for studying the LTE MIMO

1. See that by default, NetSim has set all the wired link speeds to 1000 Mbps. To do so:
   a. Right-click the wired link between the eNB and the EPC and click **Properties.**
      The Link Properties pop-up window appears.
   b. NetSim has specified a value of **1000** in the **Max_Uplink_Speed(Mbps)** and the **Max_Downlink_Speed(Mbps)** fields **and** set Uplink and Downlink BER is 0.0000001

c. Repeat steps (a) to (c) for the wired links between the EPC and the router and the router and the wired node.

2. See that by default, NetSim has created unicast applications and specified some default settings. To do so:

a. Click on Set Traffic tab and set CBR application with **Source ID** as **5**.and **Destination ID** as **3** with 90 Mbps Generation Rate (Packet Size: 1460, Inter Arrival Time: 129.78µs)

b. Set the start time to 1s.

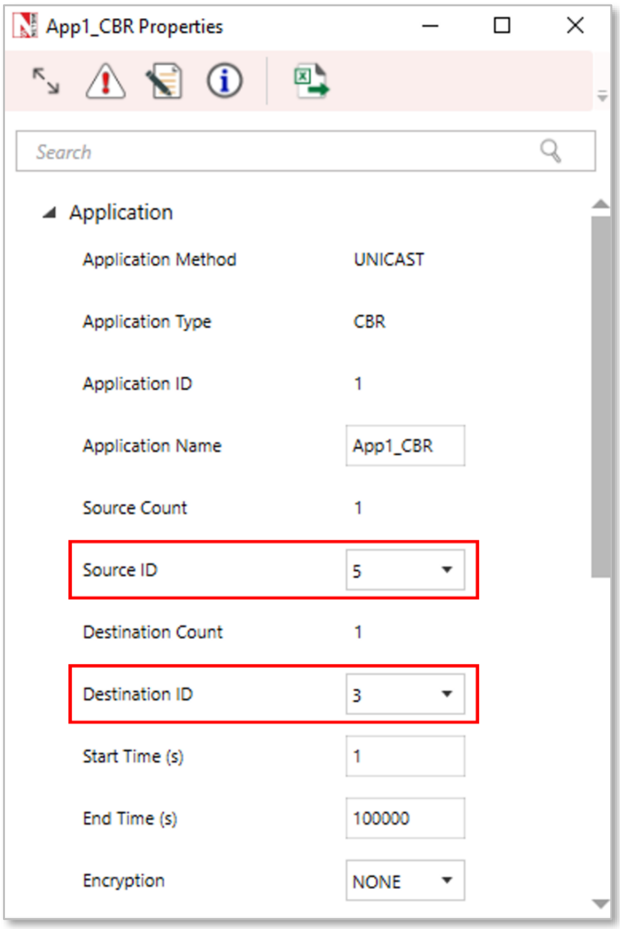


Figure 4-3: Application properties Window

4. Go to eNB properties → Interface (LTE) → PHYSICAL_LAYER.

Properties	
CC1	DL: UL Ratio – 4:1 Bandwidth – 5 MHz
CC2	DL: UL Ratio – 4:1 Bandwidth – 10 MHz
TX Antenna Count RX Antenna Count	1 For Both eNB and UE 1 For Both eNB and UE
Pathloss Model	3GPPTR38.901-7.4.1
Outdoor Scenario	RURAL_MACRO
LOS NLOS Selection	USER_DEFINED
LOS Probability	1
Shadow Fading Model	None
Fading and Beamforming	NO_FADING_MIMO_UNIT_GAIN

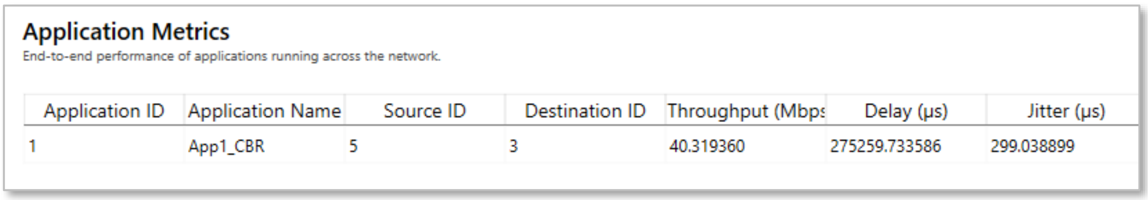
Table 4-1: eNB >Interface (LTE) >Physical layer properties

5. Simulate the LTE MIMO. To do so:
   a. Click the **Run** icon located on the toolbar.
      The **Run Simulation** pop-up window appears.
   b. Retain the default settings in the Simulation Configuration tab (Simulation Time = 2 Sec).
   c. Click **Run**.

Results and Discussion

After NetSim simulates the LTE MIMO, NetSim displays the Simulation Results window.

To interpret the results, see the values of the throughputs in the Application Metrics Table window. You will see the following throughout values for Application_1 is 40.31 Mbps.



Application Metrics
End-to-end performance of applications running across the network.

Application ID	Application Name	Source ID	Destination ID	Throughput (Mbps	Delay (µs)	Jitter (µs)
1	App1_CBR	5	3	40.319360	275259.733586	299.038899

Figure 4-4: Application Metrics Table in Result window

The Application_Throughput (Mbps) column in the table lists the values of throughput for the different values of Tx_Antennas_Count, and Rx_Antennas_Count values.

Number of Tx and Rx Antennas	Application Throughput
LTE MIMO 1*1 1*1	40.31
LTE MIMO 2*2 2*2	81.14
LTE MIMO 4*1 2*4	89.60

Table 4-2: Results Comparison

NOTE: The values of throughputs you see with the different values of Tx_Antennas_Count, and Rx_Antennas_Count values may change the position of the nodes.

5 Reference Documents

[2] 3GPP 36 series specifications for Long Term Evolution Networks.

[3] 3GPP TS 36.300 (Rel 10) Section 19.2.2.5

6 Latest FAQs

You can refer to the up-to-date FAQs about NetSim's LTE library at
https://tetcos.freshdesk.com/support/solutions/folders/14000107855