LTE and LTE-Advanced

Contents

1 About LTE and LTE-A

Long-Term Evolution (LTE) is a standard for wireless broadband communication for mobile devices and data terminals. LTE is based on the GSM/EDGE and UMTS/HSPA technologies. LTE increases the capacity and speed of wireless mobile communication by using a different radio interface and other core network improvements. LTE is the upgrade path for carriers with both GSM/UMTS networks and CDMA2000 networks. LTE uses different frequencies and bands in different countries.

LTE is commonly marketed as 4G LTE & Advance 4G, but it does not meet the technical criteria of a 4G wireless service. LTE is also commonly known as 3.95G.

LTE-Advanced or LTE-A is a major enhancement of the LTE standard. LTE-A delivers true 4G speeds, unlike current LTE networks, and is also known as True 4G. LTE-A uses several techniques and technologies (hardware and software) to meet higher network-performance standards. Some of them include:

- Increased peak data rate, DL 3 Gbps, UL 1.5 Gbps

- Higher spectral efficiency, from a maximum of 16bps/Hz in R8 to 30 bps/Hz in R10

- Increased number of simultaneously active subscribers

- Improved performance at cell edges, e.g. for DL 2x2 MIMO at least 2.40 bps/Hz/cell.

- Carrier Aggregation (CA), the enhanced use of multi-antenna techniques.

- Support for Relay Nodes (RN).

NetSim's LTE library includes LTE/LTE-A networks, LTE Femto Cell, LTE D2D and LTE VANET. Additionally, you can connect an LTE Network with Internetwork devices and run all the protocols supported in Internetworks.

2 Key Concepts in LTE and LTE-A

The following are the key concepts involved in the working of LTE and LTE-A networks.

2.1 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.

7 symbols = 0.5 milliseconds
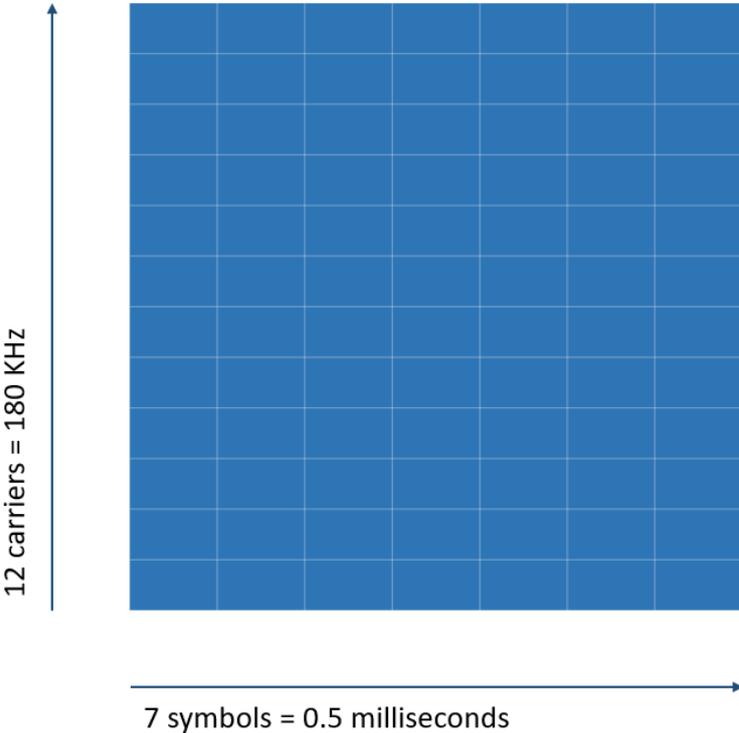
$So, the\ total\ number\ of\ symbols\ in\ a\ Resource\ block = 12\ \times 7 = 84$

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.

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

The following table lists the number of Resource blocks, carriers, and the bandwidth available for different LTE channel bandwidths.

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

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.

2.2 PHY rate calculation

In LTE, for the 20 MHz band, there are 100 Resource blocks and every Resource block has 12 X 7 = 84 symbols.

The following is an example for calculating the theoretical PHY rate for 20 MHz band, that uses 64-QAM and 4 X 4 Tx Rx antennae and without any channel (propagation) losses.

The 20 MHz band has 100 Resource blocks and every resource block has 12 X 7 = 84 symbols.

$So, 100\ Resource\ blocks\ have\ 84\ \times 100 = 8400\ symbols.$

$1\ Subframe = 1\ millisecond = 2\ time\ slots$

$which\ is, 16800\ symbols\ per\ subframe\ or\ per\ millisecond.$

$64\text{-}QAM\ can\ do\ 6\ bits\ per\ symbol.$

$So, 1\ subframe\ using\ 64\text{-}QAM\ can\ transmit\ 100800\ bits\ per\ millisecond\ (100.6\ Mbps).$

$100.6\ Mbps\ for\ a\ 1 \times 1\ Tx\ Rx\ antenna.$

$So, a\ 4 \times 4\ Tx\ Rx\ antenna\ can\ do\ 100.6 \times 4 = 403.2\ Mbps$

In real-life scenarios, signals attenuate due to propagation losses. To factor in these real-life scenarios, NetSim calculates the PHY rate based on the Transport Block Size which is specified in the 3GPP 36 Series specification.

NetSim calculates the actual, effective PHY rate as follows:

1 A signal received at the receiver has a SNR (signal to noise ratio).
2 NetSim calculates a Channel Quality Indicator (CQI) value based on the SNR.
   The SNR - CQI Table is available in the file *LTE.h*, located at *<NetSim Install directory/src/Simulation/LTE>*, and is per the LTE standard.

3   NetSim calculates a Modulation and Coding Scheme (MCS) value based on the SNR and CQI values.

The SNR - CQI - MCS table is available in the file *LTE.h and* is per the LTE standard.

4   NetSim calculates a Transport Block Size (TBS) Index based on the MCS value.

The MCS - TBS Index table is available in LTE.h which is per the LTE standard.

5   NetSim retrieves the Transport Block Size by looking up in the MCS - TBS Index table.

NetSim uses approximately 25% of overhead for controlling and signaling. So, the actual, effective PHY rate is 300 Mbps, which is 75% of the theoretical PHY rate of 403.2 Mbps.

2.3 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 only FDD. Also, NetSim does not support the Downlink-only configurations.

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

2.4 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 5, 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.

2.5 LTE and LTE-A PHY Layer Parameters

The following table lists the details of the parameters of the PHY layer in LTE.

Channel bandwidth (MHz)	1.4	3	5	10	15	20
# of Resource blocks (NRB)	6	15	25	50	75	100
# 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

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

2.6 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.
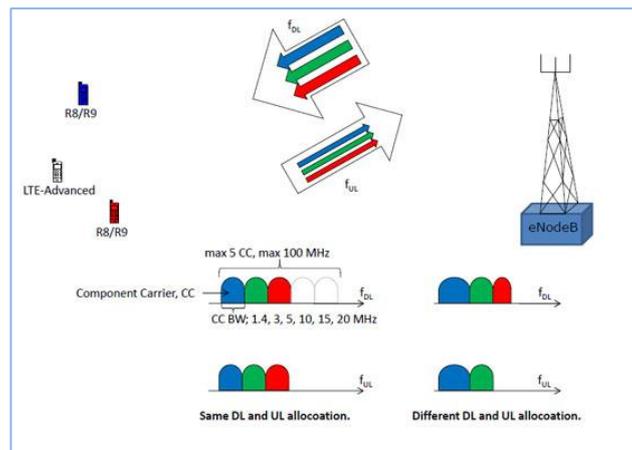
FDD can use different number of component carriers in the Downlink (DL) and Uplink (UL). But, the number of UL component carriers must always be equal to or lower than the number of DL component carriers. Also, the individual component carriers can use different bandwidths.

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

2.6.1   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.
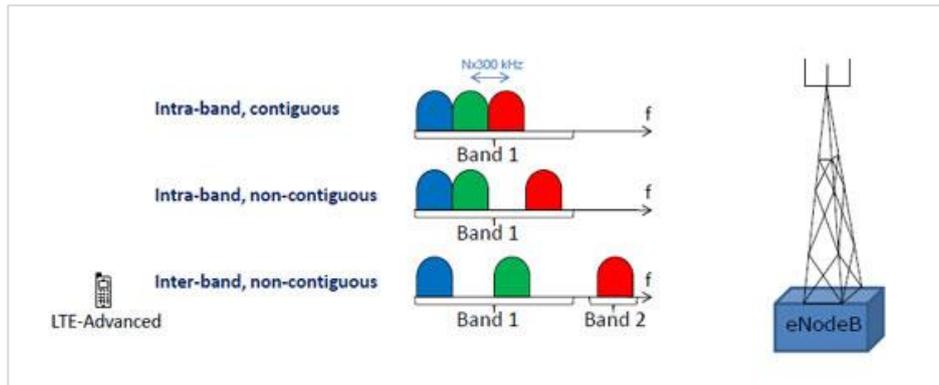
2.6.2 CA Bandwidth Classes

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

2.6.3   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.
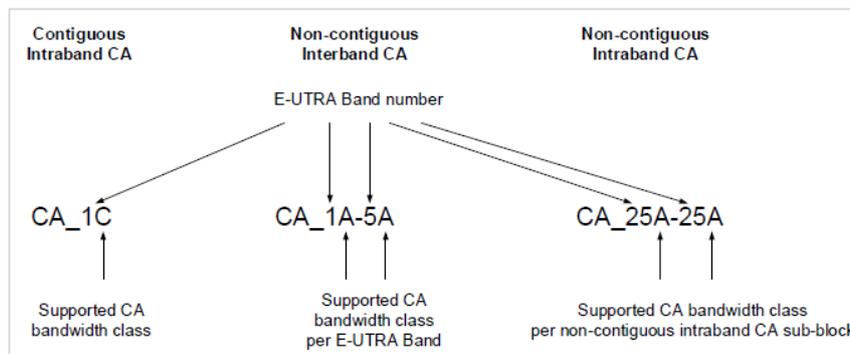
For more information about Carrier Aggregation, see

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

2.6.4   LTE Metrics

LTE Metrics table that is part of the results dashboard contains the following parameters.

Parameter	Description
Device Id	It is the unique Id of a device
Packet Transmitted	It is the number of packets transmitted by eNB and UE which is having application
Bytes Transmitted(Bytes)	It is the number of bytes transmitted by eNB and UE
Packet Received	It is the number of packets received by a eNB and UE
Bytes Received(Bytes)	It is the number of bytes received by eNB and UE
Handover Count	It represents the number of handovers occurred in a UE. Handover is a procedure for changing the serving cell of a UE

3 Simulating LTE and LTE-A

You simulate an LTE or LTE-A network to see how the features of the LTE and LTE-A work.

To simulate LTE or LTE-A in NetSim:

1. Open NetSim and click **New Simulation > LTE/LTE-A Networks** or **LTE FemtoCell** or **LTE D2D** or **LTE Vanet.**

2. Create an LTE or LTE-A network by using the following:

   a. Add a User Equipment (UE) – click the **UE** icon on the toolbar and place the UE in the grid.

   b. Add Wireless nodes, Wired nodes, and L2 Switches – click the appropriate icons on the toolbar and place the device in the grid.

   c. Add an Evolved node B (eNB) - click on the **ENB** icon on the toolbar and place the eNB in the grid.

   Every eNB should be connected to at least One UE.

   d. Add a Mobility Management Entity (MME) – click the **Router > MME** icon on the toolbar and place the MME in the grid.

   MME must be connected to an eNB or to a Router.

   e. Add a Relay – click the **ENB > Relay** icon on the toolbar and place the Relay in the grid.

   Relay must be connected to an eNB or to a UE.

3. Connect the devices in the LTE or LTE-A network by clicking the **Wired/Wireless** icon on the toolbar.

4. Configure an application as follows:

   a. Click the **Application** icon on the toolbar.

   b. Specify the source and destination devices in the network.

c. Specify other parameters such as method and type of the application.

5. Set the properties of the MME, eNB, Relay, UE, and other devices as follows:

- Right-click an MME, click **Properties** and modify the interface and layers' properties to your requirement.

- Right-click an eNB or Relay or UE and specify the parameters.

  The Transmission_Mode Index parameter is global and if you change this parameter in of eNB, Relay, or UE, NetSim updates the parameters for others.

- Right-click an Access Point or node and specify the parameters.

6. Simulate the LTE or LTE-A network as follows:

a. (Optional) Click the Plots, Packet Trace, and Event Trace icons on the toolbar to enable them.

  For more information about Plots, Packet Trace, and Event Trace, see Chapter 7, Results and Analysis in the User Manual.

b. Click the Run icon on the toolbar.

c. Set the simulation time and click **OK**.

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, 1 MME, 4 UEs, 1 router, 1 wired node, and 4 unicast applications 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 each one of the UEs.
- Simulation runs for 10 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**.

   The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.
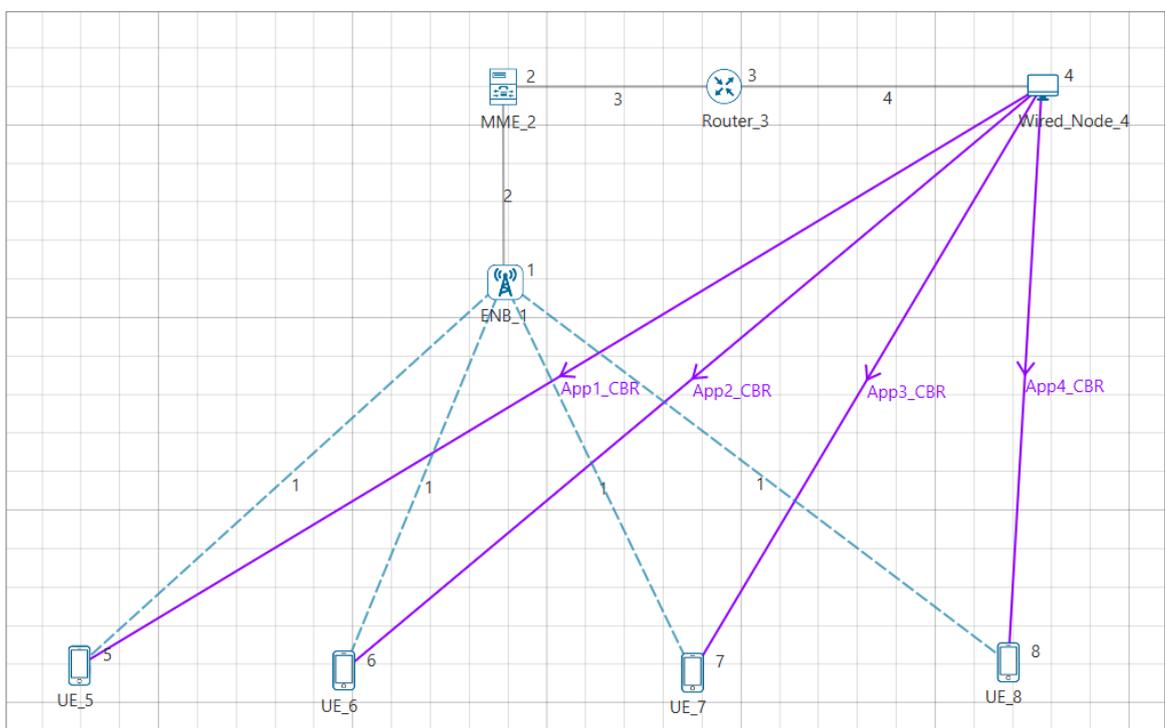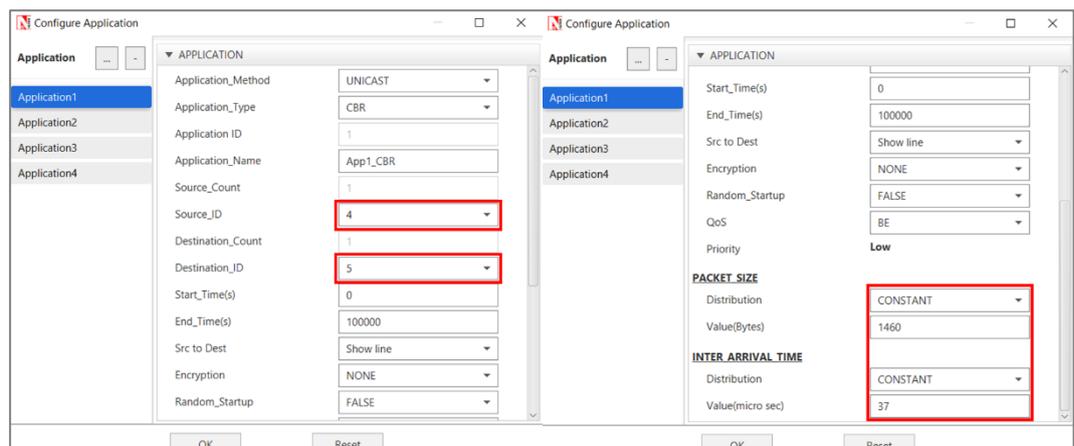

2. See that by default, NetSim has set all the wired link speeds to 1000 Mbps. To do so:

   a. Right-click the wired link between the eNB and the MME 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 MME 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 **4**.

d. **Destination_ID** drop-down list is set to **5**.

e. Scroll down and see that NetSim has specified **1460** in the **Value(Bytes)** in the PACKET SIZE area.

f. Set Transport Protocol to UDP

g. NetSim has specified **37** in the **Value(micro sec)** in the INTER ARRIVAL TIME area.

h. Click **OK**.

i. Repeat steps (a) to (G) for Application2, Application3, and Application4 and see the default values that NetSim has set.
The following figure illustrates the Configure Application pop-up window and the default settings for Application1.

4. See that by default, NetSim has specified default values for the Transmission mode index, Transmission mode, the number of Transmitter antennas, the number of Receiver antennas, and the Channel bandwidth for CA1 and CA2. To do so:

a. Right-click **ENB_1** and click **Properties**.

> The Lte_Enb pop-up window appears.

b. Click **INTERFACE_1(LTE)** in the left area.

c. Click **PHYSICAL_LAYER** in the right area.

d. Scroll down and see that NetSim has selected **0** in the **Transmission_Mode Index** drop-down list.

e. NetSim has set **1** in the **Transmission_Mode**, **Tx_Antennas_Count**, and **Rx_Antennas_Count** field.

f. Scroll down and see that NetSim has selected **20** in the **Channel bandwidth (MHz)** drop-down list, in the CA1 area.

g. Scroll down and see that NetSim has selected **20** in the **Channel bandwidth (MHz)** drop-down list, in the CA2 area.

h. Click **OK**.

i. The above given steps need to performed in **UE** Properties → **INTERFACE_1(LTE)** also**.

> The following figure illustrates step (c) and (d).
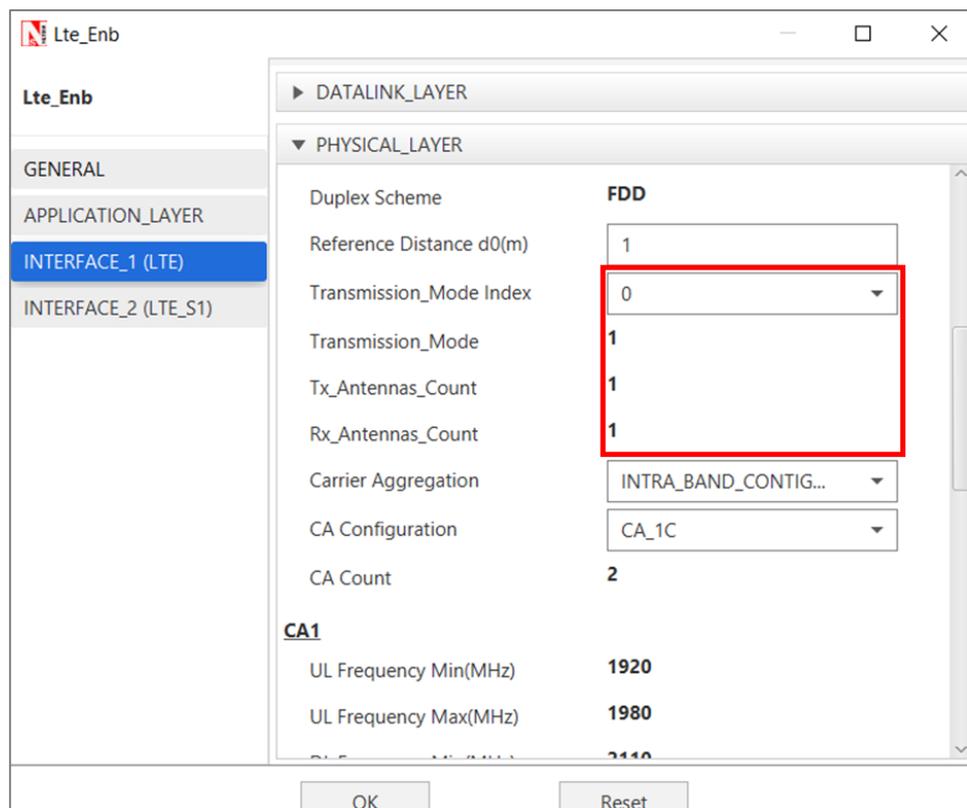
5. See that by default, NetSim has enabled Path Loss and a Path Loss model for the wireless links between the eNB and the UEs. To do so:

a. Right-click the wireless link between ENB_1 and UE_5 and click **Properties.**

The Link Properties pop-up window appears.

    b. **Channel_Characteristics** drop-down list is set to **PATHLOSS_ONLY**.

    c. **Path Loss Model** drop-down list is set to **LOG_DISTANCE**.

    d. NetSim has specified **2** in the **PathLoss_Exponent(n)** field.

    e. Click **OK**.

6. 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 = 10).

    c. Click **OK**.

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

7. 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, Application_2, Application_3, and Application_4: 36.53, 36.60, 36.66, and 36.55.

The following figure illustrates step (8).
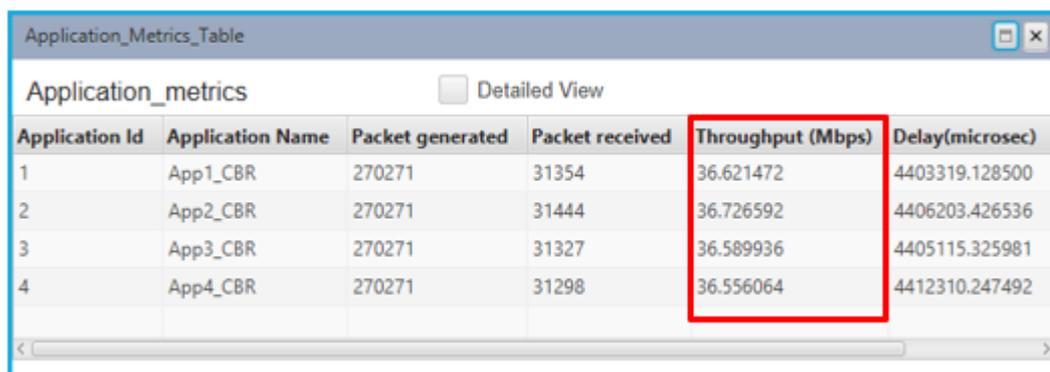
Application Id	Application Name	Packet generated	Packet received	Throughput (Mbps)	Delay(microsec)
1	App1_CBR	270271	31354	36.621472	4403319.128500
2	App2_CBR	270271	31444	36.726592	4406203.426536
3	App3_CBR	270271	31327	36.589936	4405115.325981
4	App4_CBR	270271	31298	36.556064	4412310.247492

8. Simulate the LTE MIMO for LTE example with the Transmission_Mode Index, Transmission_Mode, Tx_Antennas_Count, and Rx_Antennas_Count values displayed in the following table.

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

Transmission_Mode Index, Transmission_Mode, Tx_Antennas_Count, Rx_Antennas_Count	Application_Throughput (Mbps)
1, 2, 2, 2	36.62, 36.73, 36.59, 36.56
2, 3, 2, 2	72.69, 72.76, 72.76, 72.50
3, 3, 4, 2	72.69, 72.76, 72.76, 72.50
4, 5, 4, 2	145.31, 145.39, 145.51, 145.19
4, 5, 8, 2	145.31, 145.39, 145.51, 145.19
4, 5, 16, 2	145.13, 145.49, 145.49, 145.19

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

4.2 LTE VANET Handover

You simulate the example configuration for VANET Handover in an LTE network to understand how handovers happen in an LTE VANET network.

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

- A network with 2 eNBs, 1 MME, 2 vehicles, and a unicast application running on one of the vehicles.
- Handover is a Soft Handover SNR.

NetSim uses the following defaults for this example:

- The unicast Basic Safety Message (BSM) application transmits data Vehicle_1 to Vehicle_2.
- Set Transport Protocol to UDP
- Simulation runs for 400 seconds.
- Packet Trace is enabled.

**Note**: This example is available only if you use the NetSim Standard and Pro versions.

Note: As of this release, you can configure only up to Two Component Carriers (CCs) from the NetSim UI. If you want to configure up to Five CCs, edit the *Configuration.netsim* file and run the example simulation from the NetSim CLI.

You can also select a CC bandwidth from the list of allowed bandwidths, based on which the PHY layer parameters as shown in a table in section 2.6.2.

To simulate the example for LTE VANET Handover for LTE, in NetSim:

1. Open NetSim and click **Examples > LTE-and-LTE-A > LTE-VANET-Handover**.

   The following network diagram illustrates what the NetSim UI displays when you open the example configuration file.
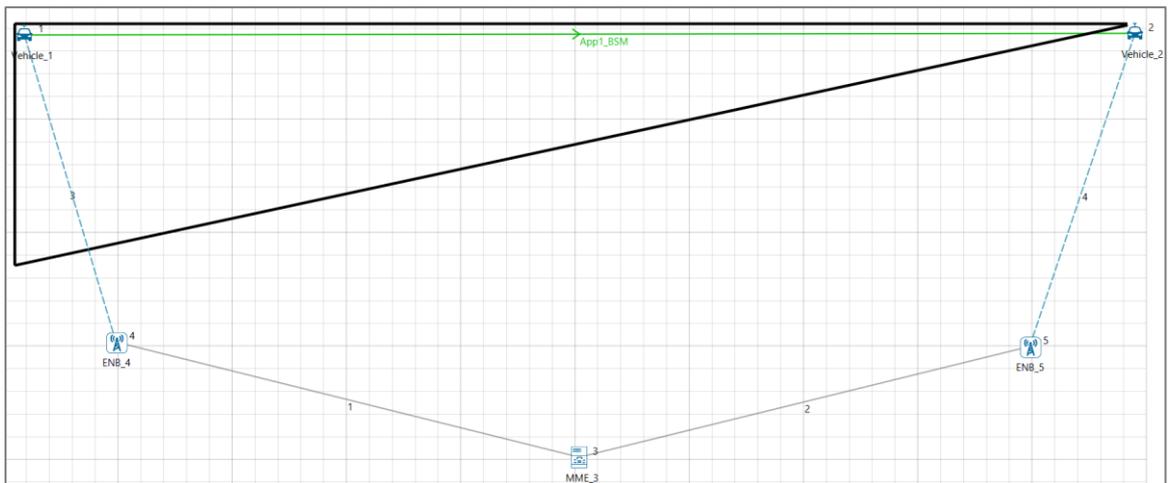
2. See that by default, NetSim has created a unicast Basic Safety Message (BSM) application and specified some default settings. To do so:

   a. Click the **Application** icon located on the toolbar.
      The Configure Application pop-up window appears.
   b. **Application_Type** drop-down list is set to **BSM**.
   c. **Source_ID** drop-down list is set to **1**.
   d. **Destination_ID** drop-down list is set to **2**.
   e. Scroll down and see that NetSim has specified **1460** in the **Value(Bytes)** in the PACKET SIZE area.
   f. NetSim has specified **1000000** in the **Value(micro sec)** in the INTER ARRIVAL TIME area.
   g. Click **OK.**

3. See that by default, NetSim has selected a predefined Simulation of Urban Mobility (SUMO) configuration file from the *C:\Program Files\NetSim Standard\Docs\Sample_Configuration\LTE\LTE_VANET_Handover\\ location*. To do so:

a. Right-click **Vehicle_1** and click **Properties.**

The Let_Vanet_Ue pop-up window appears.

b. NetSim has set the path to the SUMO configuration file as *C:\Program Files\NetSim Standard\Docs\Sample_Configuration\LTE\LTE_VANET_Handover\\Configuration.sumo.cfg.*

c. Click **OK**.

4. Simulate the LTE VANET Handover 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 = 400).

c. Click **OK**.

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

5. Interpret the results.

a. Click View Animation and see the Packet Animation.

You will see that Vehicle_1 and Vehicle_2 do the handover.

The following figure illustrates step (a).
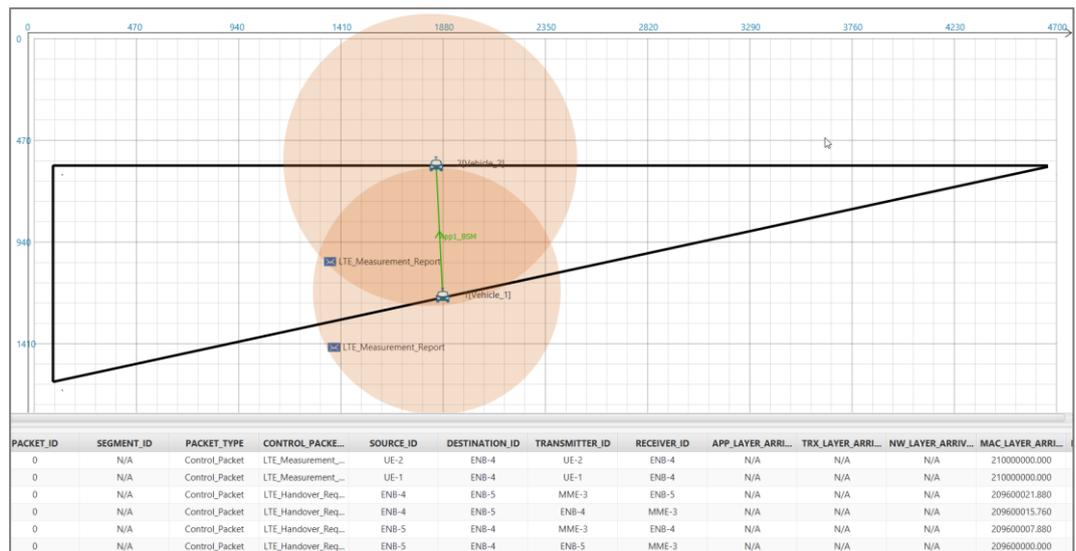
b. Click **LTE metrics** in the left area and check the **Detailed View** check box in the **LTE Metrics_Table** pop-up window.

You will see **2** in the **Handover Count** column for Vehicle_1 and **1** in the **Handover Count** column for Vehicle2.

The following figure illustrates step (b).

c. Click **Open Packet Trace** in the left area and filter the CONTROL_PACKET_TYPE/ APP_NAME column by LTE_Handover_Request and LTE_Handover_Request_Ack.

d. See the filtered rows for how the handover packet are transmitted between the two eNB's and through the MME.

The following figure illustrates step (c) and (d).

5 Reference Documents

3GPP 36 series specifications for Long Term Evolution Networks.

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