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.

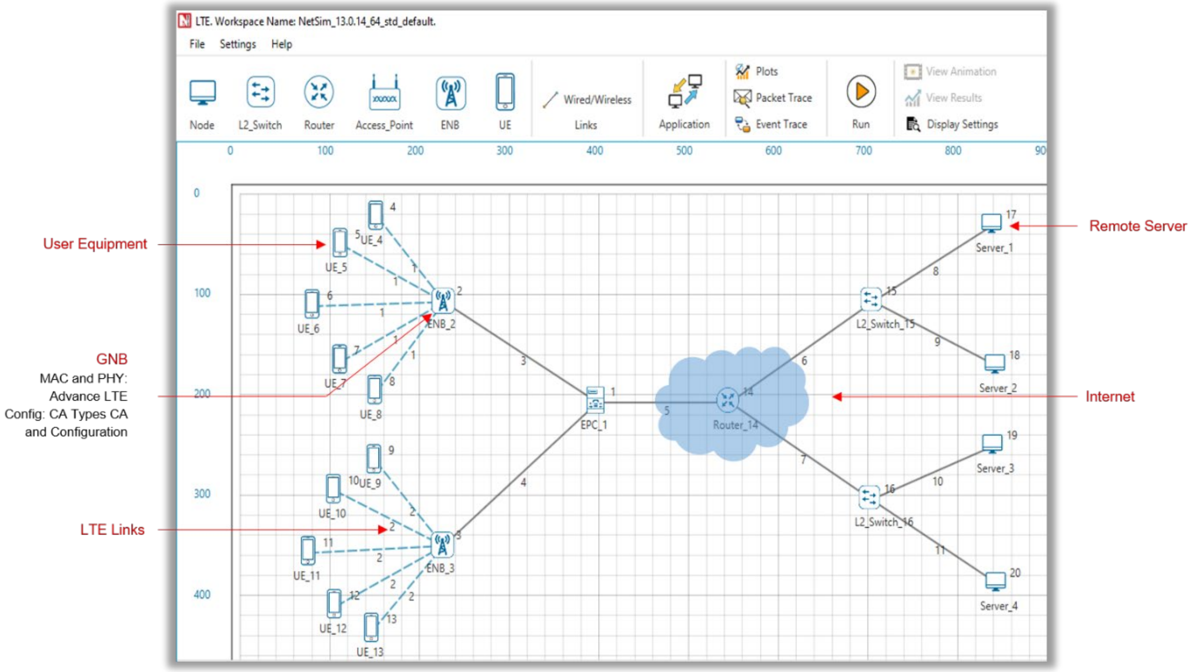


Figure 1-1: A typical LTE Network Scenario in NetSim

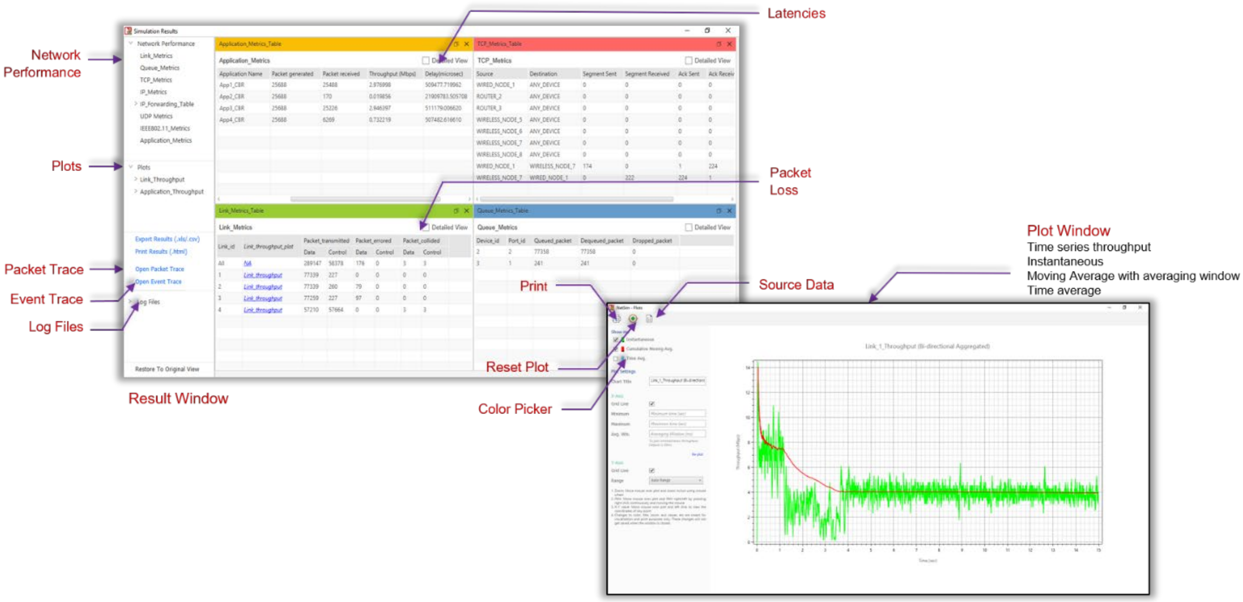


Figure 1-2: The Result dashboard and Plot window shown in NetSim after completion of simulation

2 Simulation GUI

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

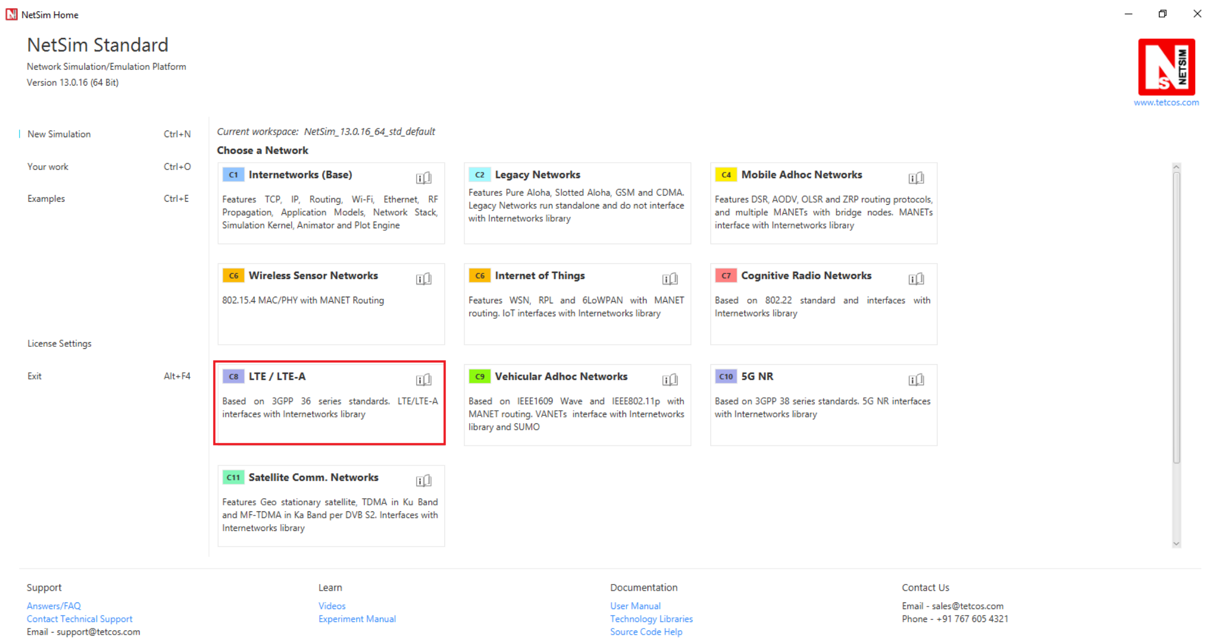


Figure 2-1: NetSim Home Screen

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, eNB (eNodeB) and UE (User Equipment).

2.2 Devices specific to NetSim LTE Library

- **UE (LTE UE)** - User Equipment
- **eNB (LTE eNB)** - Evolved NodeB
- **EPC (Evolved packet core)** – Provides end to end IP connectivity between NG (New Generation) core and gNB. 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.

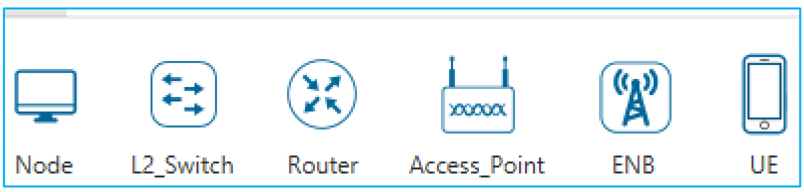


Figure 2-2: LTE Device Palette in GUI

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. gNBs 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 a L2 Switch or Access Point – Click the **L2 Devices > L2_Switch** icon or **L2 Devices > Access_Point** icon on the toolbar and place the device in the grid.
f. Add a Wired Node and Wireless Node – Click the **Node > Wired_Node** icon or **Node > Wireless_Node** icon on the toolbar and place the device in the grid.
g. Configure an application as follows:
   - Click the application icon on the top ribbon/toolbar.
   - Specify the source and destination devices in the network.
   - Specify other parameters as per the user requirement.

2.3 GUI Configuration of LTE

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

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
	Local	Fair Scheduling	Fair scheduling is a method of assigning resources to job such that all jobs get, on average, an equal share of resources over time.

UE Measurement Report Interval (ms)	Local	The Range is 120 to 40960ms.	This is the time interval between two UE Measurement report.
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	Link 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.

Note: For detailed information on RLC

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) and inter-band
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
Note: For detailed information to Frequency Range (FR1)			
Slot type	Local	Mixed, Uplink, Downlink	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	Local	FR1	Frequency range for LTE is Frequency Range 1 (FR1) that includes sub-6 GHz, frequency bands.
Operating Band	Local		The LTE operates in different operating bands corresponding to CA configuration respectively
F_Low (MHz)	Local		Lowest frequency of the Uplink/Downlink operating band.
F_High (MHz)	Local		Highest frequency of the Uplink/Downlink operating band.
Numerology	Local	$\mu = 0$	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	10	Slot within a frame is depending on the slot configuration.
Slot per Subframe	Local	1	Slot within a Subframe is depending on the slot configuration.
Slot Duration (ms)	Local	0.5	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.
ANTENNA			
TX_Antenna_Count	Local	1,2,4	The number of transmit antennas. Power is split equally among the transmit antennas.
RX_Antenna_Count	Local	1,2,4	The number of receive antennas
PDSCH CONFIG			
MCS Table	Local	QAM64	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			
MCS Table	Local	QAM64	MCS (Modulation Coding Scheme) is related to Modulation Order.
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).
CSIREPORT CONFIG			
CQI Table	Local	Table1	The CQI induces and their interpretations are chosen from Table 1 for reporting CQI based on 64QAM
CHANNEL MODEL			
Pathloss Model	Local	3GPPTR38.901-7.4.1 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 gNBs can only be outside buildings.
	Local	Urban Macro (UMa)	Buildings can be used in the scenario. UEs can be inside/outside buildings but gNBs can only be outside buildings.
	Local	Urban Micro (UMi)	Buildings can be used in the scenario. UEs can be inside/outside buildings but gNBs can only be outside buildings.
Building Height	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 gNB-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 , RAYLEIGH_WITH_EIGEN_BEAMFORMING	Referee 5G NR technology library section 3.9.3
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.

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)	Global	-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.
Beamforming Gain(dB)	Local	0-100	The antenna gain provided by signal processing technique directional transmission

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

3 Model Features

3.1 LTE Stack

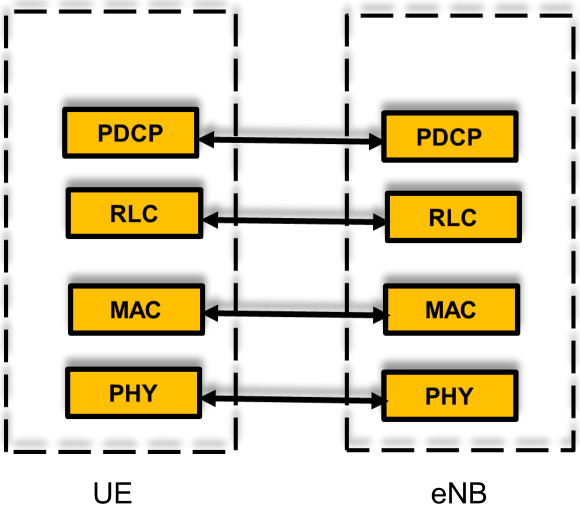


Figure 3-1: User Plane Protocol Stack

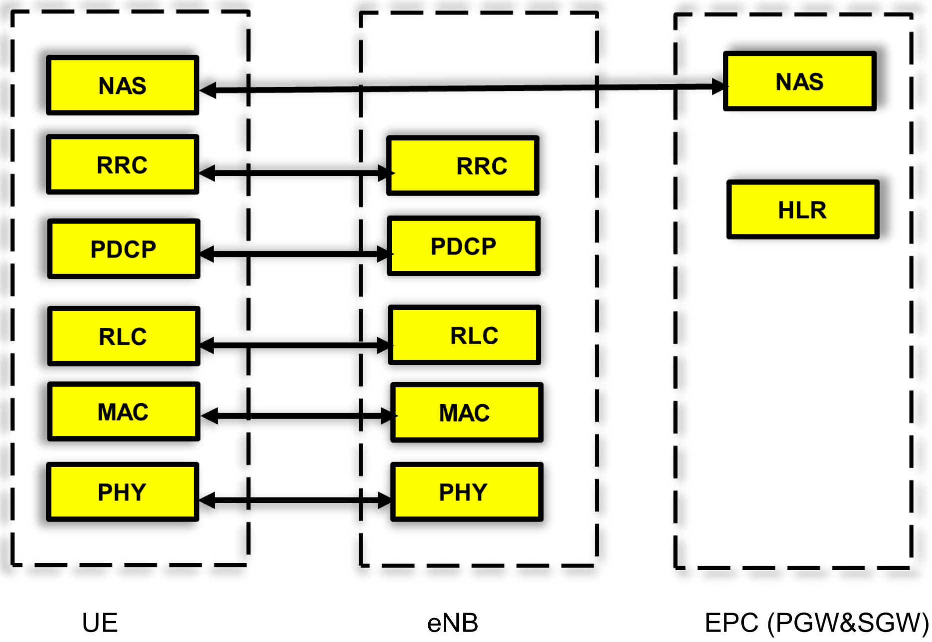


Figure 3-2: Control Plane Protocol Stack

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

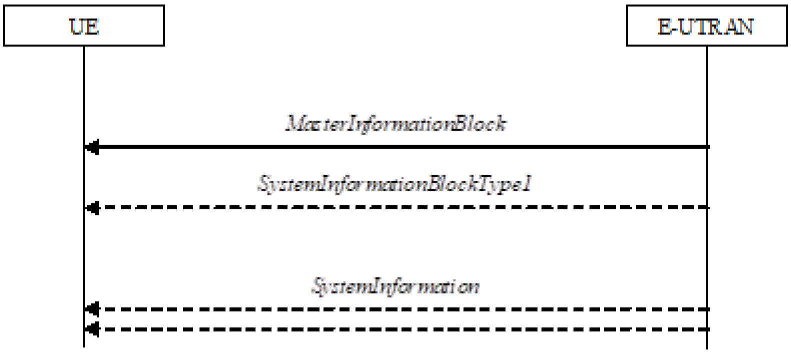


Figure 3-3 : System information acquisition

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

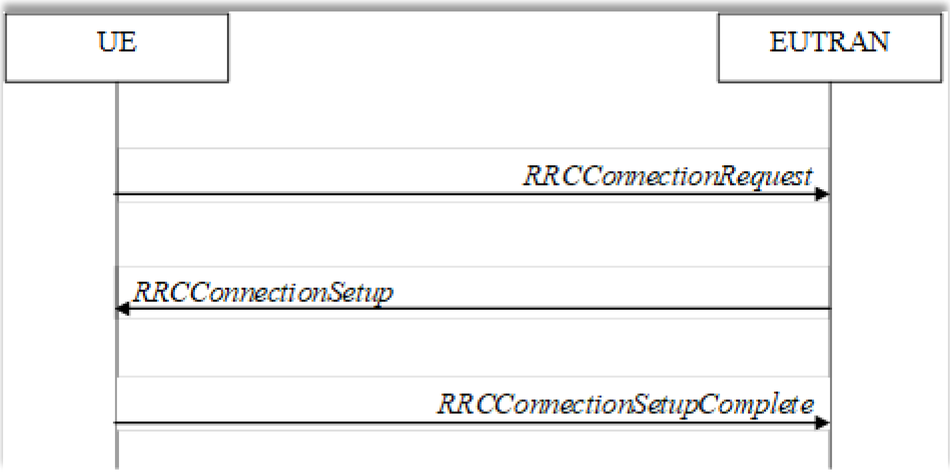


Figure 3-4 : RRC connection establishment

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**.

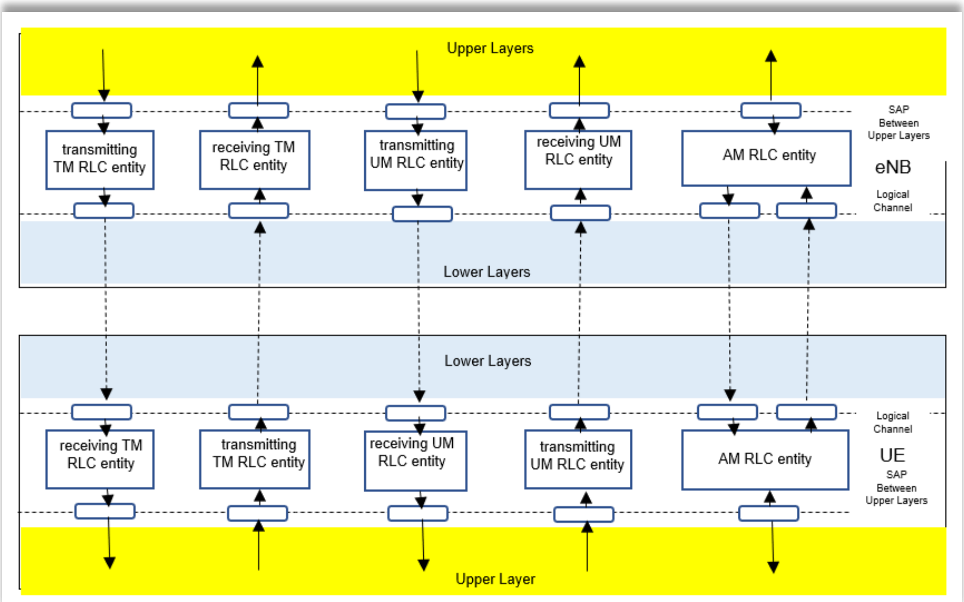


Figure 3-5: Overview Model of RLC sub layer

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.*

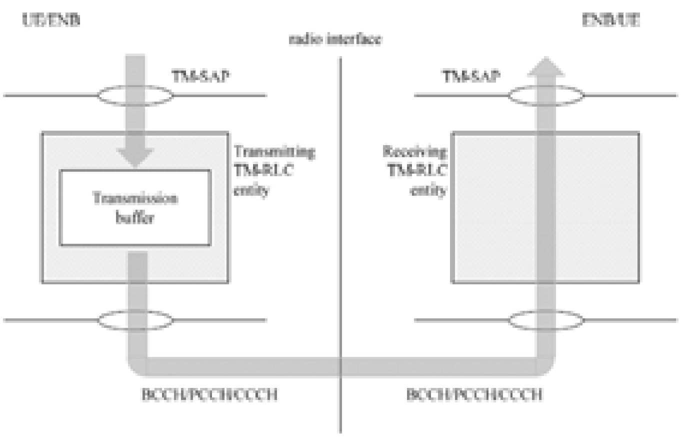


Figure 3-6: Model of two transparent mode peer entities

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.*

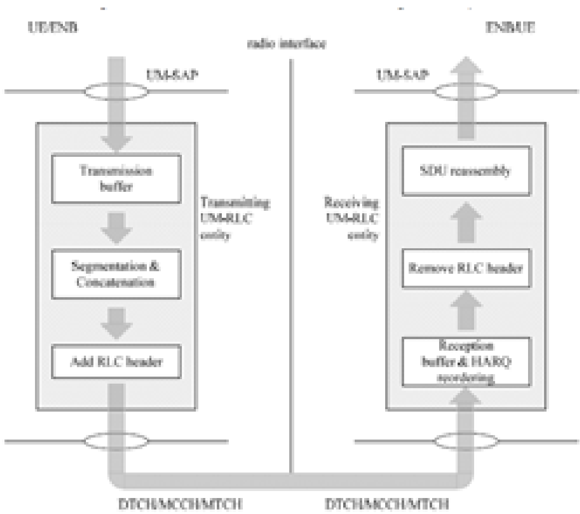


Figure 3-7: Model of two unacknowledged mode peer entities

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.*

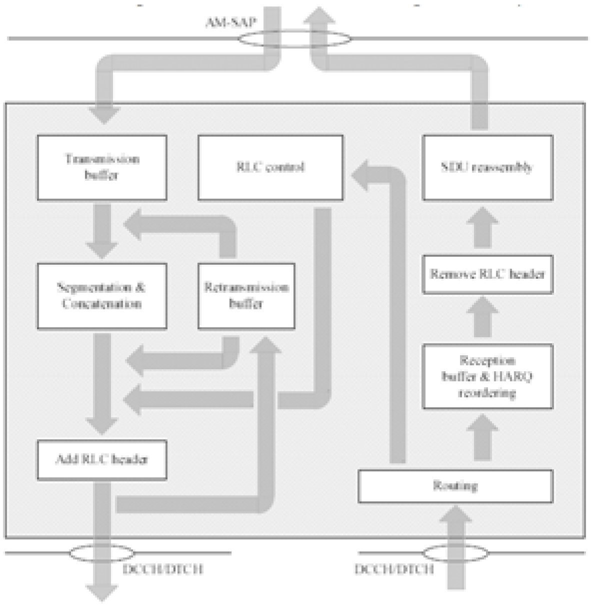


Figure 3-8: Model of an acknowledged mode entity

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.
- Fair Scheduler - It ensures equal throughputs for all active flows.

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.

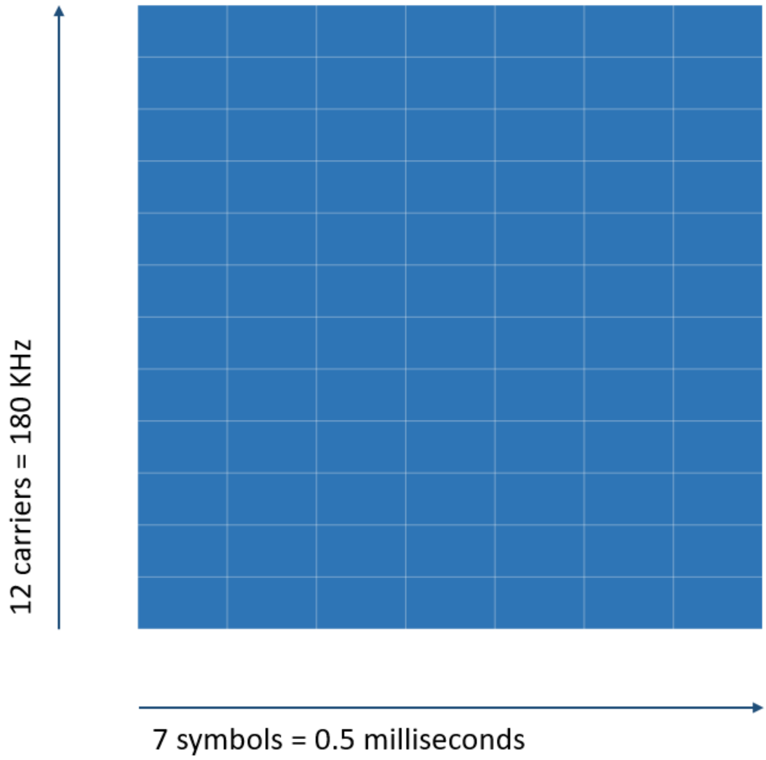


Figure 3-9: Physical Speed of the LTE Air Interface

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

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 or LTE-A 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 (MHz)	Band gap (MHz)
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

3.6.3 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.

3.6.4 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 3-4.**

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

Table 3-4: LTE and LTE-A PHY Layer Parameters

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

3.6.5 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 / gNBs are not considered.
- The received power is transmit power less propagation loss.
- The MCS values are chosen based on the received SNR.

3.6.6 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.

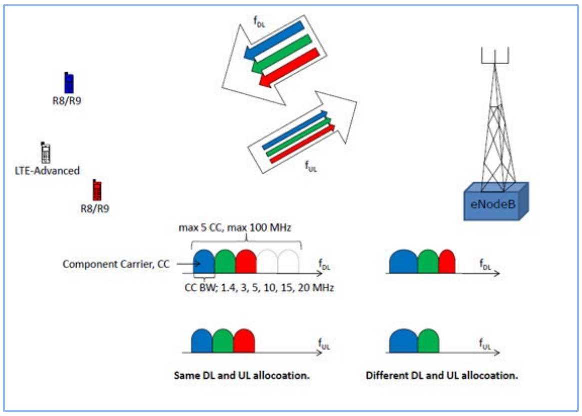


Figure 3-10: Illustrates the Carrier aggregation

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.

3.6.6.1 CA Configurations

CA can be configured as 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.

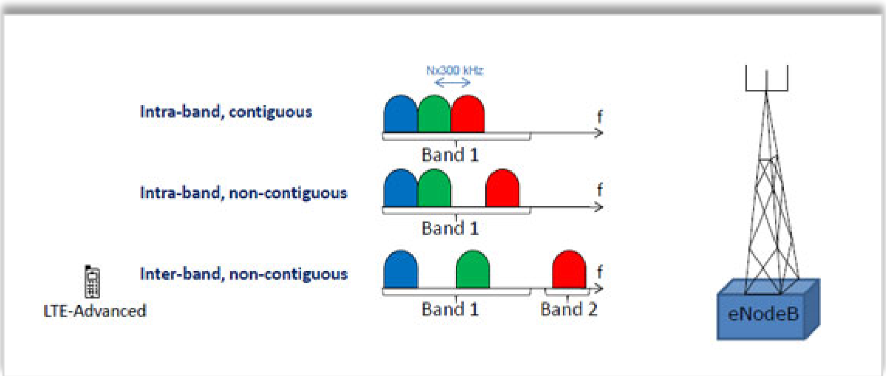


Figure 3-11: Illustrates the CA configurations

3.6.6.2 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, the 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 Configuration (ATBC)		Maximum # of CC
	NRB,agg	Maximum Tx bandwidth	
A	N <= 100	20	1
B	25 < N <= 100	20	2
C	100 < N <= 200	40	2
D	200 < N <= 300	60	3
E	300 < N <= 400	80	4
F	400 < N <= 500	100	5
I	700 < N <= 800	160	8

Figure 3-12: CA Bandwidth classes

3.6.6.3 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.

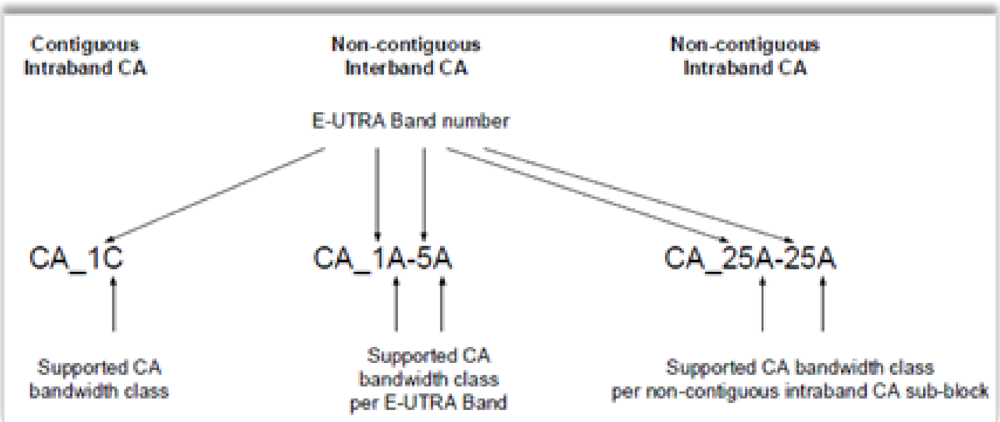


Figure 3-13: CA Configuration Naming Conventions

For more information about Carrier Aggregation, see

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

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

Carrier aggregation can be configured in the eNB's Physical layer properties. Following are the various configuration options that are available as shown **Table 3-5** and Table 3-6**.**

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, CA2_UL, CA2_DL	FR1	2500, 832	2570, 862	2620, 791	2690, 821
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,	FR1	1710, 1710, 1710	1780, 1780, 1780	2110, 2110, 2110	2200, 2200, 2200

		CA2_DL, CA3_UL, CA3_DL					

Table 3-5: 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

Table 3-6: CA Configuration Table for TDD bands

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. $T_s^{\mu} = \frac{10^{-3}}{14\times2^{\mu}}$. 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 CNTROL_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 3-14: 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 μ = 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 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_4 to the UEs.
- Simulation runs for 1 seconds.

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

1. Open NetSim and click Examples > **LTE-and-LTE-A** > **LTE-MIMO** as shown in below screenshot **Figure 4-1.**

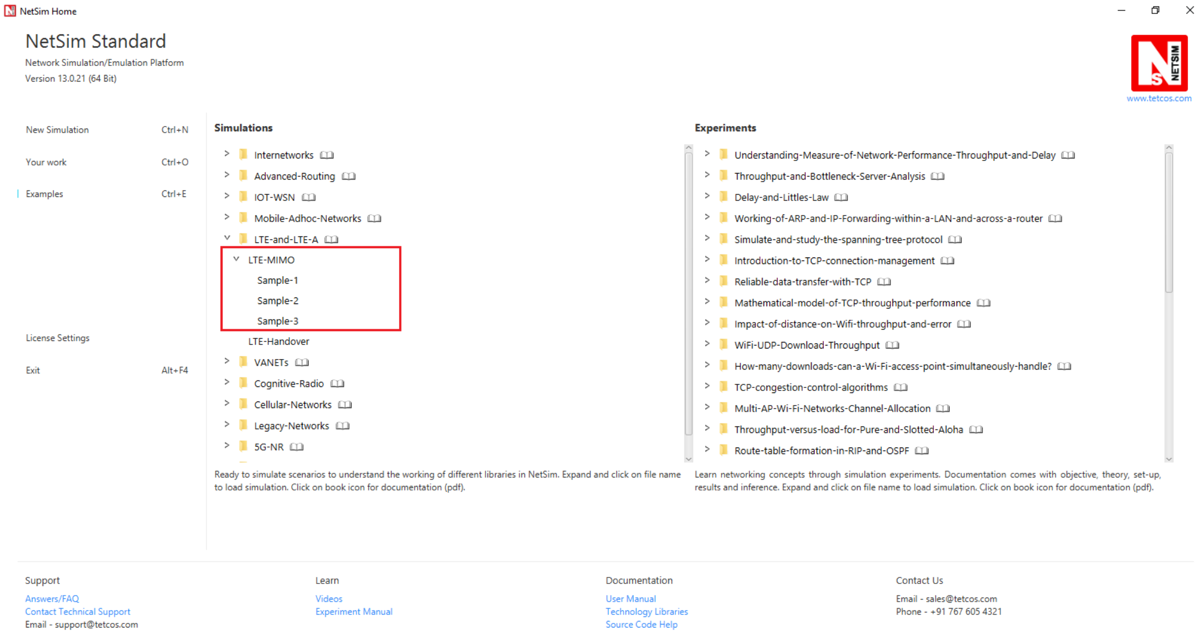


Figure 4-1: Featured Example list

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

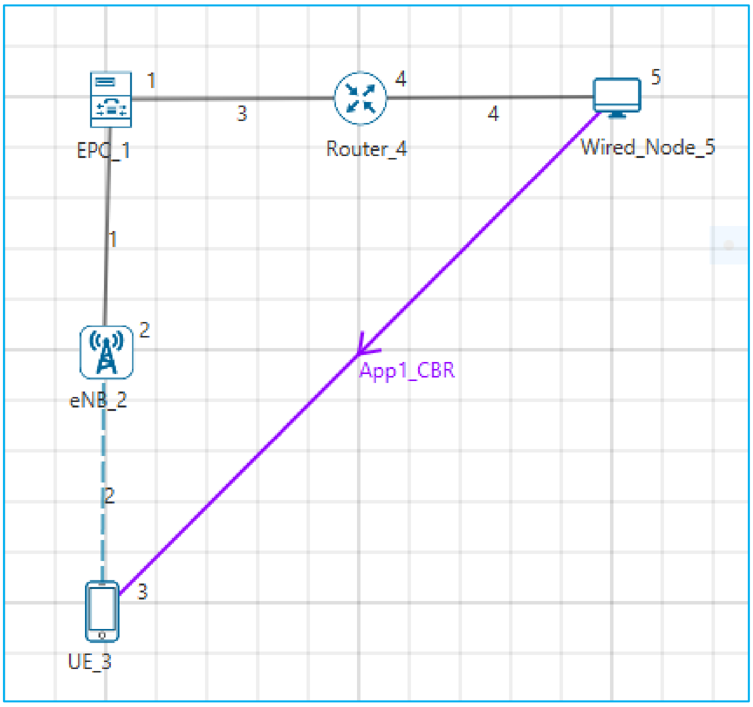


Figure 4-2: Network Topology in this experiment

2. 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**.**
c. Click **OK**.
d. Repeat steps (a) to (c) for the wired links between the EPC and the router and the router and the wired node.

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

a. Click the Application icon located on the toolbar.
   The Configure Application pop-up window appears.
b. Click **Application1** in the left area.
c. **Source_ID** drop-down list is set to **5**.
d. **Destination_ID** drop-down list is set to **3**.
e. **Application Strat** time is **1 Sec.**
f. **Scroll** down and see that NetSim has specified **1460** in the **Value (Bytes)** in the PACKET SIZE area.
g. Set Transport Protocol to UDP
h. NetSim has specified 129.78 in the **Value (micro sec)** in the INTER ARRIVAL TIME area.
i. Click **OK**.

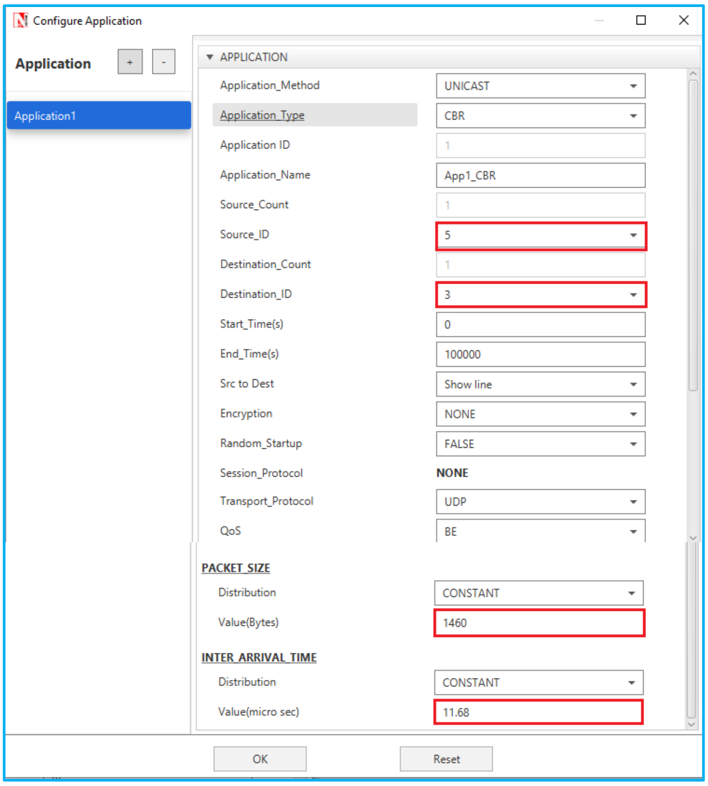


Figure 4-3: Application properties Window

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

Properties	
CA1	DL: UL Ratio – **4:1** Bandwidth – **5 MHz**
CA2	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_Probabillity	1
Shadow Fading Model	None
Fast Fading Model	None
O2I Building Penetration Model	None

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

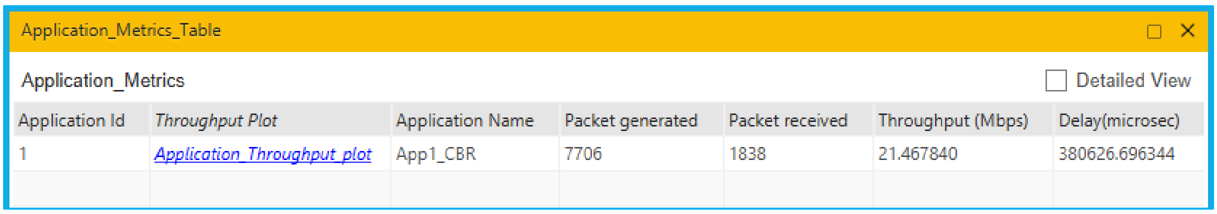
5. Simulate the LTE MIMO for LTE example. To do so:
   a. Click the **Run** icon located on the toolbar.
      The **Run Simulation** pop-up window appears.
   b. Retain the default settings in the Simulation Configuration tab (Simulation Time = 2 Sec).
   c. Click **OK**.

Results and Discussion

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

Interpret the results. To do so, see the values of the throughputs of the applications in the Throughput (Mbps) column, in the Application_Metrics_Table window.

You will see the following throughout values for Application_1 is 21.47 Mbps.


Application_Metrics_Table

Application_Metrics

Detailed View

Application Id	Throughput Plot	Application Name	Packet generated	Packet received	Throughput (Mbps)	Delay(microsec)
1	Application_Throughput_plot	App1_CBR	7706	1838	21.467840	380626.696344

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.

Samples	eNB	UE	
	Tx_Antennas_Count, Rx_Antennas_Count	Tx_Antennas_Count, Rx_Antennas_Count	Application_Throughput (Mbps)
Sample 1	**1, 1**	**1, 1**	21.47
Sample 2	**2, 2**	**2, 2**	42.94
Sample 3	**4, 4**	**2, 4**	85.81

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.

4.2 LTE-Handover

When the source node detects that a handover is required, it connects with the target eNB to commence the switching process. Once the tunnels have been moved across to the target eNB, the UE performs a handover and connects to the target node. A path switch request is made from the target eNB.

Description and Definition

1. A data call is established between the UE, S-eNB (Source-eNB) and the network elements. Data packets are transferred to/from the UE to/from the network in both directions (Downlink as well as Uplink).
2. The network sends the MEASUREMENT CONTROL REQ message to the UE to set the parameters to measure and set thresholds for those parameters. Its purpose is to instruct the UE to send a measurement report to the network as soon as it detects the thresholds.
3. The UE sends the MEASUREMENT REPORT to the Serving eNB, which contains the RQRS from all the nearby eNBs. The Serving eNB makes the decision to hand off the UE to a T-eNB (Target-eNB) using the handover algorithm mentioned in the Introduction.
4. The S-eNB issues a HANDOVER REQUEST message to the T-eNB passing necessary information to prepare the handover at the target side.
5. The T-eNB sends back the HANDOVER REQUEST ACKNOWLEDGE message including a transparent container to be sent to the UE as an RRC message to perform the handover.

6. The S-eNB generates the RRC (Radio resource control used for signaling transfer) message to perform the handover, i.e., RRC CONNECTION RECONFIGURATION message including the mobility Control Information.
7. The S-eNB starts forwarding the downlink data packets to the T-eNB for all the data bearers which are being established in the T-eNB during the HANDOVER REQ message processing.
8. The T-eNB now requests the S-eNB to release the resources. With this, the handover procedure is complete.

Analysis/Algorithm

NetSim handover algorithm utilizes the Reference Signal Received Quality (RSRQ) measurements, to trigger the handover. When the target eNB's RSRQ crosses the serving eNB's RSRQ by a factor know as margin of handover (equal to 3dB), hand over is triggered.

Open NetSim and click **Examples** > **LTE-and-LTE-A** > **LTE-Handover** as shown in below screenshot **Figure 4-5.**

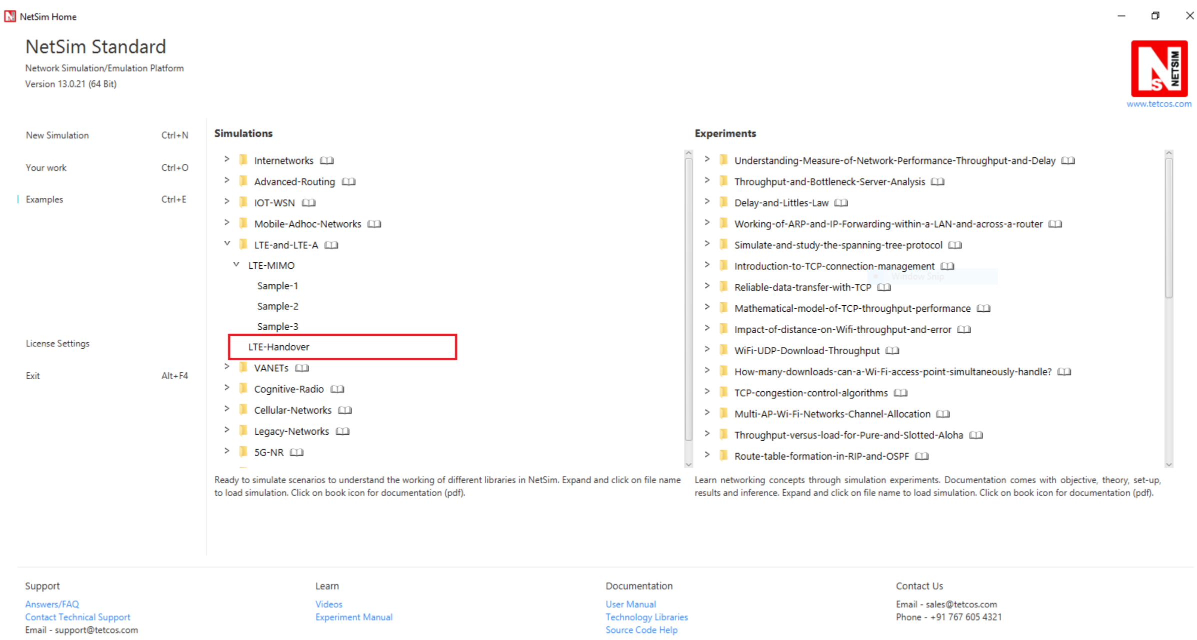


Figure 4-5: Featured Example list

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file as shown **Figure 4-6.**

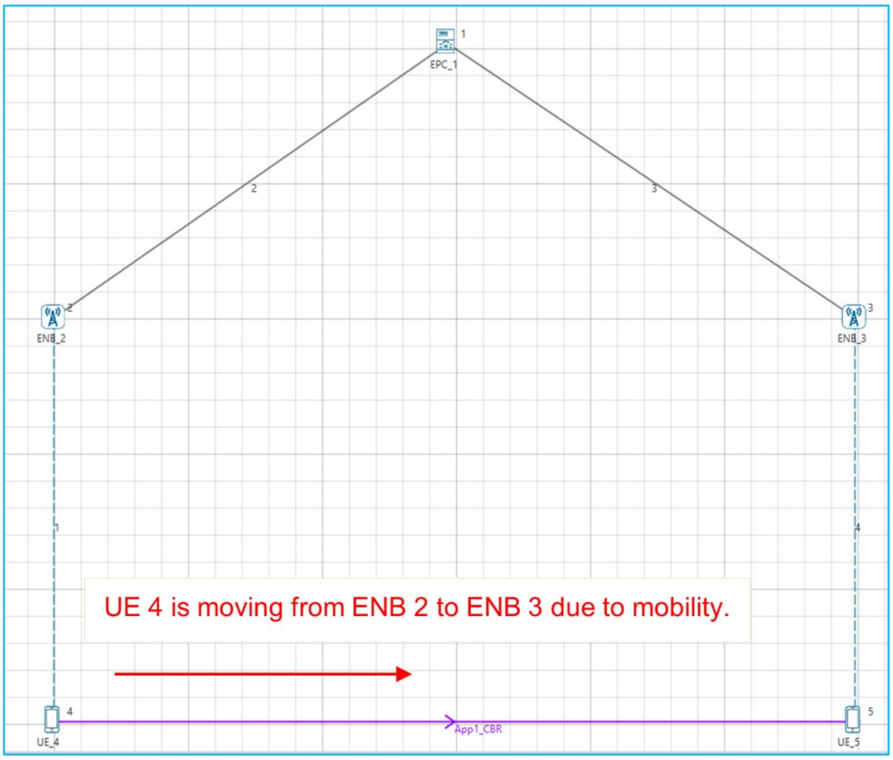


Figure 4-6: Scenario for Studying LTE-Handover

Network Settings

The following set of procedures were done to generate this sample:

Step 1: Environment Grid length: 5000m x 5000m.

Step 2: A network scenario is designed in NetSim GUI comprising of 2 ENBs, 1 EPC, and 2UEs in the "LTE/LTE-A" Network Library.

Step 3: The device positions are set as per the table given below.

	ENB 2	ENB 3	UE 4	UE 5
X Co-ordinate	1000	4000	1000	4000
Y Co-ordinate	1500	1500	3000	3000

Table 4-3: Device Position

Step 4: In the General Properties of UE 4 and UE 5, set Mobility Model as File Based Mobility.

Step 5: Right click on the eNB 2 and select Properties, the following is set Table.

Interface(LTE) Properties	
CA_TYPE	INTER_BAND_CA
CA_Configuration	DL_2A-48A_UL_2A-48A_BCSO
CA_Count	2

Numerology	0
Channel Bandwidth (MHz)	5
PRB Count	25
MCS Table	QAM64
CQI Table	TABLE1
X_Overhead	XOHO
DL UL Ratio	1:1
Outdoor Scenario	URBAN_MACRO
LOS_NLOS_Selection	USER_DEFINED
LOS Probability	1
Shadow Fading Model	None
Fading and Beamforming	NO_FADING
O2I and Building Penetration model	NONE

Table 4-4: eNB > Interface (LTE) Properties Setting

Similarly, it is set for eNB 3.

Step 6: Right click on the Application Flow **App1 CBR** and select Properties or click on the Application icon present in the top ribbon/toolbar.

A CBR Application is generated from UE 4 i.e., Source to UE 5 i.e., Destination with Packet Size remaining 1460Bytes and Inter Arrival Time remaining 20000µs. QOS is set to BE. Additionally, the **"Start Time(s)"** parameter is set to 15s, while configuring the application.

File Based Mobility

In File Based Mobility, users can write their own custom mobility models and define the movement of the mobile users. Create a mobility.txt file for UE's involved in mobility with each step equal to 0.5 sec with distance 50 m.

The NetSim Mobility File (mobility.txt) format is as follows:

```
#Initial position of the UE 4
$node_(3) set X_ 1000.0
$node_(3) set Y_ 3000.0
$node_(3) set Z_ 0.0
#Initial position of the UE 5
$node_(4) set X_ 4000.0
$node_(4) set Y_ 3000.0
$node_(4) set Z_ 0.0
```

```
#Positions of the UE 4 at specific time
$time 0.0 "$node_(3) 1000.0 3000.0 0.0"
$time 0.5 "$node_(3) 1050.0 3000.0 0.0"
$time 1.0 "$node_(3) 1100.0 3000.0 0.0"
$time 1.5 "$node_(3) 1150.0 3000.0 0.0"
$time 2.0 "$node_(3) 1200.0 3000.0 0.0"
$time 2.5 "$node_(3) 1250.0 3000.0 0.0"
$time 3.0 "$node_(3) 1300.0 3000.0 0.0"
$time 3.5 "$node_(3) 1350.0 3000.0 0.0"
$time 4.0 "$node_(3) 1400.0 3000.0 0.0"
$time 4.5 "$node_(3) 1450.0 3000.0 0.0"
$time 5.0 "$node_(3) 1500.0 3000.0 0.0"
$time 5.5 "$node_(3) 1550.0 3000.0 0.0"
$time 6.0 "$node_(3) 1600.0 3000.0 0.0"
$time 6.5 "$node_(3) 1650.0 3000.0 0.0"
$time 7.0 "$node_(3) 1700.0 3000.0 0.0"
$time 7.5 "$node_(3) 1750.0 3000.0 0.0"
$time 8.0 "$node_(3) 1800.0 3000.0 0.0"
$time 8.5 "$node_(3) 1850.0 3000.0 0.0"
$time 9.0 "$node_(3) 1900.0 3000.0 0.0"
$time 9.5 "$node_(3) 1950.0 3000.0 0.0"
$time 10.0 "$node_(3) 2000.0 3000.0 0.0"
$time 10.5 "$node_(3) 2050.0 3000.0 0.0"
$time 11.0 "$node_(3) 2100.0 3000.0 0.0"
$time 11.5 "$node_(3) 2150.0 3000.0 0.0"
$time 12.0 "$node_(3) 2200.0 3000.0 0.0"
$time 12.5 "$node_(3) 2250.0 3000.0 0.0"
$time 13.0 "$node_(3) 2300.0 3000.0 0.0"
$time 13.5 "$node_(3) 2350.0 3000.0 0.0"
$time 14.0 "$node_(3) 2400.0 3000.0 0.0"
$time 14.5 "$node_(3) 2450.0 3000.0 0.0"
$time 15.0 "$node_(3) 2500.0 3000.0 0.0"
$time 15.5 "$node_(3) 2550.0 3000.0 0.0"
$time 16.0 "$node_(3) 2600.0 3000.0 0.0"
$time 16.5 "$node_(3) 2650.0 3000.0 0.0"
$time 17.0 "$node_(3) 2700.0 3000.0 0.0"
$time 17.5 "$node_(3) 2750.0 3000.0 0.0"
```

$time 18.0 "$node_(3) 2800.0 3000.0 0.0"

$time 18.5 "$node_(3) 2850.0 3000.0 0.0"

$time 19.0 "$node_(3) 2900.0 3000.0 0.0"

$time 19.5 "$node_(3) 2950.0 3000.0 0.0"

$time 20.0 "$node_(3) 3000.0 3000.0 0.0"

$time 20.5 "$node_(3) 3050.0 3000.0 0.0"

$time 21.0 "$node_(3) 3100.0 3000.0 0.0"

Step 7: Packet Trace is enabled in NetSim GUI. At the end of the simulation, a large .csv file is containing all the packet information is available for the users to perform packet level analysis. Plots is enabled in NetSim GUI.

Step 8: The log file can enable per the information provided in **Section 3.18** 5G-NR technology library document.

Step 9: Run the Simulation for 50 Seconds.

Results and Discussion

Handover Signaling

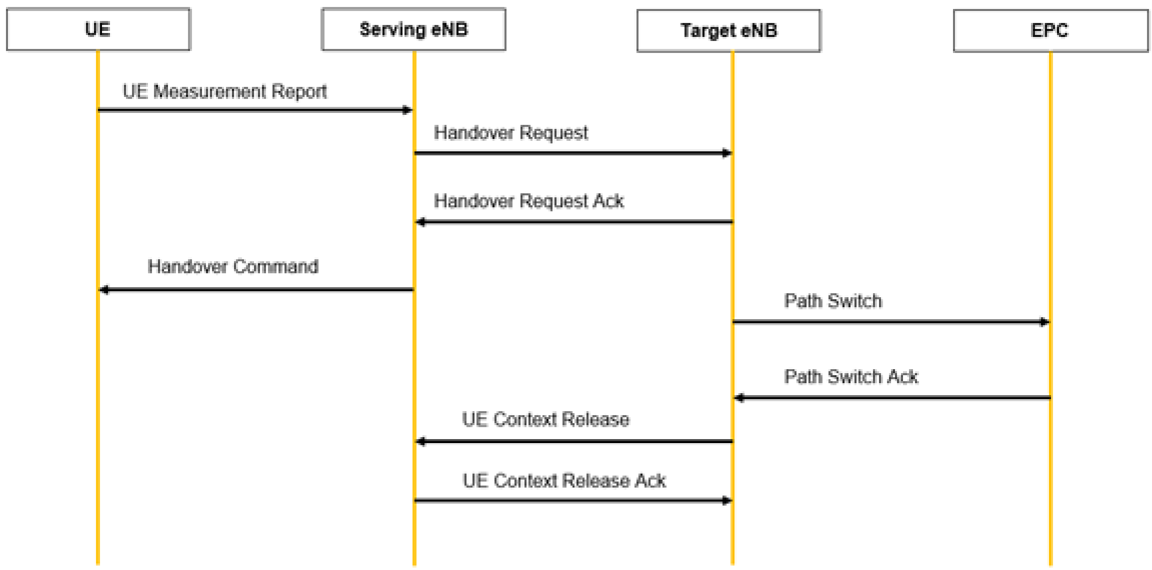


Figure 4-7: Control packet flow in the LTE handover process

Note:

- Handover Request and Handover Request Ack will be sent from the serving eNB to Target eNB through MME.
- Context Release and Context Release Ack will be sent from the serving eNB and to Target eNB through MME.

The packet flow depicted above can be observed from the packet trace.

1. UE will send the UE_MEASUREMENT_REPORT every 120ms to the connected eNB
2. The initial UE- eNB connection, eNB will send the RRC_MIB packets to the UE every 40 ms and RRC_SIB1 every 80 ms.
3. After the transmission of the RRC_MIB and RRC_SIB1 packets, the eNB will send RRC_SI packet to the UE.
4. After reception of RRC_SI packet, UE will send RRC_Setup_Request to the eNB.
5. On receiving the RRC_Setup_Request packet, the eNB will acknowledge the request by transmitting RRC_Setup packet to the UE.
6. The UE will send back the RRC_Setup_Complete packet on the receipt of RRC_Setup message.
7. As Per the configured file-based mobility, UE 4 moves towards eNB 3.
8. After 18.00s eNB 2 sends the HANDOVER REQUEST to eNB 3.
9. eNB 3 sends back HANDOVER REQUEST ACK to eNB 2.
10. After receiving HANDOVER REQUEST ACK from eNB 3, eNB 2 sends the HANDOVER COMMAND to UE 4
11. After the HANDOVER COMMAND packet is transferred to the UE, the target eNB will send the PATH SWITCH packet to the EPC_1.
12. When the EPC_1 receives the PATH SWITCH packet, it sends PATH_SWICTH_ACK packet to the eNB 3.
13. The target eNB sends CONTEXT RELEASE to source eNB, and the source eNB sends back CONTEXT RELEASE ACK to target eNB. The context release request and ack packets are sent between the source and target eNB via EPC 1.
14. RRC Reconfiguration will take place between target eNB and UE 4.

PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID	APP_LAYER_ARRIVAL_TIME(US)	TRX_LAYER_ARRIVAL_TIME(US)	NW_LAYER_ARRIVAL_TIME(US)	MAC_LAYER_ARRIVAL_TIME(US)
0	N/A	Control_Packet	RRC_MIB	ENB-3	Broadcast-0	ENB-3	UE-4	N/A	N/A	N/A	17960000
0	N/A	Control_Packet	RRC_MIB	ENB-3	Broadcast-0	ENB-3	UE-5	N/A	N/A	N/A	17960000
0	N/A	Control_Packet	UE_MEASUREMENT_REPORT	UE-4	ENB-2	UE-4	ENB-2	N/A	N/A	N/A	18000000
0	N/A	Control_Packet	UE_MEASUREMENT_REPORT	UE-5	ENB-3	UE-5	ENB-3	N/A	N/A	N/A	18000000
0	N/A	Control_Packet	HANDOVER_REQUEST	ENB-2	ENB-3	ENB-2	EPC-1	N/A	N/A	N/A	18000499
0	N/A	Control_Packet	HANDOVER_REQUEST	ENB-2	ENB-3	EPC-1	ENB-3	N/A	N/A	N/A	18000504.64
0	N/A	Control_Packet	HANDOVER_REQUEST_ACK	ENB-3	ENB-2	ENB-3	EPC-1	N/A	N/A	N/A	18000510.28
0	N/A	Control_Packet	HANDOVER_REQUEST_ACK	ENB-3	ENB-2	EPC-1	ENB-2	N/A	N/A	N/A	18000515.92
0	N/A	Control_Packet	HANDOVER_COMMAND	ENB-2	UE-4	ENB-2	UE-4	N/A	N/A	N/A	18000521.56
0	N/A	Control_Packet	RRC_SIB1	ENB-2	Broadcast-0	ENB-2	UE-4	N/A	N/A	N/A	18000000
0	N/A	Control_Packet	RRC_SIB1	ENB-2	Broadcast-0	ENB-2	UE-5	N/A	N/A	N/A	18000000
0	N/A	Control_Packet	RRC_MIB	ENB-2	Broadcast-0	ENB-2	UE-4	N/A	N/A	N/A	18000000
0	N/A	Control_Packet	RRC_MIB	ENB-2	Broadcast-0	ENB-2	UE-5	N/A	N/A	N/A	18000000
0	N/A	Control_Packet	RRC_SIB1	ENB-3	Broadcast-0	ENB-3	UE-4	N/A	N/A	N/A	18000000
0	N/A	Control_Packet	RRC_SIB1	ENB-3	Broadcast-0	ENB-3	UE-5	N/A	N/A	N/A	18000000
0	N/A	Control_Packet	RRC_MIB	ENB-3	Broadcast-0	ENB-3	UE-4	N/A	N/A	N/A	18000000
0	N/A	Control_Packet	RRC_MIB	ENB-3	Broadcast-0	ENB-3	UE-5	N/A	N/A	N/A	18000000
0	N/A	Control_Packet	PATH_SWITCH	ENB-3	EPC-1	ENB-3	EPC-1	N/A	N/A	N/A	18001499
0	N/A	Control_Packet	PATH_SWICTH_ACK	EPC-1	ENB-3	EPC-1	ENB-3	N/A	N/A	N/A	18001504.64
0	N/A	Control_Packet	UE_CONTEXT_RELEASE	ENB-3	ENB-2	ENB-3	EPC-1	N/A	N/A	N/A	18001510.28
0	N/A	Control_Packet	UE_CONTEXT_RELEASE	ENB-3	ENB-2	EPC-1	ENB-2	N/A	N/A	N/A	18001515.92
0	N/A	Control_Packet	UE_CONTEXT_RELEASE_ACK	ENB-2	ENB-3	ENB-2	EPC-1	N/A	N/A	N/A	18001521.56
0	N/A	Control_Packet	UE_CONTEXT_RELEASE_ACK	ENB-2	ENB-3	EPC-1	ENB-3	N/A	N/A	N/A	18001527.2
0	N/A	Control_Packet	RRC_RECONFIGURATION	ENB-3	UE-4	ENB-3	UE-4	N/A	N/A	N/A	18001499
0	N/A	Control_Packet	RRC_MIB	ENB-2	Broadcast-0	ENB-2	UE-4	N/A	N/A	N/A	18040000
0	N/A	Control_Packet	RRC_MIB	ENB-2	Broadcast-0	ENB-2	UE-5	N/A	N/A	N/A	18040000
0	N/A	Control_Packet	RRC_MIB	ENB-3	Broadcast-0	ENB-3	UE-4	N/A	N/A	N/A	18040000
0	N/A	Control_Packet	RRC_MIB	ENB-3	Broadcast-0	ENB-3	UE-5	N/A	N/A	N/A	18040000
0	N/A	Control_Packet	RRC_SIB1	ENB-2	Broadcast-0	ENB-2	UE-4	N/A	N/A	N/A	18080000
0	N/A	Control_Packet	RRC_SIB1	ENB-2	Broadcast-0	ENB-2	UE-5	N/A	N/A	N/A	18080000

Figure 4-8: NetSim packet trace file showing the control packets involved in handover

15. The UE 4 will start sending the UE MEASUREMENT REPORT to eNB 3

Plot of SNR vs.Time

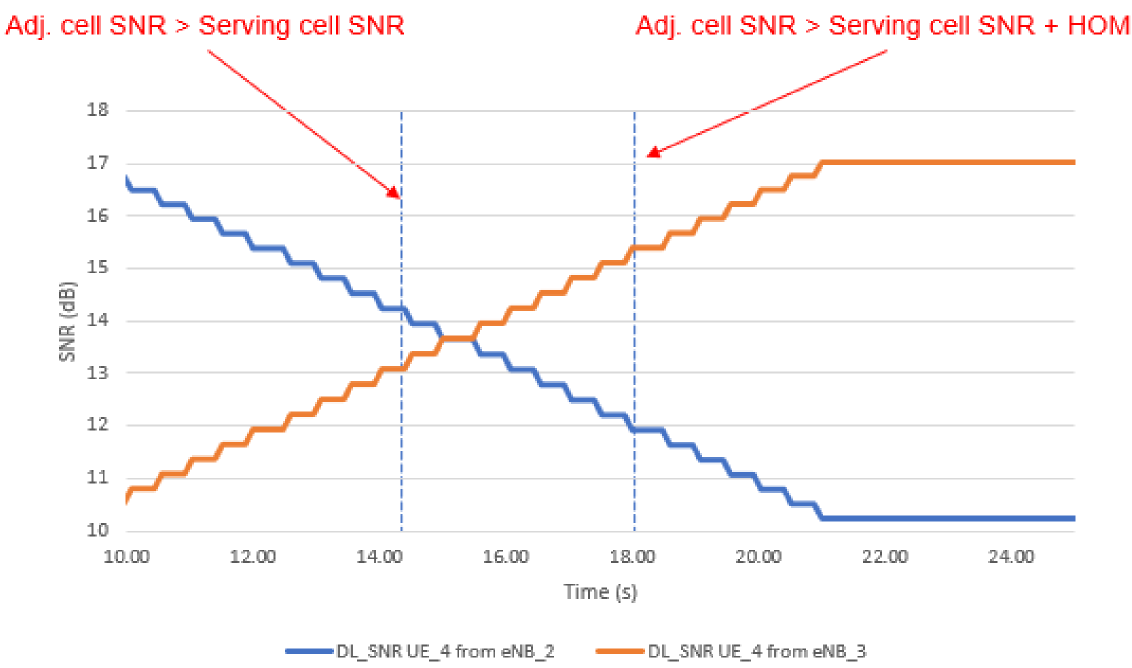


Figure 4-9: Plot of DL SNR (at UE_4 from eNB2 and eNB3) vs time

This plot can be got from the LTENRLog file. However, it would involve a fair amount of time and effort. Users can analyze the log file and see.

- Time 15s when the SNR from eNB2 is 13.65dB and the SNR from eNB3 is 13.65dB. This represents the point where the two curves intersect.
- Time 18s when the SNR from eNB 2 is 11.93dB and the SNR from eNB 3 is 15.38dB. This represents the point where Adj cell RSRP is greater than serving cell RSRP by Hand-over margin (HOM) of 3dB.

5 Reference Documents

3GPP 36 series specifications for Long Term Evolution Networks.

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