NetSim®

Accelerate Network R & D

Satellite Communication Networks

A Network Simulation & Emulation Software

By

TETCOS LLP

Contact us at
TETCOS LLP
214, 39th A Cross, 7th Main, 5th Block Jayanagar,
Bangalore - 560 041, Karnataka, INDIA.
Phone: +91 80 26630624
E-Mail: sales@tetcos.com
Visit: www.tetcos.com

Table of Contents

1 Introduction

NetSim satellite library models end-to-end, full stack, packet level communication between terrestrial nodes and Geostationary satellites. Geo satellites have the unique property of remaining permanently fixed in exactly the same position in the sky as viewed from any fixed location on Earth. This means ground-based antennas do not need to track them but can remain fixed in one direction. These satellites have orbital period that is the same as Earth's rotation period and are the most common type of communications satellites.

The Satellite MAC layer protocol supported in NetSim is TDMA for forward link and MF-TDMA for return link (based on the DVB S2 standards). The forward link is in the Ku band (12 – 18 GHz) while the return link is in the Ka band (26 – 40 GHz)

The satellite can be thought of as a relay station. It operates on the bent-pipe (transparent star) principle, sending back to Earth what comes in, with only amplification and a shift from uplink to downlink frequency.

In NetSim, the satellite communication network library interfaces with Internetworks library. This means users can connect Satellite gateway and User Terminals to devices such as Routers, Switches Wired nodes, Access point and Wireless nodes etc.

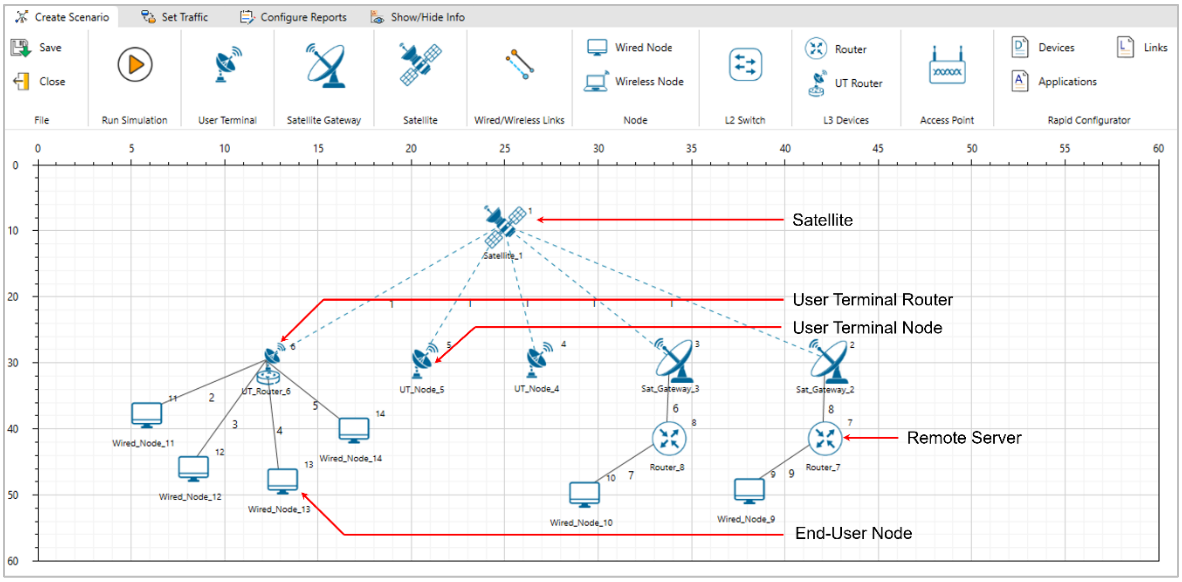


Figure 1-1: NetSim GUI showing Satellite User Terminals connected to a server via satellite links.

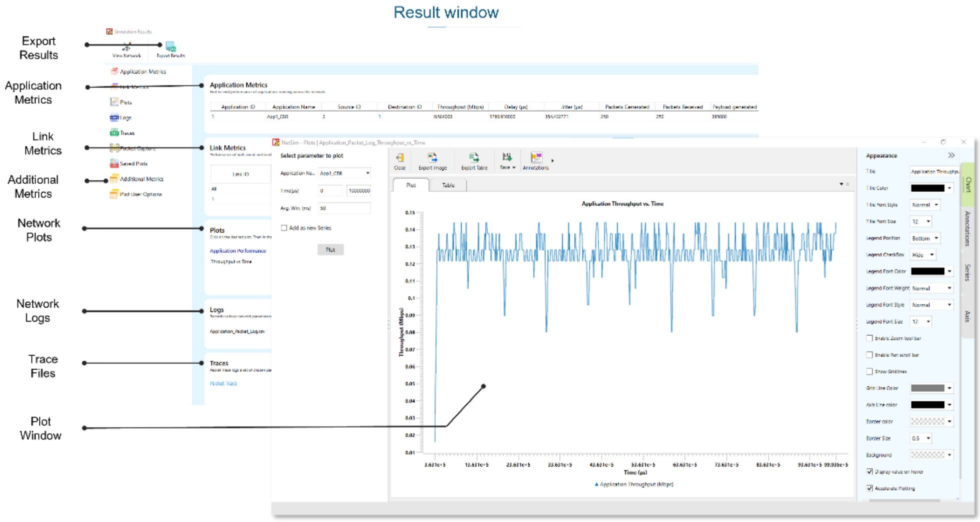


Figure 1-2: The Result dashboard and Plot window shown in NetSim after completion of simulation

The PHY layer models include:

a. Channel model: Friis free space path loss with Markov Loo fading model.
b. Modulation: QPSK, 8PSK, 16APSK, 16QAM, 32APSK with appropriate coding rates.
c. Tx, Rx Antenna gains.
d. Antenna gain to noise temperature.

All the choices of transport protocols, and all types of applications in unicast mode can be run.

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 sat-com protocols.

2 Simulation GUI

Open NetSim, Go to **New Simulation → Satellite Comm. Networks**

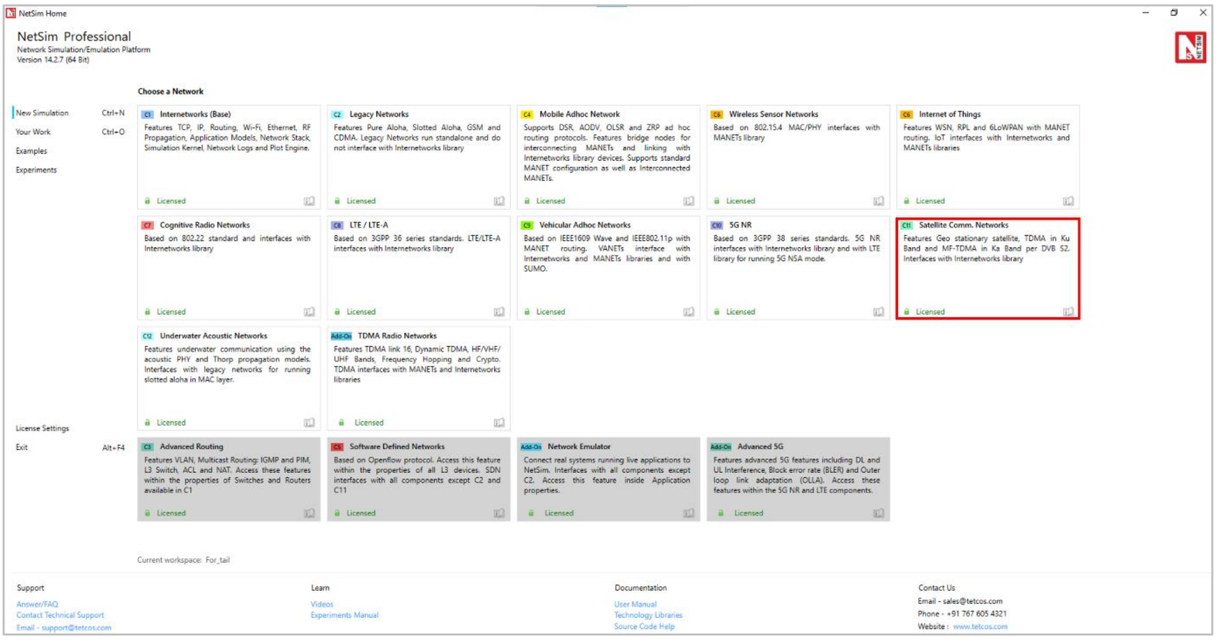


Figure 2-1: NetSim Home Screen

2.1 Create Scenario

Satellite Communication Networks palette features various devices like Wired Nodes, L2 Switch, Access Point, Wireless node, UT Router (User Terminal Router), Router, UT Node (User Terminal Node), Satellite Gateway, and Satellite.

2.2 Devices specific to NetSim Satellite Comm. Library

a. **UT** - User Terminal. The user terminals are part of the same communication network as the Satellite Gateway. The User Terminals in NetSim are UT Node and UT Router

b. **UT Router** - User Terminal Router. A UT Router is used when a separate communication network is required. The typical use case is where there are multiple devices downstream who seek to utilize the sat-com link. The UT Router cannot be a source of any traffic.

c. **Satellite Gateway:** Each gateway has two interfaces, a satellite interface and multiple wired interfaces. The satellite interface connects via the forward link to the satellite. The wired interface allows for connection to routers via the wired interface. When connected to a satellite, the user terminals mapped to the gateway are part of the same network. Multiple gateways can be configured per satellite, and round-robin scheduling is run (at the Network control center (NCC) which is not displayed in NetSim GUI)

d. **Satellite:** Since the satellite model is a bent pipe and satellite does not have an IP. NetSim supports single satellite communication, and it can be connected to multiple gateways and to multiple user terminals. The satellite node cannot be the source of any traffic. The default altitude of the Satellite is 35,768,000 meters, which represents the circular geosynchronous orbit.
e. **Coordinate System:** NetSim uses a Geodetic co-ordinate system. The altitude is from Mean Seal level. The geocentric co-ordinate system uses distance from the centre of the earth.

Figure 2-2: The devices present in the ribbon in NetSim's GUI

2.3 Placement of devices on the grid environment

a. Add a User Terminal (UT) – Click the **User Terminal > UT Node** icon on the toolbar and place the device in the grid. UT Node must be connected to Satellite.
b. Add a UT Router – Click the **User Terminal > UT Router** icon on the toolbar and place the device in the grid. UT Router must be connected to a Node or to a L2 Switch or to a Router or to an Access_Point or Satellite.
c. Add a Satellite – Click the **Satellite** icon on the toolbar and place the Satellite in the grid. Satellite must be connected to a Satellite Gateway or to a UT Node or to a UT Router.
d. Add a Satellite Gateway – Click the **Satellite Gateway** icon on the toolbar and place the Satellite Gateway in the grid. Satellite Gateway must be connected to a Satellite or to a Router.
e. Add a Router – Click the **Router** icon on the toolbar and place the Router in the grid.
f. Add a Wired Node – Click the **Wired Node** icon on the toolbar and place the device in the grid.
g. Add a L2 Switch – Click the **L2 Switch** icon on the toolbar and place the device in the grid.
h. Add an Access Point – Click the **Access Point** icon on the toolbar and place the Access Point in the grid.
i. Add a Wireless Node – Click the **Wireless Node** icon on the toolbar and place the device in the grid.

2.4 Enable Packet Trace, Event Trace (Optional)

Click Packet Trace / Event Trace icon in the Configure Reports option and check Enable Packet Trace / Event Trace check box. For detailed help about the packet and event trace, please refer to **sections 8.4** and **8.5** in the User Manual.

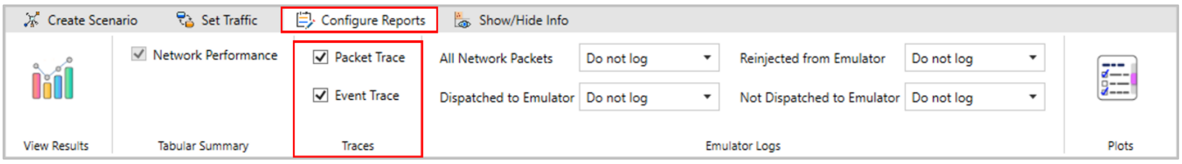


Figure 2-3: Enable Packet Trace, Event Trace & Plots options on top ribbon

2.5 Enable protocol specific logs and plots

NetSim provides protocol-specific logs for Satellite libraries, which users can enable before running a simulation. These can be enabled by clicking on configure reports in top ribbon > clicking on plots > choosing as desired, and running the simulation.

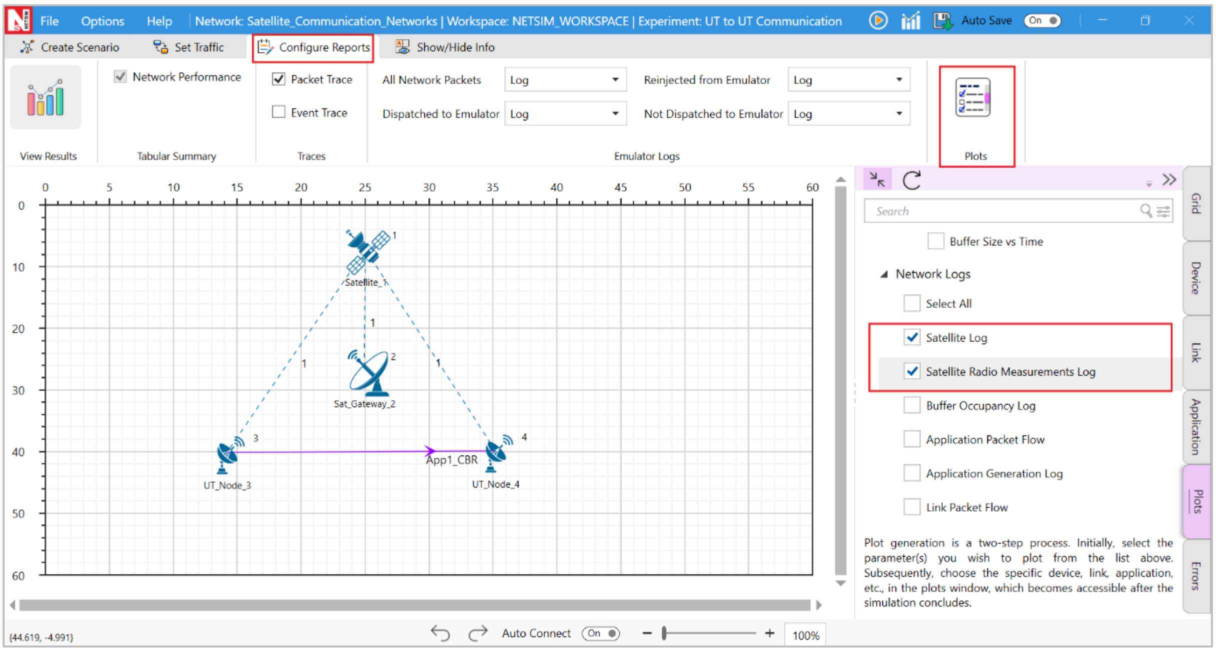


Figure 2-4: Enabling the Network logs in Satellite network

Similarly, users can enable the plots for Satellite Radio Measurements.

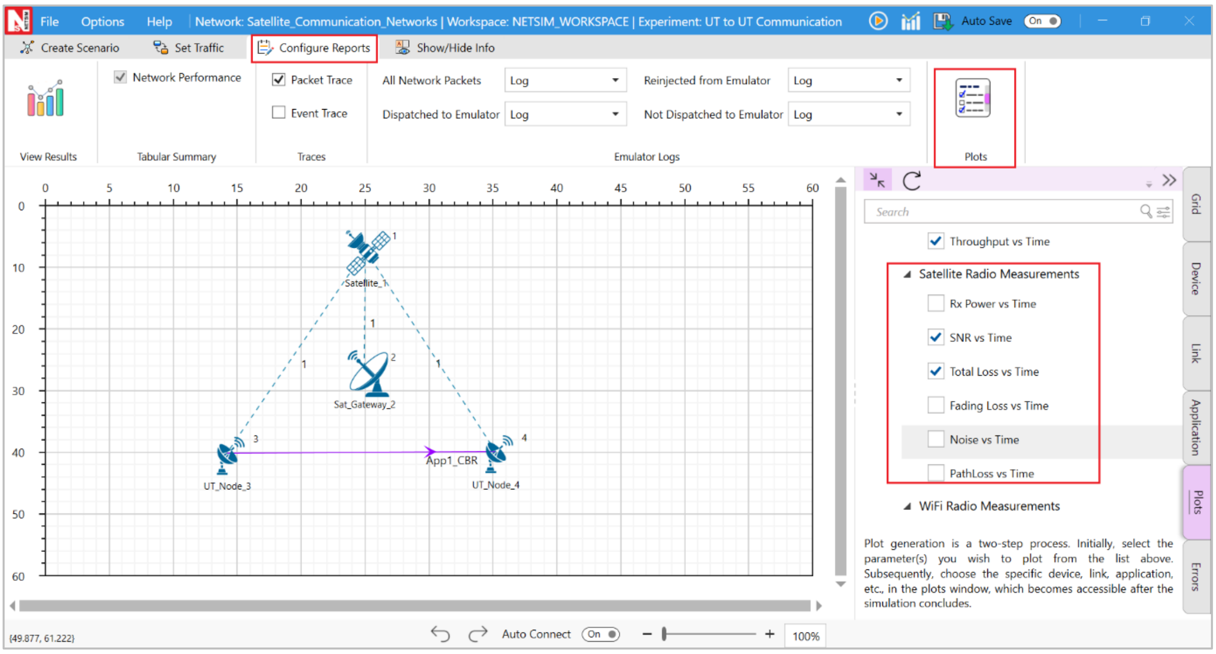


Figure 2-5: Enabling the Plots in Satellite

2.6 GUI Configuration Parameters

The SATELLITE parameters can be accessed by right clicking on a Satellite, Satellite Gateway, UT Router or UT and selecting Interface (SATELLITE) Properties → Datalink and Physical Layers.

Satellite Properties Interface (Satellite) – Physical Layer			
Parameter	**Type**	**Range**	**Description**
G/T (dBk)	Local	0-100000dBk	Antenna gain-to-noise-temperature is (G/T) where G is the antenna gain in decibels at the receive frequency, and T is the equivalent noise temperature of the receiving system in kelvins.
Tx Power	Local	-10000dBW to 10000dBW	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.
Access Protocol	Fixed	TDMA	TDMA allows a number of clients to access a single radio-frequency channel without interference by allocating unique time slots to each user within each channel, reducing the loss of packets and improving the data rate thereby delivering QoS to the clients.
	Fixed	MF-TDMA	Multi-frequency time-division multiple access is a technology for dynamically sharing bandwidth resources in an over-

			the-air two-way communications network.
Base Frequency (GHz)	Local	Ku-band: 12-18GHz Ka-band: 26-40GHz	The “band” in use refers to the radio frequencies used to and from the satellite: Ku-band services uses the 12 - 18 GHz, and Ka-band services uses the 26- 40 GHz segment of the electromagnetic spectrum
Band	Fixed	KU	Microwave frequency band used for satellite communication and broadcasting, using frequencies in the range of 12 -18 GHz
	Fixed	KA	Microwave frequency band used for satellite communication and broadcasting, using frequencies in the range of 26 - 40 GHz
Rolloff Factor	Local	0-1	In NetSim, Symbol Rate = BW / (1+Roll of factor) and Bit Rate = Symbol rate * Modulation order * CodeRate
Spacing Factor	Local	0-1	In NetSim EffectiveBandwidth (Hz) = AllocatedBandwidth (Hz) / ((RollOffFactor + 1.0) * (SpacingFactor + 1.0)); Spacing factor should be in the range of [0,1]
Carrier Bandwidth (Hz)	Local	0-1000000 Hz	Bandwidth of the carrier in Hz
Framecount in Superframe	Local	0-1000000	Number of frames present in a superframe.
Frame Bandwidth (Hz)	Local	0-1000000 Hz	Bandwidth of the frame in Hz.
Frame Usage Mode	Local	NORMAL SHORT	Baseband frame usage modes.
Modulation	Local	QPSK 8PSK 16APSK 16QAM 32APSK	Modulation is the process of varying one waveform in relation to another waveform. It is used to transfer data over an analog channel.
Coding Rate	Local	1/3,1/2, 3/5, 2/3, 3/4, 4/5, 5/6, 8/9, 9/10	It states what portion of the total amount of information that is useful(non-redundant). This code rate typically a fractional number.
Slot Count in Frame	Local	Short Frame: QPSK-90, 8PSK-60, 16APSK/16QAM-45, 32APSK-36 Normal Frame: QPSK-360, 8PSK-240, 16APSK/16QAM-180, 32APSK-144	The number of slots per frame. The number of slots per frame is based on modulation and frame type chosen.

Symbol per Slot	Local	0-1000000	The number of TDMA symbols within a slot, the default value of symbol per slot is 90.
Pilot Block Size (Symbols)	Local	0-1000000 symbols	Size of pilot block in symbols
Pilot Block Interval (Slots)	Local	0-1000000 slots	Interval (in symbols) between Pilot blocks
Pilot Header (Slots)	Local	0-1000000 slots	The pilot block header size in slots.
Frame Header Length (Bytes)	Local	0-1000000 bytes	Baseband frame header length in bytes
BER Model	Local	Fixed	BER value is based on the user input and is independent of the received SINR.
		FILE BASED	File Based is a feature in NetSim with which users can define the BER. Users will have to provide a BER_FILE.txt file as input to NetSim by clicking on the Open file link the Physical Layer-Properties of the device.
		MODEL BASED	BER is computed using the SINR-BER formula for the chosen Modulation and coding. The pathloss and fading models are used in the SINR calculation.
BER	Local	0.00000001-1	This parameter is shown is the *Fixed* option is chosen for the BER model parameter. Users can set the Bit Error Rate (BER) in the range shown.
UT Properties			
Interface (Satellite) – Physical Layer			
Parameter	Parameter	Parameter	Parameter
Tx Antenna Gain (dB)	Local	0-1000000dB	A relative measure of an antenna's ability to direct or concentrate radio frequency energy in a particular direction or pattern at the transmitter side.
Rx Antenna Gain (dB)	Local	0-1000000dB	A relative measure of an antenna's ability to receive radio frequency energy in a particular direction or pattern at the receiver side.

Table 2-1: Satellite, Satellite Gateway, UT Router or UT and selecting Interface (SATELLITE) Properties → Physical Layers Description

Propagation Model			
Link Properties			
Parameter	**Type**	**Range**	**Description**
Propagation Medium	Link	Air	Medium of propagation in NetSim would be Air for RF waves.
Channel Characteristics	Fixed	Pathloss and Fading and Shadowing	Path loss and fading and shadowing: In pathloss models, for a fixed distance between source and destination, path loss is same. We get varied path loss

			for some distance between source and destination in shadowing and fading is variation of the attenuation of a signal with various variables. These variables include time, geographical position, and radio frequency.
Shadowing Model	Fixed	NONE	
Pathloss Model	Link	Friis Free Space	It Used to model the LOS path loss incurred in the channel. the Friis Free space model is restricted to unobstructed clear path between the transmitter and the receiver.
Pathloss Exponent (η)	Fixed	2	Path loss exponent indicates the rate at which the path loss increases with distance. The value depends on the specific propagation environment.
Fading Model	Fixed	Markov Loo	Each state of the three-state Markov channel models obeys the Loo distribution with different parameters; while the state transition is modeled as a first-order Markov random process.
Direct Signal Mean (dB)	Link	-∞ to ∞	Mean value of the direct signal, value can be differentiated according to the state.
Direct Signal Standard Dev (dB)	Link	0 to ∞	Standard Deviation of the direct signal value can be differentiated according to the state.
RMS Multipath Power (dB)	Link	-∞ to ∞	RMS squared multipath power in dB
Number of Direct Signal Oscillators	Link	0 to ∞	Number of direct signal oscillator is used for frequency conversion process in superheterodyne receiver.
Number of Multipath Oscillators	Link	0 to ∞	Number of multipath oscillators is used to generate higher oscillation frequencies.
Direct Signal Doppler (Hz)	Link	0 to ∞	
Multipath Doppler (Hz)	Link	0 to ∞	The normalized PSD (its integral in the whole frequency range equals to one) constitutes the PDF for the Doppler frequencies, arising from the different angles of arrival the multipath components have with respect to the receiver's motion.
Initial Probability	Link	0 to 1	An initial probability distribution, defined on S, specifies the starting state. Usually this is done by specifying a particular state as the starting state.

Table 2-2: Propagation Model/Wireless Link Properties Description

2.6.1 Mapping of User Terminal (UT Node / UT Router) to Satellite Gateway

Each satellite can be connected to multiple Satellite Gateways and to Multiple User Terminals. The following screen shot shows how to map the User Terminal to Satellite Gateway as shown Figure 2-6.

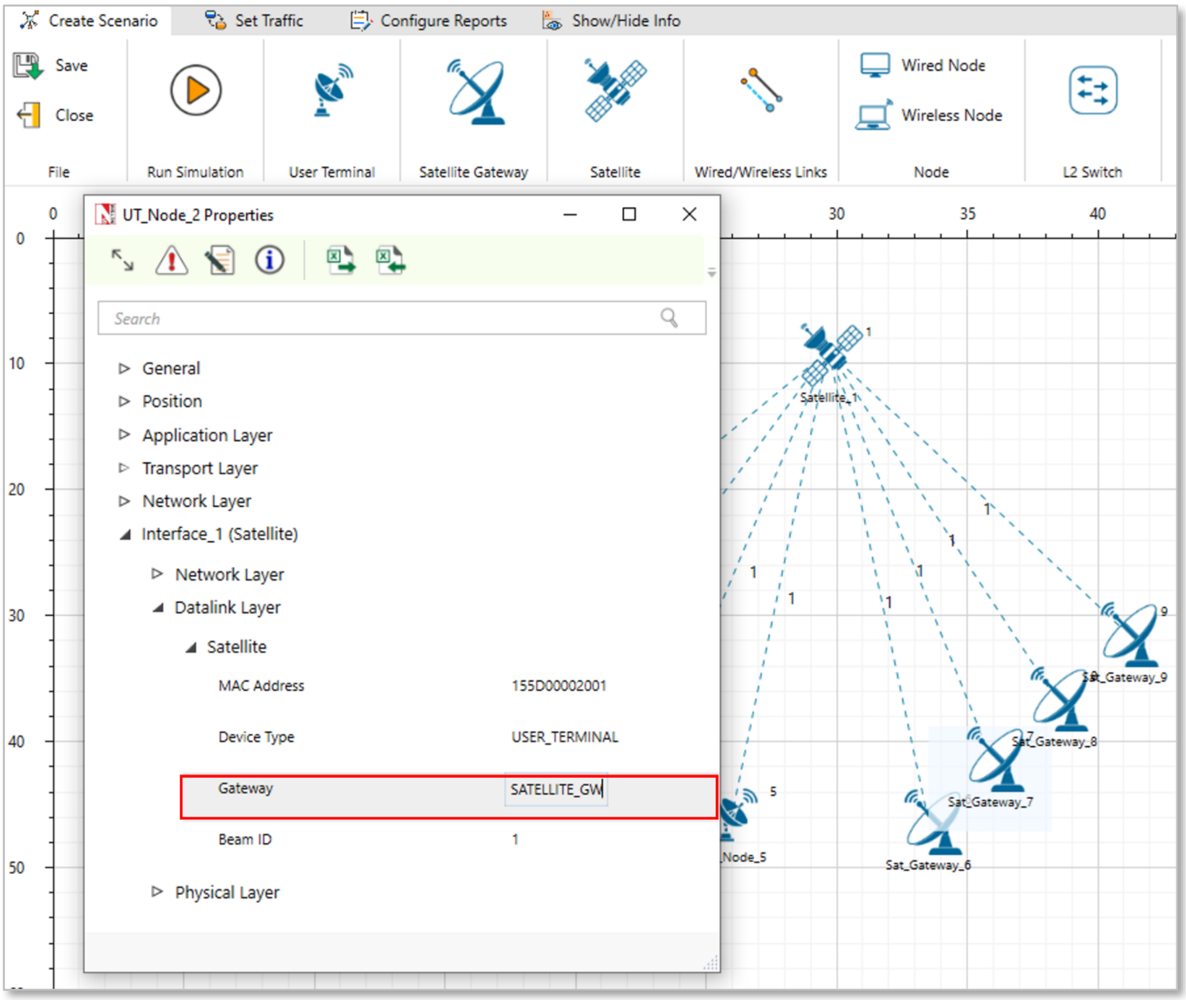


Figure 2-6: Mapping of User Terminal (UT Note / UT Router) to Satellite Gateway

In order to Map User Terminal (UT Node / UT Router) to Satellite Gateway right click go to the properties of **UT Node/UT Router → INTERFACE1 (SATELLITE) → DATALINK LAYER → Gateway** user can map the Satellite Gateway with UT Node / UT Router accordingly.

Additionally, in the UT Router/UT Node -> Interface Satellite the default gateway IP should be set as the IP of the connected Satellite Gateway.

Incorrect mapping of the Satellite Gateway and/or the default Gateway IP address, in the properties of the UT Node / UT Router could lead application crash or NIL application throughputs.

2.6.2 Configuring Static Routes

After mapping the UT Router/UT Node to a Satellite Gateway, static routes need to be configured in the devices to forward traffic. Let us consider the following network scenario as shown Figure 2-7.

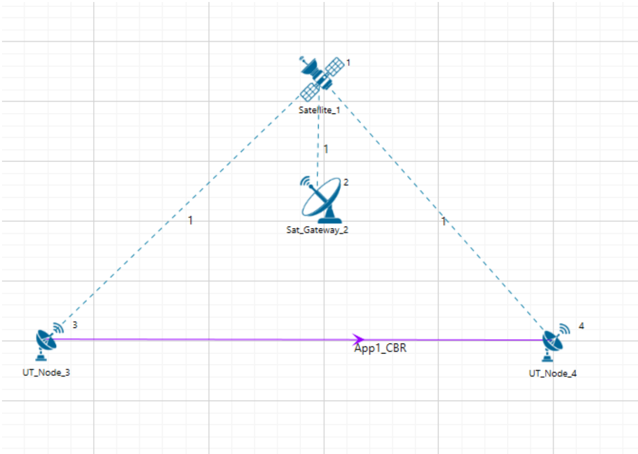


Figure 2-7: Network Topology in this experiment

In this network scenario, for UDP traffic to be sent from UT Node 3 to UT Node 4, static routes need to be set in UT Node 3 and in the Satellite Gateway 2.

If TCP traffic needs to be sent from UT Node 3 to UT Node 4, then static routes need to be set in UT Node 4 as well. This is essential for connection establishment and sending acknowledgements.

Refer the featured example on Configuring applications from UT Node to UT Node for detailed information on static route configuration.

3 Model Features

3.1 TDMA Forward Link and MF TDMA Return Link

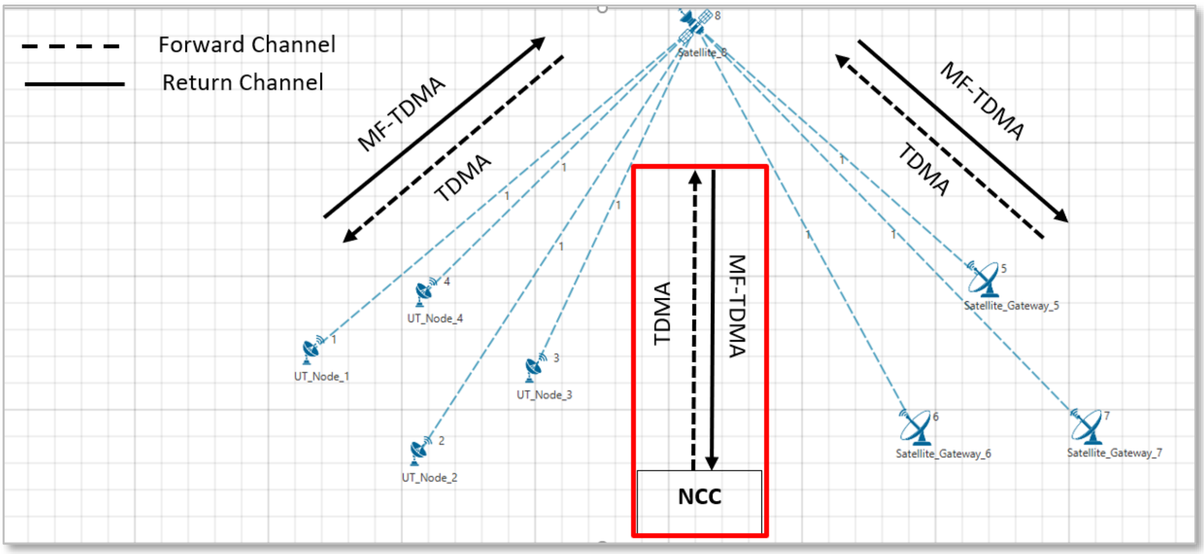


Figure 3-1: Forward and Return links. The Network Control Centre (NCC) is not displayed in NetSim and is assumed to be part of every satellite

In NetSim, a Forward link is defined as the direction from Satellite Gateway to Satellite to UT Node / UT Router. A Return link is defined as the direction from the UT Node / UT Router to Satellite to the Satellite Gateway.

The protocol operating in the Forward link is Time Division Multiple Access (TDMA). The protocol operating in the Return link is Multi Frequency Time Devision Multiple Access (MF-TDMA).

Both the Forward link and Return link transmissions in NetSim are modeled as Layer-2 transmissions. The framing is as explained in the subsequent paragraph.

Each Super Frame is composed of a number of Frames. This is taken as a user input, given by the attribute Framecount in SuperFrame available in Satellite -> Interface Satellite -> Physical Layer properties. The frames in turn are composed of carriers (in frequency) and slots (in symbols). The number of carriers would be

$$Number\ of\ Carriers = \frac{Frame\ Bandwidth\ (Hz)}{Carrier\ Bandwidth\ (Hz)}$$

The number of slots per frame is determined by the modulation scheme chosen by the user.

3.2 Modulation and coding schemes supported

1. QPSK with coding rates 1/3, 1/2,1/4, 2/5, 3/5, 2/3, 3/4, 4/5, 5/6, 8/9, 9/10
2. 8PSK with coding rates 3/5, 2/3, 3/4, 5/6, 8/9, 9/10
3. 16APSK with coding rates 2/3, 3/4, 4/5, 5/6, 8/9, 9/10
4. 16QAM with coding rates 3/4, 5/6
5. 32APSK with coding rates 3/4, 4/5, 5/6, 8/9, 9/10

Note:

- The modulation and coding rate are specified in Table 12 on page 32 of the ETSI EN 302 307-1 European Standard

3.3 Physical layer framing for forward and return links

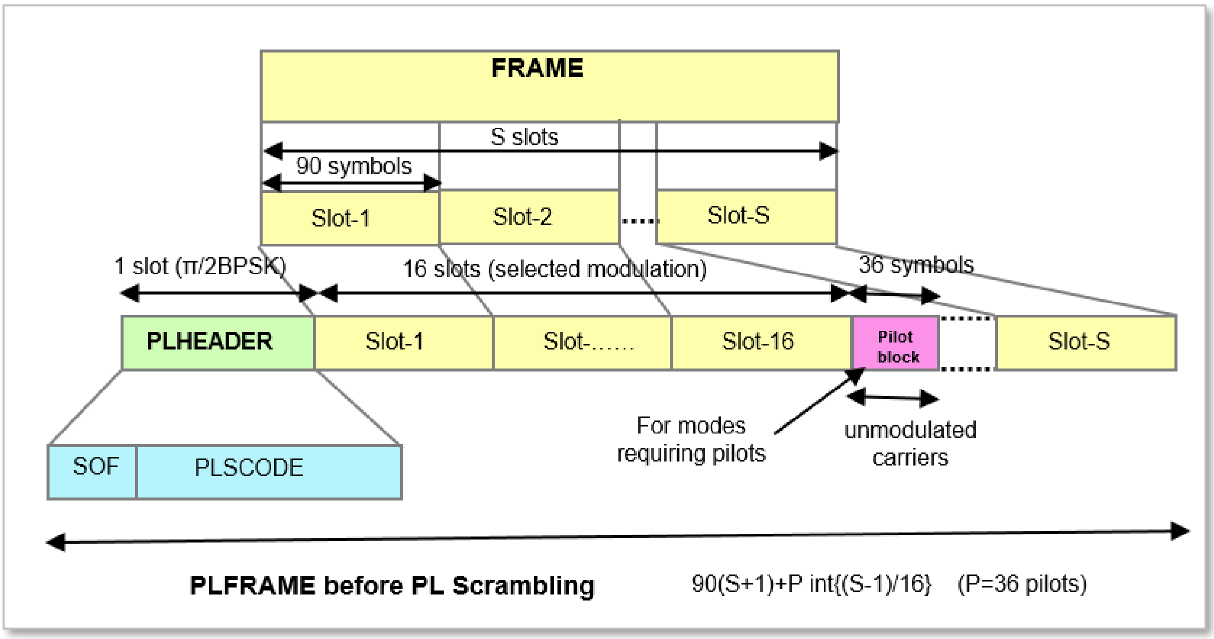


Figure 3-2: Format of a "Physical Layer Frame" PLFRAME

	$\eta_{ldpc} = 64800$ $(normal\ frame)$		$l = 16200$ $(short\ frame)$	
η_{MOD} $(bits/Hz)$	S	η % $no-pilot$	S	η % $no-pilot$
2	360	99.72	90	98.90
3	240	99.59	60	98.36
4	180	99.45	45	97.83
5	144	99.31	36	97.30

Table 3-1: S = number of SLOTs per FRAME (number of symbols per slot is 90)

The normal frame and short frame setting can be done using the Frame Usage Mode parameter in the GUI as shown Figure 3-3.

Changing the Modulation scheme in UI would change the value of S (Slot count in frame)

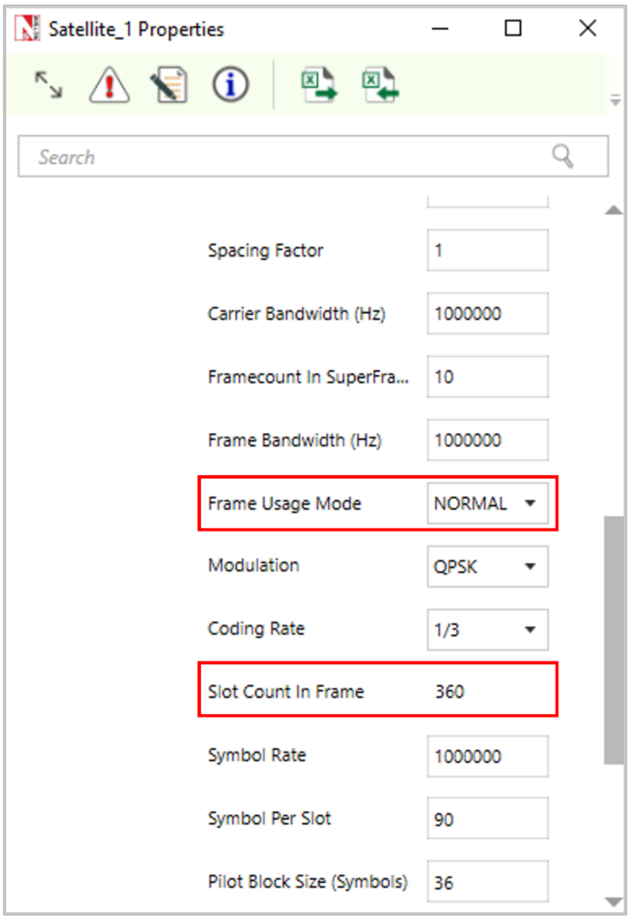


Figure 3-3: Satellite > Physical layer properties window

Default NetSim GUI settings

- Symbols per slot: 90
- Pilot Block size (symbols): 36
- Pilot block interval (slots): 16
- PL header size (slots): 1
- Frame header size (In bytes): 10 (per ETSI EN 302 307 V1.3.1)
- Frame Type: Normal (Options are normal or short)

3.4 Satellite PHY: Data Rate

Given below is the data rate calculation methodology for both forward and return links. The parameter values used are the default values in NetSim GUI.

$$Symbol\ Rate = \frac{BW}{\left(1 + (Roll\ of\ factor)\right)}$$

$$Bit\ Rate = Symbol\ rate \times Modulation\ order \times CodeRate$$

$$Bandwidth\ (Hz) = Frame\_Bandwidth\ (Hz) = 10^6\ Hz$$

$$Central\ Frequency\ (Hz) = Base\ Frequency\ (Hz) + \frac{Bandwidth\ (Hz)}{2.0}$$

$$Central\ Frequency\ (Hz) = 26 \times 10^{9} + \frac{10^{6}}{2} = 2.60005 \times 10^{10} Hz$$

$$Effective\ Bandwidth\ (Hz) = \frac{Carrier\ Bandwidth\ (Hz)}{(RollOfFactor + 1.0) \times (SpacingFactor + 1.0)}$$

$$Effective\ Bandwidth\ (Hz) = \frac{10^{6}}{(1.0 + 1.0) \times (1.0 + 1.0)} = 25 \times 10^{4}\ Hz$$

$$Symbol\ Rate = Effective\ Bandwidth\ (Hz) = 25 \times 10^{4} Hz$$

$$Modulation\ Bits = 2$$

The number of Modulation Bits depends on the modulation scheme per the table below:

Modulation	Modulation bits
QPSK	2
8PSK	3
16APSK/16QAM	4
32APSK	5

Table 3-2: Modulation bits for different modulation

$$Slots = Slot\ Count\ in\ Frame + Pilot\ Header\ (slots) = 360 + 1 = 361$$

$$Data\ Symbols = Slots \times Symbol\ per\ Slot = 361 \times 90 = 32490$$

$$Pilot\ Slot = \frac{Slots}{Pilot\ Block\ Interval} = \frac{361}{16} = 22$$

$$Pilot\ Symbol = Pilot\ Slot \times Pilot\ block\ Size\ (symbols) = 22 \times 36 = 792\ Symbols$$

$$Total\ Symbol = Pilot\ Symbol + Data\ Symbols = 792 + 32490 = 33282$$

$$Frame\ length = \frac{Total\ Symbol}{Symbol\ Rate} \times 1000000 = \frac{33282}{250000} \times 1000000 = 133128\ \mu s$$

$$Pilot\ Block\ Length = \frac{Pilot\ block\ Size}{Symbol\ Rate} \times 1000000 = \frac{36}{250000} \times 1000000 = 144\ \mu s$$

$$Slot\ Length = \frac{Symbol\ per\ Slot}{Symbol\ Rate} \times 1000000 = \frac{90}{250000} \times 1000000 = 360\ \mu s$$

$$SuperFrame\ Duration = Frame\ length \times Frames\ per\ SuperFrame = 133128 \times 10 = 1331280\ \mu s$$

$$Bits\ per\ Slot = Symbol\ per\ slot\ \times Modulation\ Bits \times Coding\ Rate = 90 \times 2 \times \frac{1}{2} = 90$$

$$Bits\ per\ Frame = Bits\ per\ Slot \times\ Slot\ Count\ in\ Frame = 90 \times 360 = 32400$$

$$Data\ Rate = \frac{Bits\ per\ Slot}{Slot\ Length} = \frac{90\ bits}{360\ \mu s} = 0.25 \times 10^6\ bits/sec = 0.25\ Mbps$$

3.5 Analytical throughput estimation

Let us an example in which the Packet Size (App layer) is 1460B which translates to 1488B at the PHY layer after addition of overheads, with QPSK modulation and $\frac{1}{2}$ coding rate. For this modulation and coding rate the raw PhyRate of the channel is 162249 bps using the formulas given in 3.4. The analytical throughput estimate for such a scenario would be:

$$PacketTransmissionTime = \frac{PacketSize(at\ PHY) \times 8}{PhyRate(bps)} = \frac{1488 \times 8}{162249} = 0.0733687s = 73368.7\mu s$$

$$PacketsPerFrame = \lfloor\frac{FrameTime}{PacketTransmissionTime}\rfloor = \lfloor\frac{133128}{73368.7}\rfloor = \lfloor 1.81 \rfloor = 1$$

$PacketsPerFrame$ is the number of packets that can be packed in a frame, and hence the greatest integer or floor function is used.

$$BytesPerFrame = PacketsPerFrame \times PacketSize(B) = 1488 \times 1 = 1488$$

$$NumberOfFramesPerSecond = \frac{1}{Frame\ Duration(s)} = \frac{1}{0.133128} = 7.51$$

$$PhyThroughput = NumberOfFramesPerSecond \times (BytesPerFrame \times 8) = 7.51 \times (1488 \times 8) = 89399.04\ bps = 0.089\ Mbps$$

$$ApplicationThroughput = \frac{1460}{1488} \times PhyThroughput = 0.087\ Mbps$$

3.6 PHY rate for various modulations and coding rates

Modulation	Modulation bits	Slot Count in a frame	Coding Rate	PHY Rate (Mbps)
QPSK	2	360	1/3	0.167
			1/2	0.250
			1/4	0.125
			2/5	0.200
			3/5	0.300
			2/3	0.333
			3/4	0.375
			4/5	0.400
			5/6	0.417
			8/9	0.444
			9/10	0.450
8PSK	3	240	3/5	0.450
			2/3	0.500
			3/4	0.561
			5/6	0.625
			8/9	0.667
			9/10	0.675
16APSK	4	180	2/3	0.667
			3/4	0.750
			4/5	0.800
			5/6	0.833
			8/9	0.889
			9/10	0.900
16QAM	4	180	3/4	0.750
			5/6	0.833
32APSK	5	144	3/4	0.936
			4/5	1.000
			5/6	1.042
			8/9	1.111
			9/10	1.125

Table 3-3: List of support modulation schemes and coding rates, and their respective PHY Rates

3.7 Satellite PHY: Land Satellite Channel Model

3.7.1 Propagation

The distance between the ground nodes and the satellite determines the propagation delay and path loss of the radio signal. The distance is computed based on the cartesian distance between the ground nodes and the satellite. NetSim computes the propagation delay of the radio signal traveling from the source node to the destination node at the speed of light. The propagation model calculates the weakening of the radio signal as it propagates from the source node per the pathloss and fading model.

3.7.2 Pathloss Model – Friis Free Space Propagation

The free space propagation model is used to predict received signal strength when the transmitter and receiver have a clear, unobstructed line-of-sight path between them. Satellite communication systems and microwave line-of-sight radio links typically undergo free space propagation. The free space power received by a receiver antenna which is separated from a radiating transmitter antenna by distance d, is given by the Friis free space equation.

$$P_r = P_t + G_t + G_r + 20\log_{10}\left(\frac{\lambda}{(4*\pi*do)}\right) + \left(10 \times 2 \times \log_{10}\left(\frac{do}{d}\right)\right)$$

where $P_t$is the transmitted power.

P_r is the received power.

G_t is the transmitter antenna gain.

G_r is the receiver antenna gain.

d is the T-R separation distance in meters.

λ is the wavelength in meters.

3.7.3 Fading model

NetSim uses a 3 state (state 1, state 2 and state 3) Markov model to simulate fading.

The conditional probabilities of state s_{n+1} given the state $s_n$are described by state transition probabilities p_{ij}

Where S_1, S_2, S_3 denotes respective channel state, P_{ij} is the probability the Markov process goes from state *i* to state *j*.

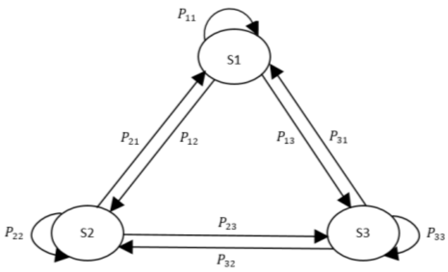


Figure 3-4: Switching of three-state Markov process

The switching among each state is described by a transition matrix P, which is

$$P = \begin{pmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{pmatrix}$$

Each state of the three-states of the Markov model obeys the Loo distribution with different parameters, while the state transition is modeled as a first-order Markov random process.

The Loo distribution considers the received signal as a sum of two signal components. A log-normally distributed direct signal expresses the slow fading component corresponding to varying shadowing conditions of the direct signal. A Rice distribution characterizes the fast-fading component due to multipath effects.

The Loo parameter triplet consists of the mean, the standard deviation for the log-normally distributed direct signal, and the average multipath power.

$$N(\mu, \sigma^2) + R$$

Depending on the current state interval and on the environment of the terminal, a new random Loo parameter triplet is generated. The output of the channel model is a time-series of the received signal in form of a complex envelope.

And finally, the model computes the Loo distributed time-series including Doppler shaping for every new state interval, which is the output of the proposed LMS channel model.

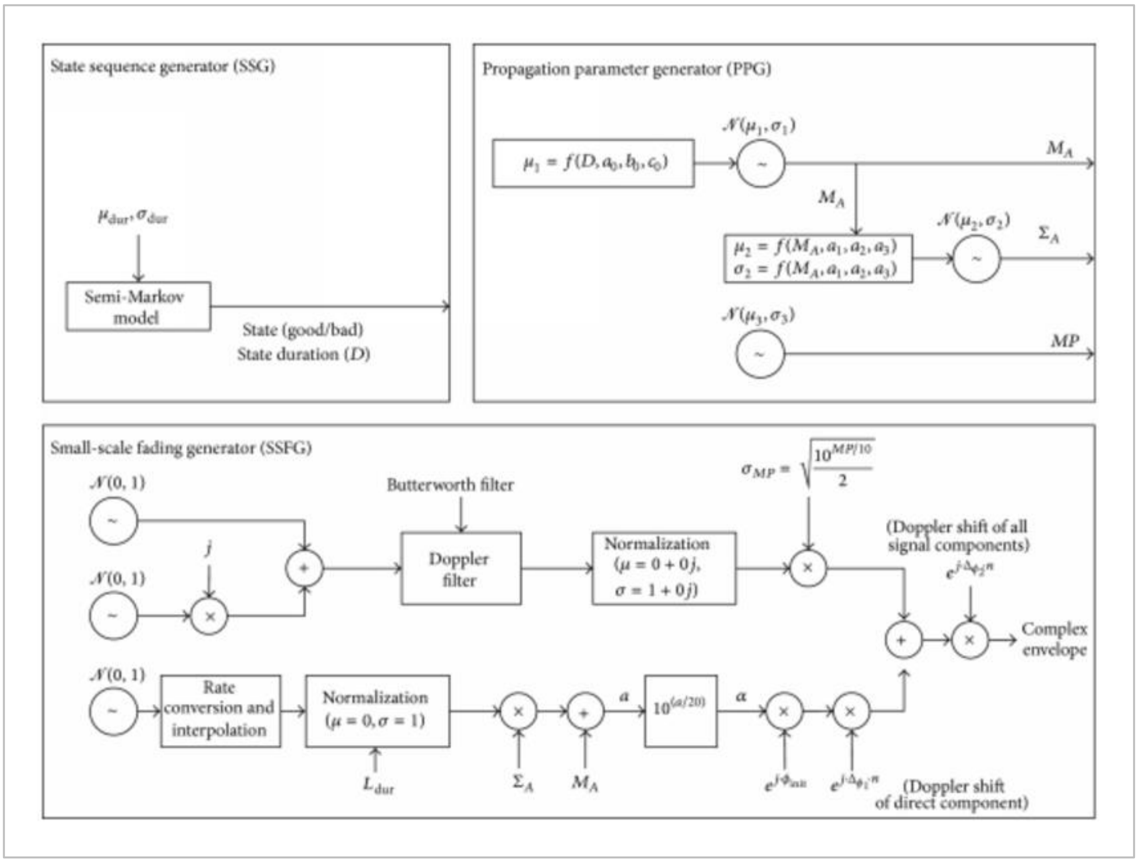


Figure 3-5: The Satellite LMS channel Model

3.7.4 SNR - BER Calculation

$$SNR\ (dBm) = \ log_{10}\left(\frac{Received\ power\ (in\ mW)}{Thermal\ Noise\ (in\ mW)}\right)$$

The SNR is calculated separately for each 'hop' of each link. This means the calculation is done from Gateway to Satellite and then separately again from Satellite to UT, and vice versa.

$Noise = k_B\,T\,B$ where k_B is the Boltzman's constant, B is the carrier bandwidth and T is the temperature calculated per user input of $\frac{G}{T}(dBK)$ in NetSim UI.

NetSim provides three options for BER.

- Model Based: The BER is then calculated for each link based on the SNR. Please see Propagation-Models.pdf document for detailed information on BER calculation.
- Fixed: the BER value can be input in the GUI. If this option is chosen, the SNR (derived from propagation model) is not used.
- File Based: SNR – BER table should be provided in a file per the format given below. This table should be in increasing order of SNR. The SNR is calculated by NetSim from the RF propagation model. For this SNR, the appropriate BER is selected from this table. BER is 1.0 for any SNR value below SNR1, and BER is 0.0 for any SNR greater than SNRn.

  SNR1, BER1

  SNR2, BER2

  …

  SNRn, BERn

Note: Users can enable the Satellite Propagation Log to see the SNR calculated from RF propagation model and then choose appropriate entries of SNR, BER values into the BER-File to see the impact on throughput.

3.8 Results

Please refer NetSim User manual **section 8** for Results and Analysis.

3.8.1 Satellite Log

NetSim Satellite Log file records UT Satellite association, calculated superframe, frame, slot, bandwidth, etc., This log can be enabled/disabled by going to Plots option and checking/unchecking the Satellite Log option under the Network Logs section as shown below:

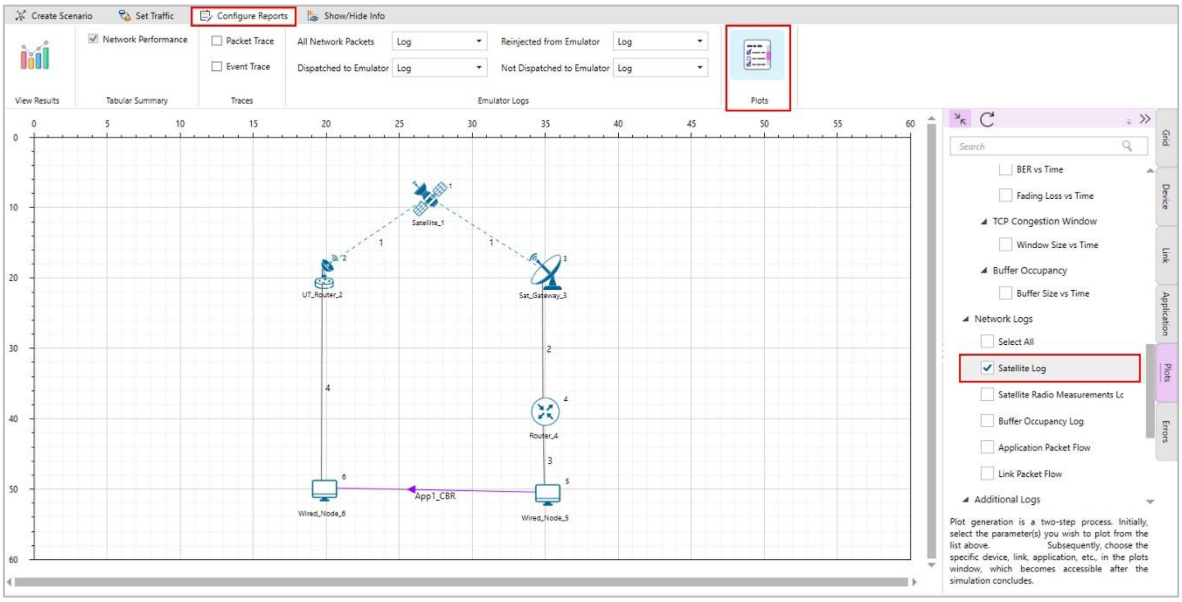


Figure 3-6: Enabling Satellite Log file.

A log file specific to satellite communication, is generated post simulation as shown in screen shot below,

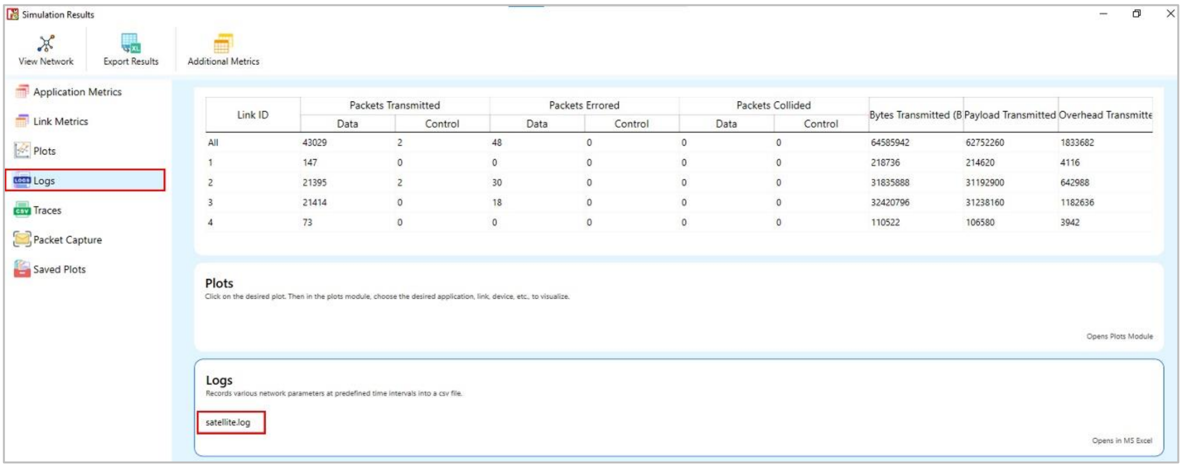
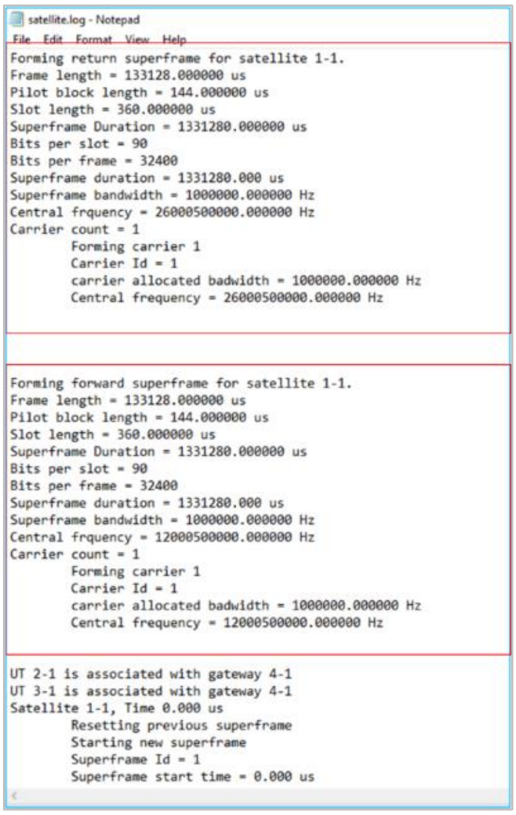


Figure 3-7: Result Window

On opening, the satellite log file would look like the image below.



```
satellite.log - Notepad
File Edit Format View Help
Forming return superframe for satellite 1-1.
Frame length = 133128.000000 us
Pilot block length = 144.000000 us
Slot length = 360.000000 us
Superframe Duration = 1331280.000000 us
Bits per slot = 90
Bits per frame = 32400
Superframe duration = 1331280.000 us
Superframe bandwidth = 1000000.000000 Hz
Central frquency = 26000500000.000000 Hz
Carrier count = 1
        Forming carrier 1
        Carrier Id = 1
        carrier allocated badwidth = 1000000.000000 Hz
        Central frequency = 26000500000.000000 Hz


Forming forward superframe for satellite 1-1.
Frame length = 133128.000000 us
Pilot block length = 144.000000 us
Slot length = 360.000000 us
Superframe Duration = 1331280.000000 us
Bits per slot = 90
Bits per frame = 32400
Superframe duration = 1331280.000 us
Superframe bandwidth = 1000000.000000 Hz
Central frquency = 12000500000.000000 Hz
Carrier count = 1
        Forming carrier 1
        Carrier Id = 1
        carrier allocated badwidth = 1000000.000000 Hz
        Central frequency = 12000500000.000000 Hz

UT 2-1 is associated with gateway 4-1
UT 3-1 is associated with gateway 4-1
Satellite 1-1, Time 0.000 us
        Resetting previous superframe
        Starting new superframe
        Superframe Id = 1
        Superframe start time = 0.000 us
```

Figure 3-8: NetSim Satellite communication log file

This file logs details such as

- UT – Satellite Gateway association
- Calculated Super frame, frame, slot, bandwidth, carrier count etc. for each satellite.
- Frame by frame transmissions with time stamps

3.8.2 Satellite Radio Measurements Log

NetSim Satellite Radio Measurements Log file records Tx Power, Rx power, Pathloss, fading Loss, Noise, SNR, etc. This log can be enabled/disabled by going to Logs option and checking/unchecking the Satellite Radio Measurements Log option under the Network Logs section as shown below:

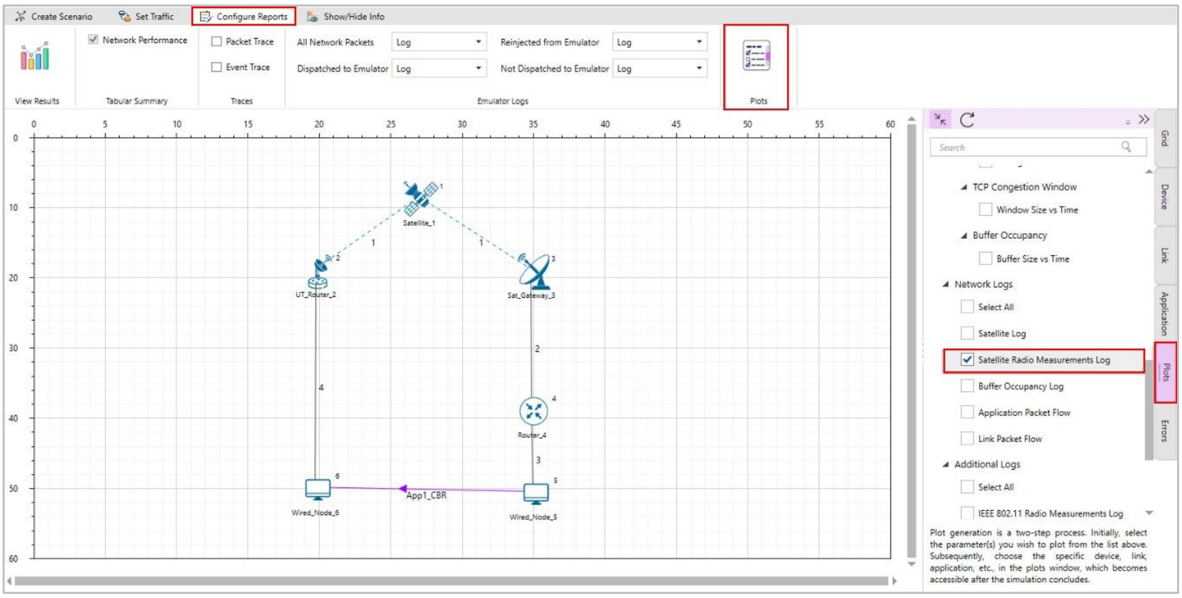


Figure 3-9: Enabling Satellite Radio Measurements Log file.

The Satellite Radio Measurements.csv file will contain the following information:

- Time in Milliseconds
- Transmitter Name
- Receiver Name
- Transmitter Power in dBm
- Pathloss in dB
- Shadowing Loss in dB
- Fading Loss in dB
- Total Loss in dB
- Received Power in dBm
- Noise in dBm
- SNR in dB

Satellite Radio Measurements log files will be available under the Logs in the results window as shown below:

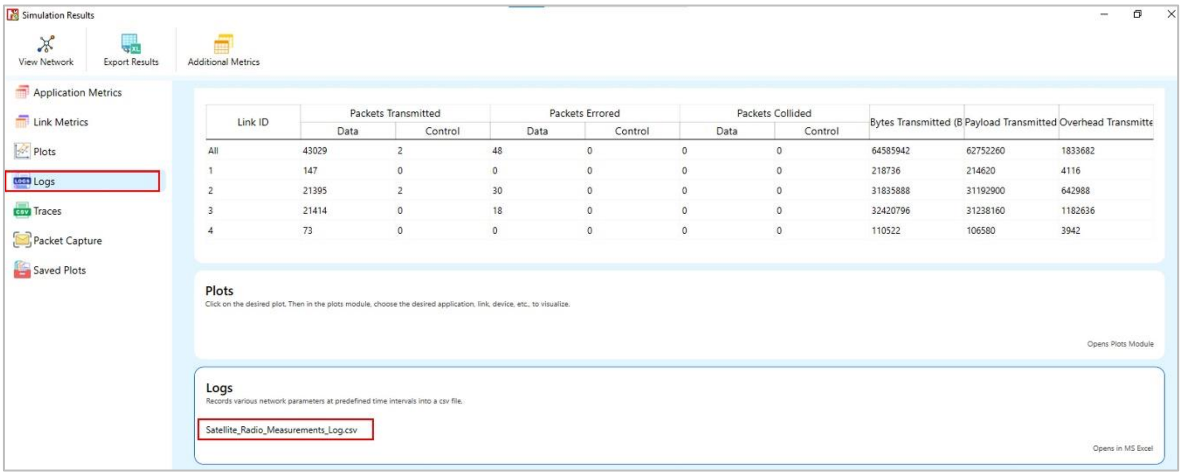


Figure 3-10: Result Window

Users can see Tx Power, Rx power, pathloss, fading-loss, Total loss, noise, and SNR values in the Log files for each forward and return link.

Time(ms)	Transmitter Name	Receiver Name	Tx_Power(dBm)	PathLoss(dB)	FadingLoss(dB)	TotalLoss(dB)	Rx_Power(dBm)	Noise(dBm)	SNR(dB)
237.931149	SAT_GATEWAY_3	SATELLITE_1	39	193.510692	1.732609	195.243301	-38.510692	-110.199169	69.955868
341.779712	SATELLITE_1	UT_ROUTER_2	45	193.242838	4.095229	197.338067	-49.242838	-110.199169	56.861102
371.059149	SAT_GATEWAY_3	SATELLITE_1	39	193.510692	-5.377359	188.133333	-38.510692	-110.199169	77.065836
474.907712	SATELLITE_1	UT_ROUTER_2	45	193.242838	4.988	198.230838	-49.242838	-110.199169	55.968331
504.187149	SAT_GATEWAY_3	SATELLITE_1	39	193.510692	5.482806	198.993498	-38.510692	-110.199169	66.205671
608.035712	SATELLITE_1	UT_ROUTER_2	45	193.242838	18.957523	212.200362	-49.242838	-110.199169	41.998807
637.315149	SAT_GATEWAY_3	SATELLITE_1	39	193.510692	4.722253	198.232945	-38.510692	-110.199169	66.966224
741.163712	SATELLITE_1	UT_ROUTER_2	45	193.242838	-18.527609	174.71523	-49.242838	-110.199169	79.483939
770.443149	SAT_GATEWAY_3	SATELLITE_1	39	193.510692	18.157234	211.667926	-38.510692	-110.199169	53.531243
874.291712	SATELLITE_1	UT_ROUTER_2	45	193.242838	-7.395134	185.847704	-49.242838	-110.199169	68.351464
903.571149	SAT_GATEWAY_3	SATELLITE_1	39	193.510692	-7.345008	186.165685	-38.510692	-110.199169	79.033484
1007.419712	SATELLITE_1	UT_ROUTER_2	45	193.242838	6.544351	199.787189	-49.242838	-110.199169	54.411979
1036.699149	SAT_GATEWAY_3	SATELLITE_1	39	193.510692	6.947203	200.457895	-38.510692	-110.199169	64.741273
1140.547712	SATELLITE_1	UT_ROUTER_2	45	193.242838	6.068953	199.311791	-49.242838	-110.199169	54.887378
1169.827149	SAT_GATEWAY_3	SATELLITE_1	39	193.510692	6.157934	199.668626	-38.510692	-110.199169	65.530543
1273.675712	SATELLITE_1	UT_ROUTER_2	45	193.242838	-8.450437	184.792401	-49.242838	-110.199169	69.406768

Figure 3-11: Satellite Radio Measurements log file

3.9 Omitted Features

- Regenerative transponder where the signal is demodulated, decoded, re-encoded and modulated aboard the satellite.
- Impact of Rain/Weather on signal propagation
- Forward Error Coding in Layer 2
- IPv6 Addressing
- No support for LEO, MEO

4 Featured Examples

4.1 Bandwidth variation through MCS configuration

Open NetSim, Select **Examples ->Satellite Communication -> Bandwidth variation through MCS configuration** then click on the tile in the middle panel to load the example as shown in Figure 4-1.

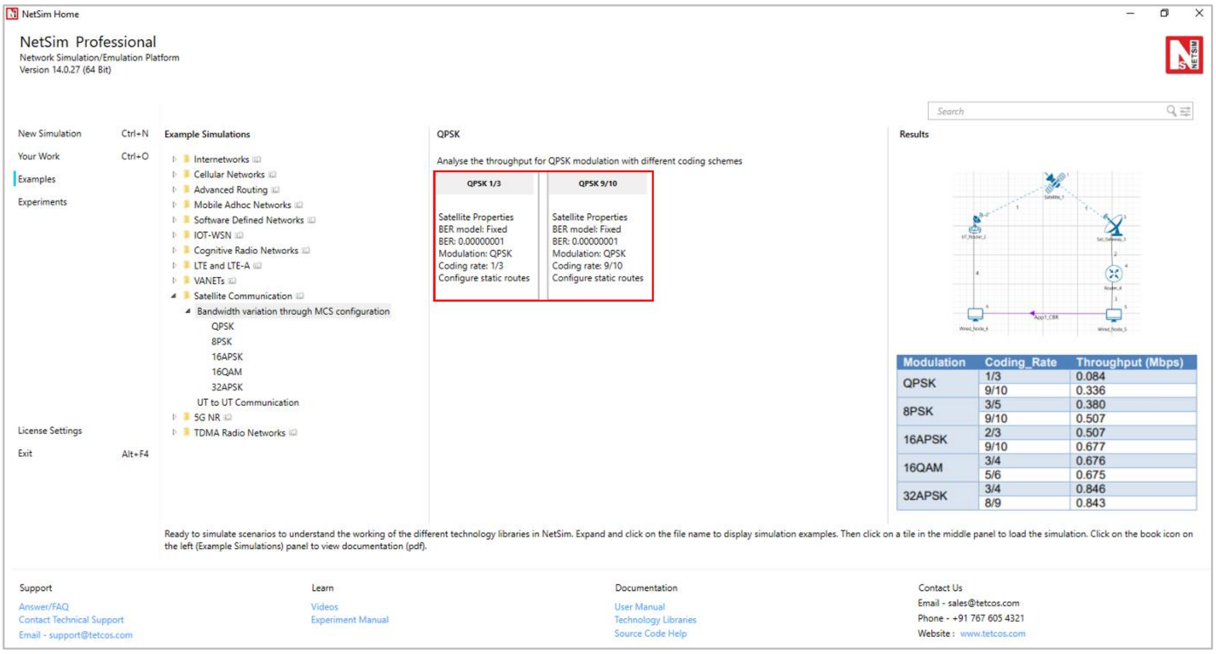


Figure 4-1: List of scenarios for the example of Bandwidth variation through MCS configuration

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

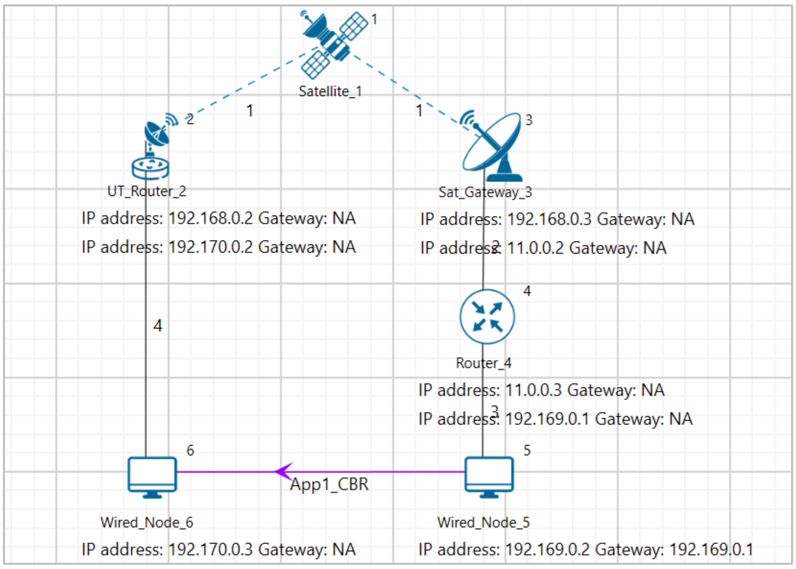


Figure 4-2: Network set up for studying the Bandwidth variation through MCS configuration.

Settings done in example config file:

1. Set the following property as shown in the table below. To configure it, click on the satellite device, expand the property panel on the right side, and change the property as below.

Satellite Properties -> Interface (Satellite) -> Physical Layer-> Forward	
BER Model	Fixed
BER	0.00000001

Table 4-1: Satellite Properties > Interface (Satellite) > Physical Layer > Forward

2. Click on UT Router and set the following property as shown in below given table.

UT Router Properties -> Interface (Satellite) -> Datalink Layer	
Gateway	Sat Gateway 3

Table 4-2: UT Router Properties > Interface (Satellite) > Datalink Layer

Note: For manually configured scenario, user need to mention the gateway name for UT nodes under datalink layer.

3. Go to Router 4 properties -> Network Layer ->Enable - Static IP Route ->Click on Static Route IP via GUI.

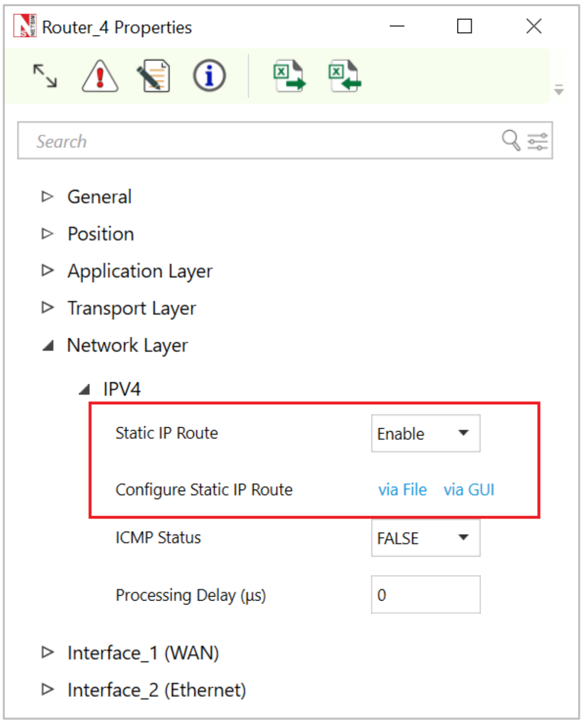


Figure 4-3: Router Network layer properties window

Set the properties in Static Route IP window as per the screenshot below and click on **Add**. Click on **OK.**

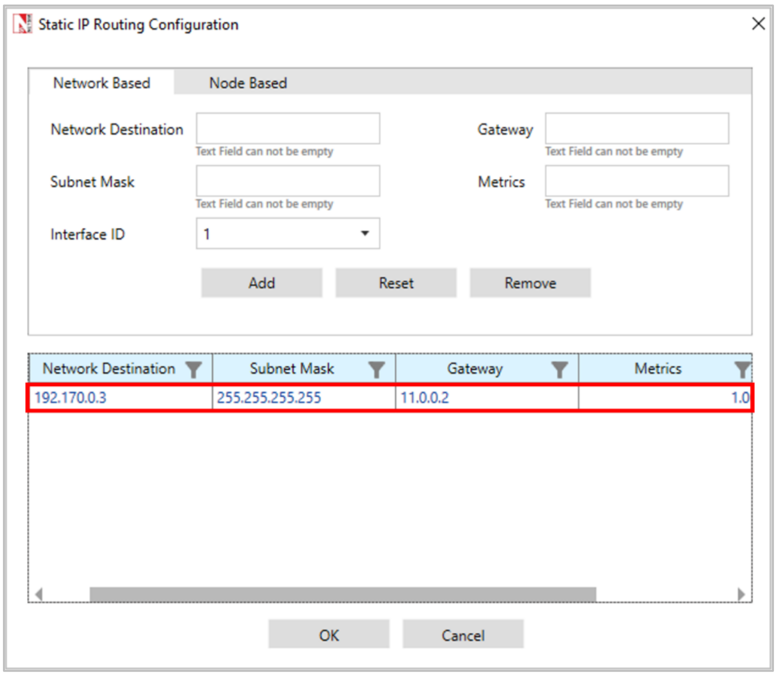


Figure 4-4: Configuring Static route window for router

4. Go to Sat Gateway 3 properties -> Network Layer ->Enable - Static IP Route ->Configure Static Route IP via GUI. Set the properties in Static Route IP window as per the screenshot below and click on **Add**. Click on **OK.**

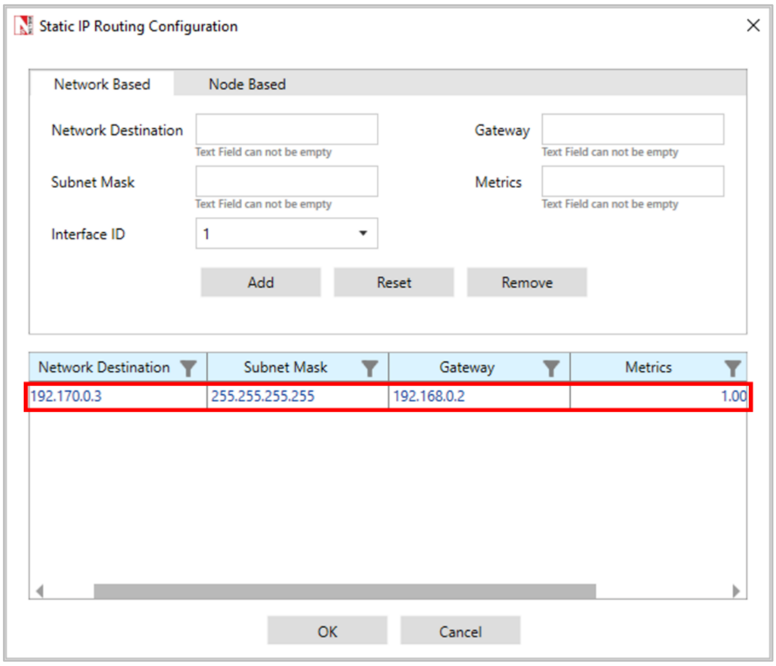


Figure 4-5: Configuring Static route window for Sat_Gateway_3

5. Go to UT Router 2 properties -> Network Layer -> Enable - Static IP Route -> Configure Static Route IP via GUI. Set the properties in Static Route IP window as per the screenshot below and click on **Add**. Click on **OK.**

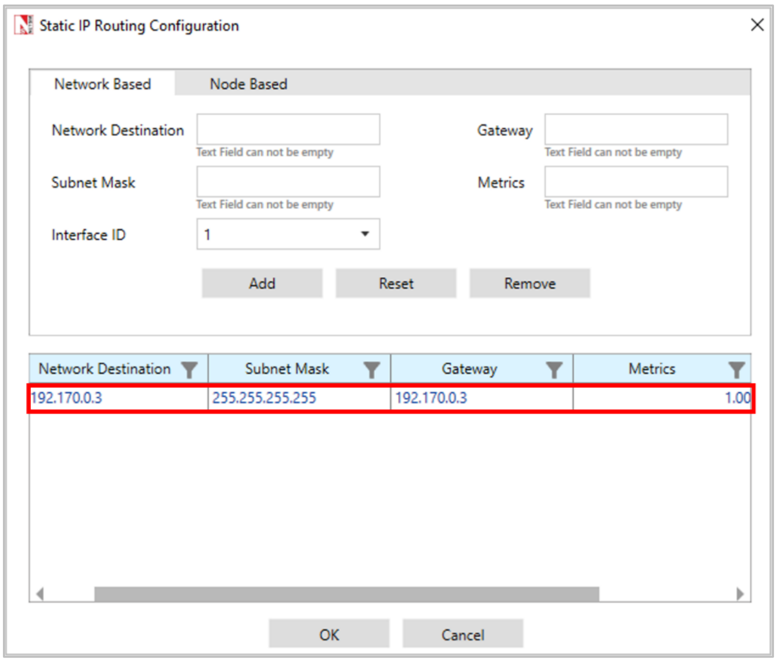


Figure 4-6: Configuring Static route window for UT_Router_2

6. Create a CBR application from set traffic tab in ribbon on the top between source id 5 to destination id 6 with packet size as 1460Bytes and Inter Arrival time as 467µs (Generation Rate=25Mbps). Transport Protocol is set to **UDP**.
7. Change the Satellite Properties → Interface (Satellite) → Physical Layer → Forward → Modulation and respective coding rates as shown in below Table 4-3 but for return link is fixed Modulation-> 32APSK and Coding Rate ->3/4.
8. Run simulation for 10 seconds and observe the result.

Note: Satellite properties in the physical layer changes done only for the forward and Return layer properties.

Result: Observe the application throughput as we change the modulation scheme (Satellite Properties → Interface (Satellite) → Physical Layer → Forward → Modulation) and respective coding rates (Satellite Properties → Interface (Satellite) → Physical Layer → Forward → Coding Rate).

Modulation	Coding Rate	Throughput (Mbps)
QPSK	1/3	0.084
	9/10	0.336
8PSK	3/5	0.379
	9/10	0.504
16APSK	2/3	0.505
	9/10	0.675
16QAM	3/4	0.677
	5/6	0.677
32APSK	3/4	0.844
	8/9	0.846

Table 4-3: Compare the different Modulation Scheme and Coding Rate vs. Throughput

4.2 Configuring applications from UT Node to UT Node

Open NetSim, Select **Examples ->Satellite Communication -> UT to UT Communication** then click on the tile in the middle panel to load the example as shown in below screenshot

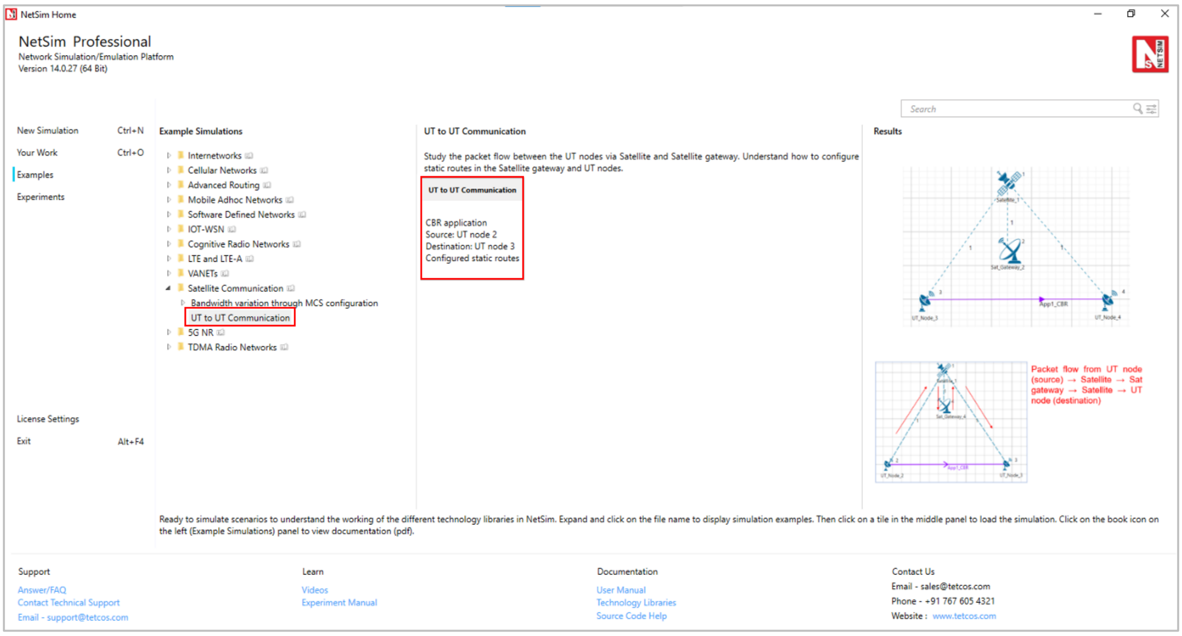


Figure 4-7: List of scenarios for the example of UT to UT Communication

The following network diagram illustrates, what the NetSim UI displays when you open the example configuration file as shown Figure 4-8.

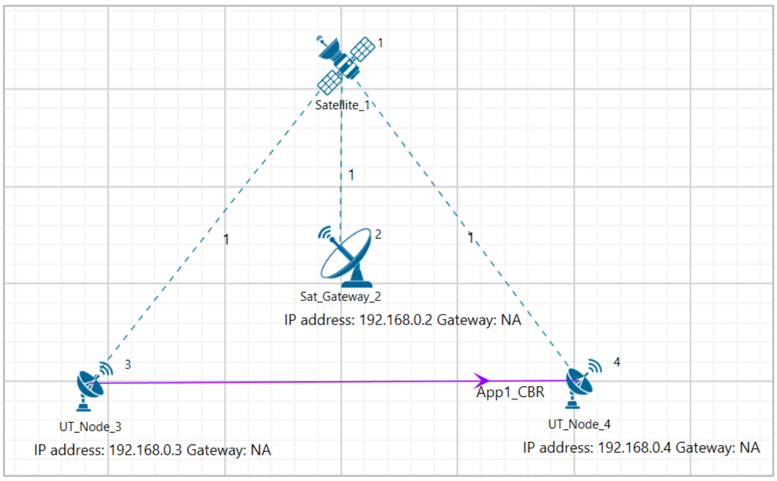


Figure 4-8: Network set up for studying the UT-to-UT Communication

Settings done in example config file

1. Click on UT node and expand the property panel on the right side and set the following property as shown in below given table:

UT Node Properties -> Interface (Satellite) -> DataLink Layer	
Gateway	Sat Gateway 2

Table 4-4: UT Node Properties > Interface (Satellite) > DataLink Layer

2. Similarly, go to UT Node 3 properties -> Network Layer -> Enable - Static IP Route ->Configure Static Route IP.

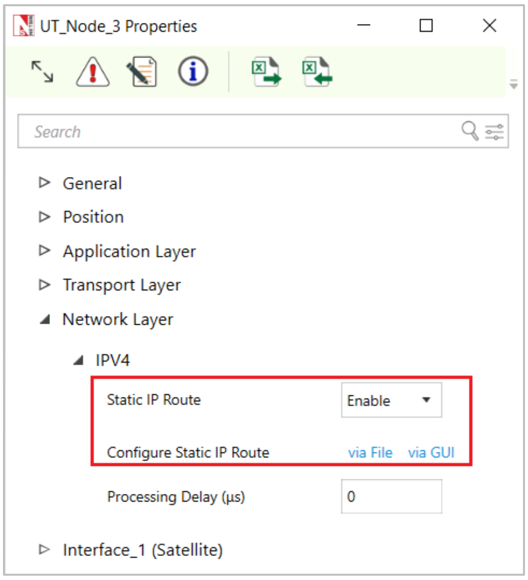


Figure 4-9: Network layer properties window for UT Node 2

3. Set the properties in Static Route IP window as per the screenshot below and click on **Add**. Click on **OK.**

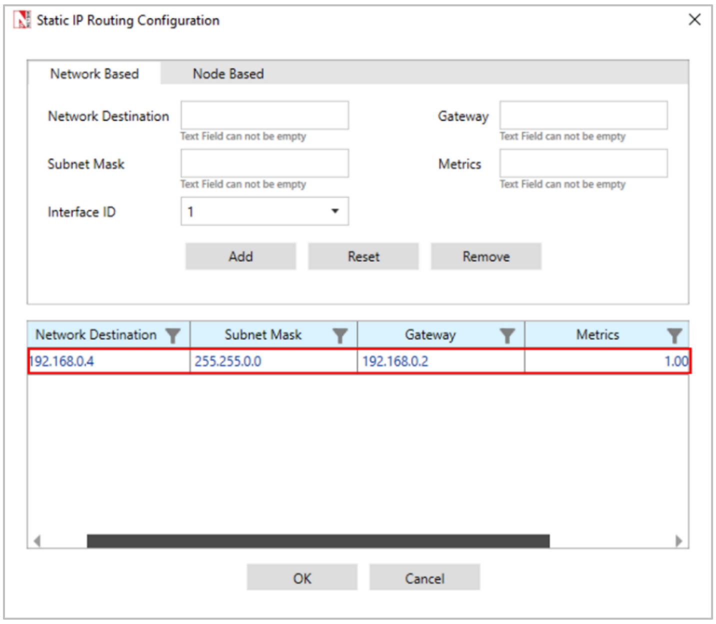


Figure 4-10: Configure static route for UT Node 2

4. Go to Sat Gateway 2 properties -> Network Layer -> Enable - Static IP Route ->Configure Static Route IP via GUI.

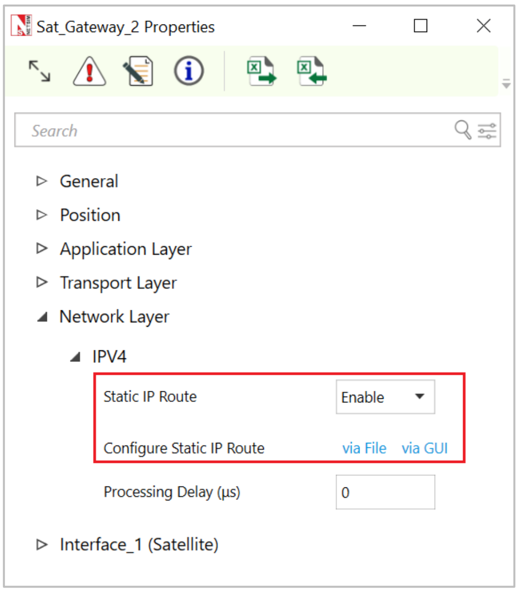


Figure 4-11: Network layer properties window for Sat Gateway 2

5. Set the properties in Static Route IP window as per the screenshot below and click on **Add**. Click on **OK.**

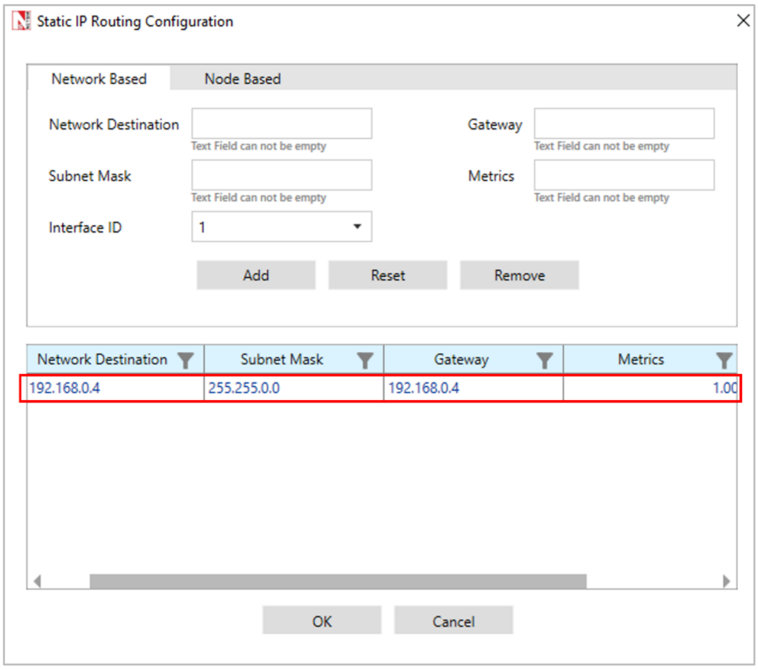
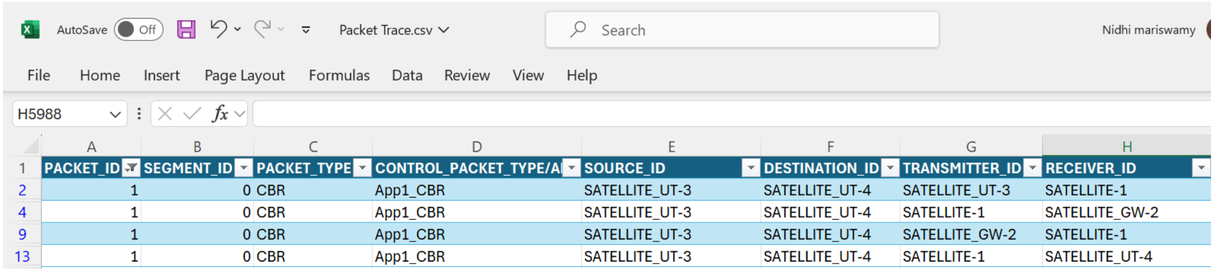


Figure 4-12: Configure static route for Satellite Gateway 4

6. Create application from set traffic tab in the ribbon on the top and set application properties as default (Packet Size: 1460, Inter Arrival Time: 20000 µs)
7. Click on application and set Transport Protocol to **UDP** in property panel.
8. Enable Packet Trace and Plots from the configure report tab.
9. Run simulation for 100 seconds and observe the result.

Result: Go to the result window and open packet trace, filter the PACKET_ID to 1. There, the user can observe the packet flow from UT node (source) → Satellite → Sat gateway → Satellite → UT node (destination)



	PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/A	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
2	1	0	CBR	App1_CBR	SATELLITE_UT-3	SATELLITE_UT-4	SATELLITE_UT-3	SATELLITE-1
4	1	0	CBR	App1_CBR	SATELLITE_UT-3	SATELLITE_UT-4	SATELLITE-1	SATELLITE_GW-2
9	1	0	CBR	App1_CBR	SATELLITE_UT-3	SATELLITE_UT-4	SATELLITE_GW-2	SATELLITE-1
13	1	0	CBR	App1_CBR	SATELLITE_UT-3	SATELLITE_UT-4	SATELLITE-1	SATELLITE_UT-4

Figure 4-13: Packet Trace

5 Reference Documents

1. ETSI, "Digital Video Broadcasting (DVB); Second generation DVB interactive satellite system (DVB-RCS2); Part 2: Lower layers for satellite standard," *ETSI EN 301 545-2 V1.2.1,* Apr. 2014.
2. ETSI, "Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for broadcasting, interactive services, news gathering and other broadband satellite applications (DVB-S2)," *ETSI EN 302 307 V1.2.1*, Aug. 2009.
3. L. Lu, D. Guo, A. Liu, and M. Yang, "Analysis of channel model for GEO satellite mobile communication system," in *Proc. Nat. Conf. Inf. Technol. Comput. Sci. (CITCS)*, 2012.
4. C. Loo, "A statistical model for a land mobile satellite link," *IEEE Trans. Veh. Technol.*, vol. 34, no. 3, pp. 122–127, Aug. 1985.