

NetSim[®]

Accelerate Network R & D

Satellite Communication Networks

A Network Simulation & Emulation Software

By



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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 an 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.

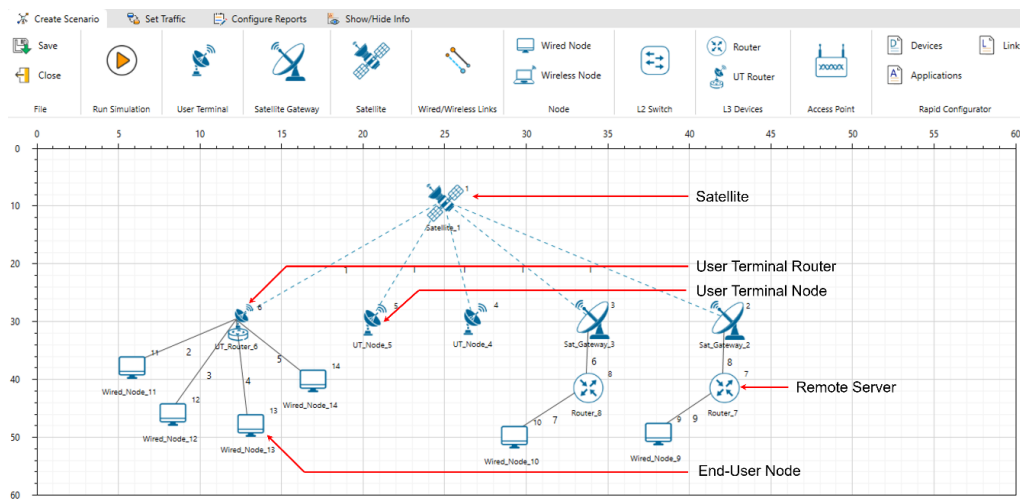


Figure 1-1: NetSim GUI showing Satellite User Terminals connected to a server via satellite links.

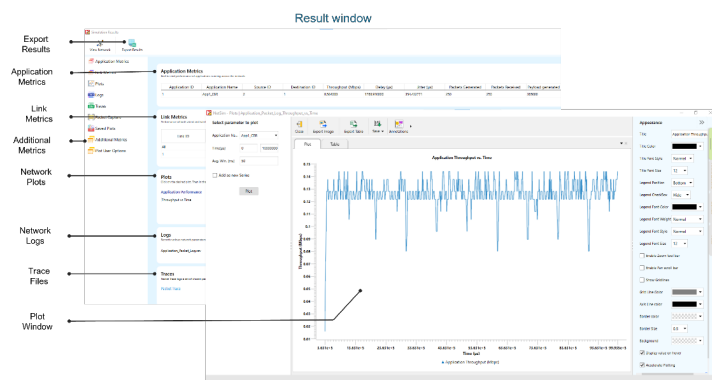


Figure 1-2: The Result dashboard and Plot window shown in NetSim after completion of simulation.

The PHY layer models include:

- Channel model: Friis free space path loss with Markov Loo fading model.
- Modulation: QPSK, 8PSK, 16APSK, 16QAM, 32APSK with appropriate coding rates.

- Rx Antenna gains.
- 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

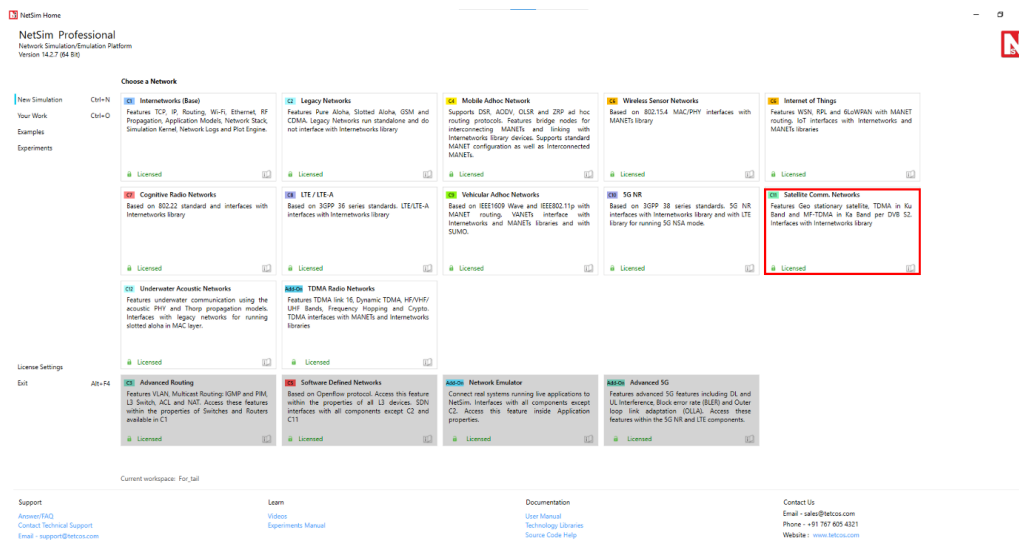


Figure 2-1: NetSim Home Screen.

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

- 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
- 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.
- 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)
- Satellite: Since the satellite model is a bent pipe, the 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.

- **Coordinate System:** NetSim uses a Geodetic co-ordinate system. The altitude is from Mean Sea level. The geocentric co-ordinate system uses distance from the centre of the earth.

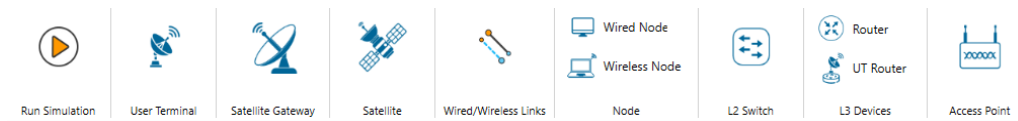


Figure 2-2: The devices present in the ribbon in NetSim's GUI.

2.3 Placement of devices on the grid environment

- 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.
- 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 an L2 Switch or to a Router or to an Access_Point or Satellite.
- 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.
- 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.
- Add a Router – Click the Router icon on the toolbar and place the Router in the grid.
- Add a Wired Node – Click the Wired Node icon on the toolbar and place the device in the grid.
- Add an L2 Switch – Click the L2 Switch icon on the toolbar and place the device in the grid.
- Add an Access Point – Click the Access Point icon on the toolbar and place the Access Point in the grid.
- 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.

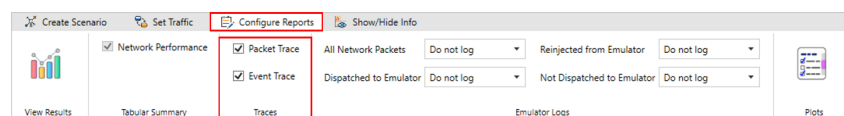


Figure 2-3: Enable Packet Trace, Event Trace & Plots options on top ribbon.

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.

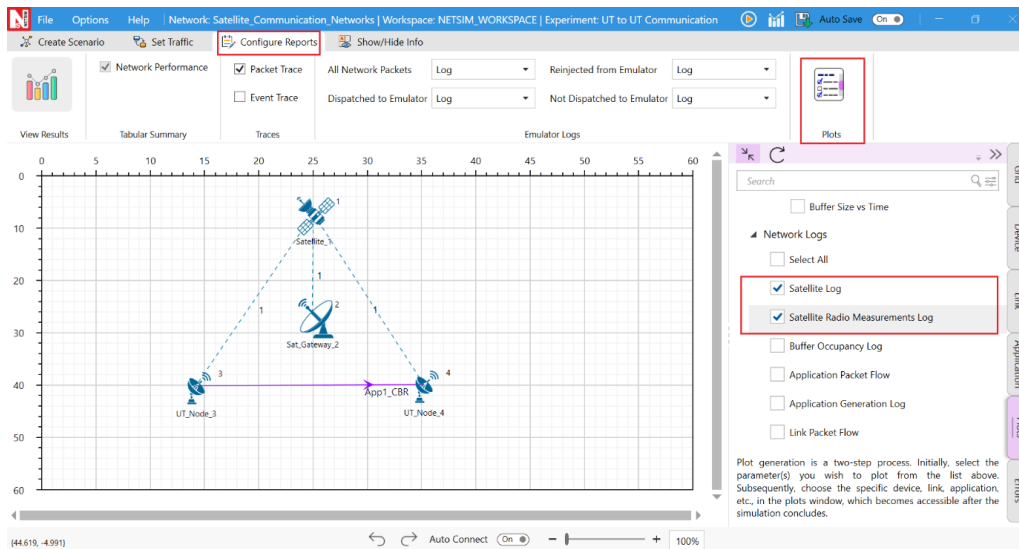


Figure 2-4: Enabling the Network logs in Satellite network.

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

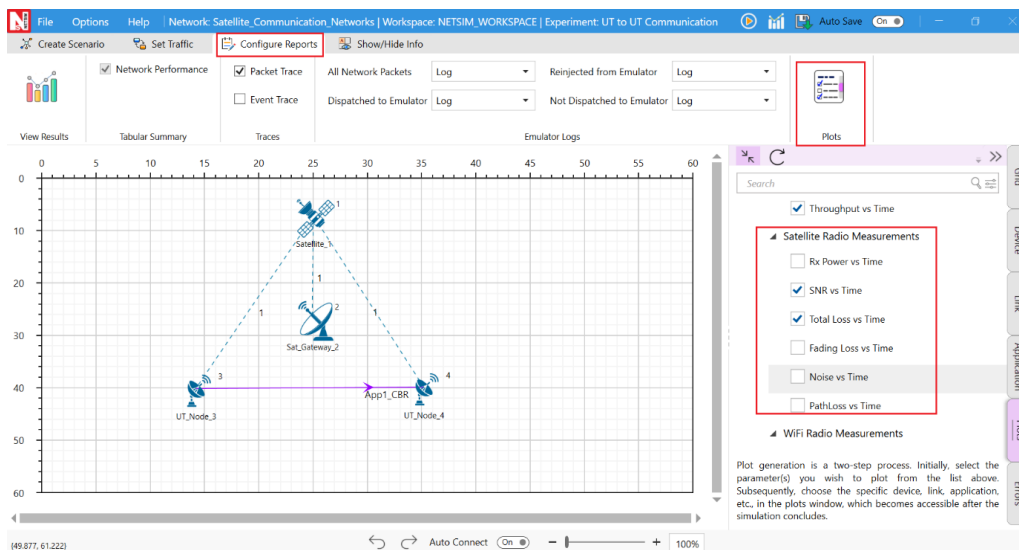


Figure 2-5: Enabling the Plots in Satellite.

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.

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

Parameter	Type	Range	Description
Satellite Properties			
Interface (Satellite) – Physical Layer			

Continued on next page

Table 2-1 continued from previous page

Parameter	Type	Range	Description
Link Model	Local	Satellite Link, Abstract Link	The Satellite Link implements a detailed physical layer model that captures RF propagation characteristics such as free-space pathloss, antenna gain, EIRP, additional losses, noise figure, interference (CIR), exact geometric and SNR/SINR-based adaptive and fixed modulation and coding. The Abstract Link represents an idealized communication channel model implemented under the Physical Layer.
Noise Figure (dB)	Local	1–12	Represents the receiver’s internal noise contribution. A lower noise figure indicates that the receiver is more sensitive and capable of detecting weaker signals.
Carrier to Interference Ratio (dB)	Local	–20 to +20	Measures the strength of the desired signal compared to the interference power in the channel.
Exact Geometric Interference (dB)	Local		Geometric interference arises when multiple beams sharing the same channel ID overlap, leading to co-channel interference at user terminals.
Antenna aperture Radius (m)	Local	0.1 – 5	This parameter defines the antenna’s aperture radius. Used for antenna gain calculations.
Frequency reuse factor	Local	FR1, FR2, FR3, FR4	Represents the number of channels allocated per beam configuration. FR1 indicates full frequency reuse across all beams, while FR3 reduces inter-beam interference by using three distinct frequency groups.
Beam radius (km)	Local	Based on band it varies	The beam radius is calculated based on the frequency band, satellite altitude, and antenna aperture radius for the selected scenario. It is defined at the point where the beam power drops to half of its maximum value (3 dB beamwidth).
Beam count	Local	1, 7, 19	This parameter defines the number of beams formed in the coverage area. A value of 1 corresponds to a single central beam. The 7-beam configuration consists of one central beam surrounded by a single hexagonal ring, while the 19-beam configuration consists of the central beam with two hexagonal layers of surrounding beams.

Continued on next page

Table 2-1 continued from previous page

Parameter	Type	Range	Description
G/T (dBK)	Local	Manual	Antenna gain-to-noise-temperature (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.
G/T (dBK)		Auto	Computed using the noise figure and the RX gain
Antenna model	Local	TR 38.811 S.6.4.1, ITU-R S.672-4	TR 38.811 S.6.4.1: The normalized antenna gain pattern, corresponding to a typical reflector antenna with a circular aperture, is considered. ITU-R S.672-4: To model the off-axis behavior of satellite antennas, the ITU-R S.672 recommendation specifies that, for single-feed circular or elliptical beam spacecraft antennas operating in the fixed-satellite service (FSS).
LN Value (dB)	Local	-25, -20	LN is near-in-side-lobe level in dB relative to the peak gain required by the system design.
LF Value (dB)	Local	-100 to 10	LF represents the minimum gain level (in dB) beyond which the antenna pattern does not decrease further.
a, b, α	Local		Values are updated based on the LN selection as per ITU-R specification.
z	Local	1	(major axis/minor axis) for the radiated beam.
LB (dB)	Local	$LB = 15 + LN + 0.25 G_m + 5 \log z$ dBi or 0 dBi whichever is higher.	LB is the back lobe gain level used in the antenna pattern
Theta HPBW (°)	Local	1-10	One-half the 3 dB beamwidth in the plane of interest (3 dB below G_m) (degrees)
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.
Access Protocol	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: 12-18 GHz, Ka-band: 26-40 GHz	The “band” in use refers to the radio frequencies used to and from the satellite. Ku-band services use the 12-18 GHz, and Ka-band services use the 26-40 GHz segment of the electromagnetic spectrum.

Continued on next page

Table 2-1 continued from previous page

Parameter	Type	Range	Description
Band	Fixed	KU	Microwave frequency band used for satellite communication and broadcasting, using frequencies in the range of 12–18 GHz
Band	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 off 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
Frame count in Superframe	Local	0–1000000	Number of frames present in a superframe.
MCS Selection	Local	Fixed MCS, Adaptive MCS	Fixed MCS: The modulation and coding rate remain constant throughout the simulation. Adaptive MCS mode: The physical layer dynamically adjusts the modulation and coding rate based on the Signal-to-Noise Ratio (SNR) calculated from the link-budget model.
MCS Index table	Local	Index, Modulation, Coding rate, Spectral efficiency	The MCS Index Table defines the mapping between modulation and coding schemes used for data transmission.
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 is typically a fractional number.
BER Model	Local	Fixed	BER value is based on the user input and is independent of the received SINR.
BER Model	Local	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.
BER Model	Local	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.

Continued on next page

Table 2-1 continued from previous page

Parameter	Type	Range	Description
BER	Local	0.00000001–1	This parameter is shown if the Fixed option is chosen for the BER model parameter. Users can set the Bit Error Rate (BER) in the range shown.
Additional loss (dB)	Local	–20 to +20	Represents attenuation in the signal path due to imperfections
EIRP Density (dBW/MHz)	Local	35–70	This parameter defines the effective isotropic radiated power per unit bandwidth.
Link speed (Mbps)	Local	1–100	Defines the constant data rate available on the link and is used to compute the packet transmission time.
Propagation delay (ms)	Local	Auto computed, Fixed (1–100)	Auto computed: Calculated automatically based on device distance and the speed of light. Fixed: A constant delay value entered by the user.

UT Properties**Interface (Satellite) – Physical Layer**

Rx Antenna Gain (dB)	Local	0–1000000 dB	A relative measure of an antenna's ability to receive radio frequency energy in a particular direction or pattern at the receiver side.
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Table 2-2: *Propagation Model/Wireless Link Properties Description.*

Parameter	Type	Range	Description
Propagation Model			
Link Properties			
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 the same. We get varied path loss for the same distance between source and destination in shadowing, and fading is the 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	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.

Continued on next page

Table 2-2 continued from previous page

Parameter	Type	Range	Description
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	$-\infty$ 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	$-\infty$ to ∞	RMS squared multipath power in dB
Number of Direct Signal Oscillators	Link	0 to ∞	Number of direct signal oscillators 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.

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 in Figure 2-6.

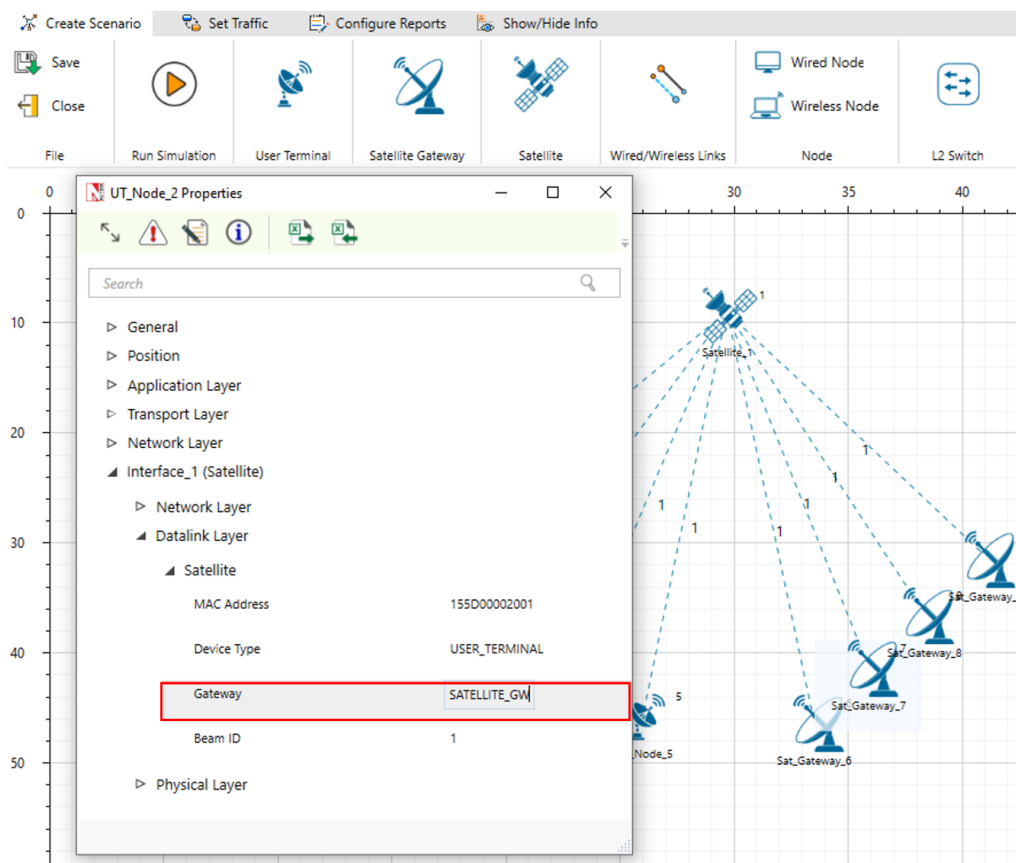


Figure 2-6: Mapping of User Terminal (UT Node / UT Router) to Satellite Gateway.

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 to 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 in Figure 2-7.

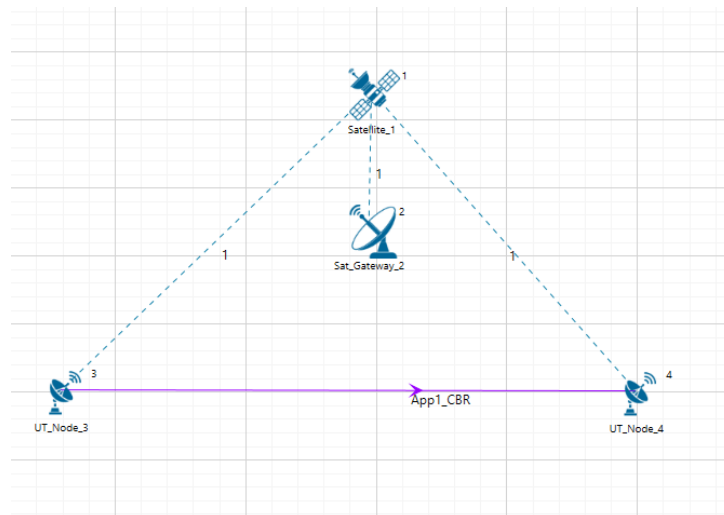


Figure 2-7: Network Topology in this experiment.

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

2.6.3 Mobility model in Satellite

Satellite and UT devices support file-based mobility in Satellite.

In the File Based Mobility model, users can write their own custom mobility models and define the movement of the mobile users. The content should be per the NetSim Mobility File Format explained below. Users can also generate the mobility files using external tools like SUMO (Simulation of Urban Mobility), etc.

The NetSim Mobility File setting and format is explained below:

Step 1: Right click to open Properties as a new window of Satellite or UT. Then properties > Position Properties > Mobility model as File Based Mobility and click on Open Mobility file.

Step 2: Open the csv file and write the node mobility in the format shown below.

```
<TIME IN SECONDS>,<DEVICE ID>Lat(°),Lon(°),Alt(m)
```

#Time(s)	Device ID	Lat(deg)	Lon(deg)	Alt(m)
0	10	0.145573	-74.7018	769779
1	10	0.145575	-74.6461	769779
2	10	0.145576	-74.5904	769779
3	10	0.145578	-74.5346	769779
4	10	0.145579	-74.4789	769779
5	10	0.14558	-74.4232	769779
6	10	0.145582	-74.3675	769779
7	10	0.145582	-74.3118	769779
8	10	0.145583	-74.256	769779
9	10	0.145584	-74.2003	769779
10	10	0.145584	-74.1446	769779
11	10	0.145584	-74.0889	769779
12	10	0.145584	-74.0332	769779
13	10	0.145584	-73.9774	769779
14	10	0.145584	-73.9217	769779
15	10	0.145584	-73.866	769779
16	10	0.145583	-73.8103	769779
17	10	0.145583	-73.7546	769779
18	10	0.145582	-73.6989	769779

Figure 2-8: *Mobility.csv file with inputs added via MS Excel.*

3 Model Features

Under the Physical Layer, two types of links are modeled in the Satellite communication system.

- Abstract Link
- Satellite Link

3.1 Abstract Link Model

The Abstract Link represents an idealized communication channel model implemented under the Physical Layer. It applies to both the Forward and Return directions. Unlike the Satellite Link, with Abstract Link NetSim does not perform link-budget or radio-frequency calculations.

Configurable Parameters

The Abstract Link behaviour is characterized by a small set of user-specified parameters that determine the resulting throughput, delay, etc.

Link Speed (Mbps)

Defines the constant data rate available on the link and is used to compute the packet transmission time.

Bit Error Rate (BER)

Represents the probability of bit errors occurring during transmission over the communication link.

Propagation Delay (ms)

Represents the signal propagation delay, which can be either:

- Auto Computed: Calculated automatically based on device distance and the speed of light.
- Fixed: A constant delay value entered by the user.

3.2 Satellite Link Model

The Satellite Link implements a detailed physical layer model that captures RF propagation characteristics such as free-space pathloss, antenna gain, EIRP, additional losses, noise figure, interference (CIR), and SNR/SINR-based adaptive and fixed modulation and coding.

With this model NetSim performs link-budget-based calculations to determine received signal strength and signal quality parameters such as SNR, and SINR. In the current implementation, SNR-based link-budget computation is applied only for the service links (User-terminal (UT) \leftrightarrow Satellite).

- UT \rightarrow Satellite (Uplink)
- Satellite \rightarrow UT (Downlink)

For the feeder links (i.e., Gateway \leftrightarrow Satellite), SNR calculation is not applied. These links operate using the same link-speed and propagation delay values, computed for the service link.

3.3 TDMA Forward Link and MF TDMA Return Link

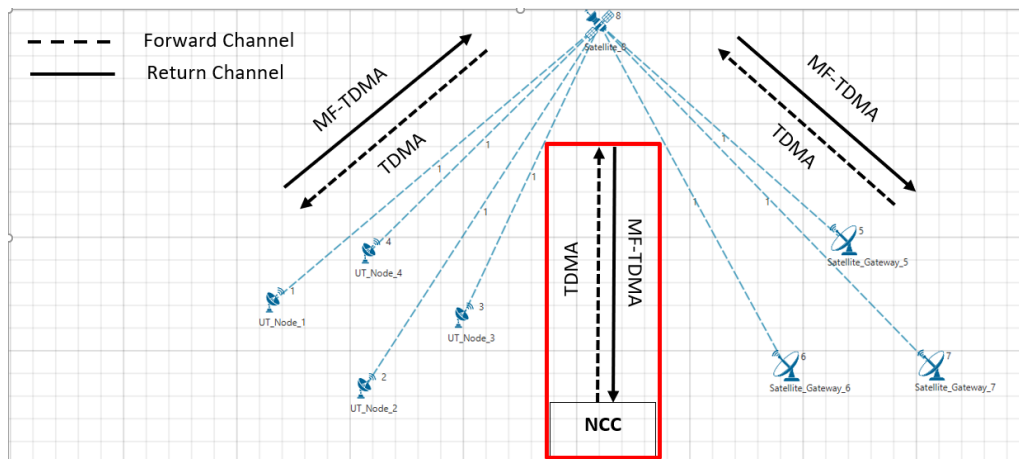


Figure 3-1: Forward and Return links. The Network Control Centre (NCC) is not displayed in NetSim and is assumed to be part of every satellite.

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 Division 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 Frame count in Superframe available in Satellite \rightarrow Interface Satellite \rightarrow Physical Layer properties.

3.4 Downlink MAC Scheduling

- The satellite MAC implements a beam-based, event-driven TDMA scheduling mechanism with adaptive modulation and coding (AMC).
- Scheduling decisions are made dynamically at run time, and transmission timing is driven by frame completion events, not by fixed time boundaries.
- Each beam operates as an independent scheduler, allowing parallel transmissions without global synchronization.

Beam Formation

Each UT is associated with a beam; this selection is based on maximum SINR.

Each beam maintains its list of UTs.

Beam-wise Scheduling

Each beam operates as an independent TDMA scheduler.

Frame transmissions occur independently at each beam.

Scheduling decisions within one beam do not affect other beams.

Frame Allocation and Round Robin Scheduling

- Each transmitted frame is assigned to exactly one UT.
- Frame assignment follows a round-robin (RR) policy within the beam.
- The round-robin state is maintained per beam, not globally.

Scheduling Flow (Per Beam)

- A frame is scheduled for a UT.
- The frame is transmitted.
- At frame completion, the next frame for the same beam is immediately scheduled.
- The next UT is selected using round-robin rotation.
- This creates a continuous transmission chain per beam.

Packet Packing within Frames:

Once a frame is assigned to a UT buffer, packets are packed into the frame.

Packing Rules

Packets are packed sequentially from the buffer head (FIFO).

Packet size is evaluated in bits.

A packet is included only if it fully fits within the remaining frame capacity.

Partial packet transmission is not supported.

Packing stops when:

The next packet exceeds the remaining frame capacity.

The buffer becomes empty.

At the end of packing, the frame contains only the packets that fully fit within its capacity.

Frame Length and Payload Capacity Computation

- The total frame size is fixed as per DVB-S2 specifications

$$Frame_Bits = 64800$$

- Symbol rate is the effective bandwidth that we set in the GUI
- Based on the selected modulation and coding
- Number of Symbols per Frame

$$SymbolsPerFrame = Frame_Bits / Mod_Bits$$

- Frame Duration

$$FrameDuration = (SymbolsPerFrame / SymbolRate)$$

- Usable Payload Capacity

$$PayloadBits = Frame_Bits \times CodingRate$$

Impact of SINR (Adaptive MCS)

Higher SINR results in the selection of higher-order modulation and coding schemes. This leads to:

Shorter frame duration

Higher payload capacity

Lower SINR results in longer frame durations and reduced payload capacity.

Frame duration directly influences superframe timing.

NOTE: Uplink scheduling is not implemented currently.

3.5 Modulation and coding (MODCOD) schemes selection

The Modulation and Coding Scheme (MCS) determines the combination of modulation order and coding rate used in the physical layer for both the Forward and Return links.

NetSim supports two MCS configuration modes: Fixed MCS and Adaptive MCS.

Fixed MCS Mode

- In Fixed MCS mode, the modulation and coding rate remain constant throughout the simulation.
- The user selects the desired modulation type (e.g., QPSK, 8PSK, 16APSK, etc.) and coding rate from the GUI.
- The selected MCS values are applied to all devices, irrespective of variations in the channel or SNR conditions.

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
6. These modulation and coding rates are specified in Table 12 on page 32 of the ETSI EN 302 307 – European Standard.

Adaptive MCS Mode In Adaptive MCS mode, the physical layer dynamically adjusts the modulation and coding rate based on the Signal-to-Noise Ratio (SNR) calculated from the link-budget model.

MCS Configuration files

- NetSim uses external configuration files to define the mapping between SNR and the corresponding Modulation and Coding Scheme (MCS).
- Separate CSV files are used for the Forward and Return links:
- ForwardLink_Modulation.csv
- ReturnLink_Modulation.csv
- The format of the CSV files is as shown below:
- Index, Modulation, Coding Rate and Spectral Efficiency

Modulation CodingRate SpectralEfficiency

Forward link Spectral efficiency values

QPSK	0.333333	0.56
QPSK	0.5	0.87
QPSK	0.666667	1.26
QPSK	0.75	1.42
QPSK	0.833333	1.6
8PSK	0.666667	1.7
8PSK	0.75	1.93
8PSK	0.833333	2.13

Continued on next page

Continued from previous page

Modulation CodingRate SpectralEfficiency

16QAM	0.75	2.59
16QAM	0.833333	2.87

Return link Spectral efficiency values

QPSK	0.25	0.490243
QPSK	0.333333	0.656448
QPSK	0.4	0.789412
QPSK	0.5	0.988858
QPSK	0.6	1.188304
QPSK	0.666667	1.322253
QPSK	0.75	1.487473
QPSK	0.8	1.587196
QPSK	0.833333	1.654663
QPSK	0.888889	1.766451
8PSK	0.6	1.779991
QPSK	0.9	1.788612
8PSK	0.666667	1.980636
8PSK	0.75	2.228124
8PSK	0.833333	2.478562
16APSK	0.666667	2.637201
8PSK	0.888889	2.646012
8PSK	0.9	2.679207
16APSK	0.75	2.966728
16APSK	0.8	3.165623
16APSK	0.833333	3.300184
16APSK	0.888889	3.523143
16APSK	0.9	3.567342
32APSK	0.75	3.703295
32APSK	0.8	3.951571
32APSK	0.833333	4.11954
32APSK	0.888889	4.397854
32APSK	0.9	4.453027

Figure 3-2: The default spectral efficiency to MCS mapping when the adaptive MCS option is chosen

Adaptive MCS Selection Logic

- Obtain the Signal-to-Interference-Noise Ratio (SINR).
- Convert SNR from dB to Linear Scale.

$$SINR_{Linear} = 10^{\left(\frac{SINR_{dB}}{10}\right)} \quad (1)$$

- Compute Spectral Efficiency (SE)

$$\text{Spectral Efficiency} = \log_2(1 + SINR_{Linear}) \quad (2)$$

- Select the Appropriate MCS files based on the link direction.
- The selected CSV file defines how spectral efficiency maps to the corresponding modulation and coding rate.
- The entry with the largest spectral-efficiency threshold that is less than or equal to the computed

SE is chosen.

- This Adaptive MCS mechanism enables dynamic adjustment of modulation and coding according to real-time channel conditions.
- As the SNR increases, higher-order modulation and coding rates are selected to enhance spectral efficiency and throughput.

The modulation, coding rate and spectral efficiency values used in NetSim’s Adaptive MCS configuration are derived from the OpenSAND MODCOD database (<https://github.com/CNES/opensand/wiki/acm>).

3.6 Physical layer framing for forward and return links

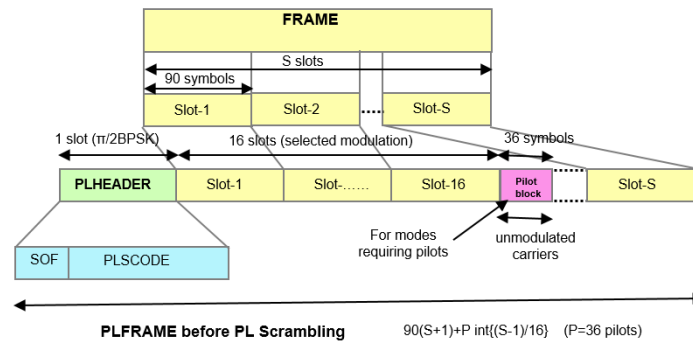


Figure 3-2: Format of a “Physical Layer Frame” PLFRAME.

Default settings in NetSim

- Frame Type: Normal (Options are normal or short)

3.7 Satellite PHY

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.

$$\text{Symbol Rate} = \frac{BW}{(1 + (\text{Roll off factor}))} \tag{3}$$

$$\text{Bit Rate} = \text{Symbol rate} \times \text{Modulation order} \times \text{CodeRate} \tag{4}$$

$$\text{Bandwidth (Hz)} = \text{Frame_Bandwidth (Hz)} = 10^6 \text{ Hz}$$

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

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

$$\text{Effective Bandwidth (Hz)} = \frac{\text{Carrier Bandwidth (Hz)}}{(\text{RollOffFactor} + 1.0) \times (\text{SpacingFactor} + 1.0)} \tag{5}$$

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

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

$$\text{Modulation Bits} = 2$$

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

Table 3-2: *Modulation bits for different modulations.*

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

3.8 Satellite PHY: Land Satellite Channel Model

3.8.1 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.

3.8.2 Earth fixed spot beams and cells

NetSim provides three methods for configuring satellite beams:

Standard setup:

The Standard Setup option allows users to quickly configure satellite beams using predefined parameters without manually entering beam coordinates or importing external files. NetSim automatically calculates the beam geometry, radius, and coverage area based on the selected inputs.

- Number of spot beams.
- NetSim can presently support configurations of 1, 7, or 19 spot beams.
- The 7-cell setup consists of a central hexagonal cell surrounded by 6 adjacent cells.
- The 19-cell configuration has two layers of surrounding cells around a central hexagonal cell.
- NetSim will automatically compute the tessellated beams (cells) based on number of spot beams.

User-defined beam configuration:

This option allows users to upload an Excel/CSV file containing beam parameters such as beam count, Frequency reuse, Satellite altitude (km), HPBW (theta), Aperture radius (m), Band, Beam centers, Antenna model and Beam radius (km) details instead of relying on automatic or standard setup.

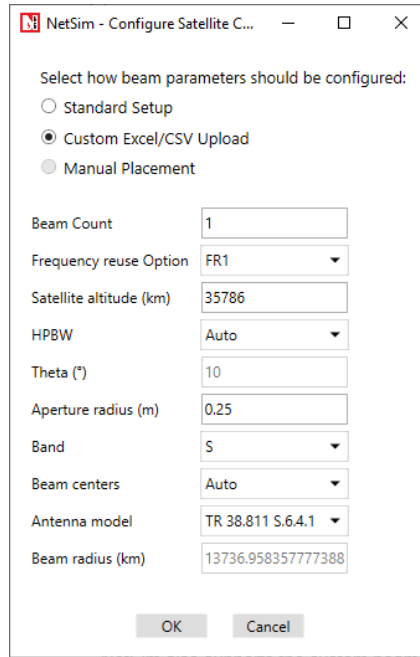


Figure 3-3: User-defined beam configuration.

Manual Placement:

The Manual Placement option allows complete user control over beam locations, coverage regions, and satellite altitude. Unlike the Standard Setup or CSV Upload options, no beam parameters are auto-generated. This mode is intended for advanced users who want full flexibility in defining exact beam geometry.

3.8.3 Link budget calculations

UT is sending to Satellite:

The carrier-to-noise ratio, CNR in dB, is calculated per the equation described in TR 38.821 Section 6.1.3.1, given by

$$CNR = EIRP - \text{MaxAntennaGain} + \text{AngularGain} + Rx \frac{G}{T} - k - PL_{FS} - PL_{AD} - B \quad (6)$$

where:

CNR is the carrier to noise ratio (also sometimes termed as SNR or signal to noise ratio) in dB

EIRP is the effective isotropic radiated power in dBW

$Rx \frac{G}{T}$ is the antenna-gain-to-noise temperature in dB/K of the receiver

k is the Boltzmann constant with the value of -228.6 dBW/K/Hz

PL_{FS} is the free space path loss (FSPL) in dB

PL_{AD} is the additional loss in dB

B is the channel bandwidth in dBHz (i.e., $10 \log_{10}(BW)$, where *BW* is bandwidth in Hz)

$Rx \frac{G}{T}$ is obtained using the expression

$$Rx \frac{G}{T} = G_{rx} - N_f - 10 \log_{10} (T_0 + (T_a - T_0) \times 10^{-0.1 \times N_f}) \quad (7)$$

where:

G_{rx} is the receive antenna gain in dBi.

N_f is the noise figure in dB

T_0 is the ambient temperature in degrees Kelvin, set to 290 by default

T_a is the antenna temperature in degrees Kelvin. $T_a = 150$

The CNR expression is used in both directions i.e., terrestrial to satellite and satellite to terrestrial.

Satellite is sending to the UT:

$$CNR = EIRP - \text{MaxAntennaGain} + \text{AngularGain} + \text{UTRx_Gain} - k - PL_{FS} - PL_{AD} - B \quad (8)$$

Elevation angle:

$$\alpha = \sin^{-1} \left(\frac{D}{R_u \cdot L} \right) \quad (9)$$

Where,

$$R_u = \sqrt{x_{ue}^2 + y_{ue}^2 + z_{ue}^2} \quad (10)$$

$$L = \sqrt{(x_{sat} - x_{ue})^2 + (y_{sat} - y_{ue})^2 + (z_{sat} - z_{ue})^2} \quad (11)$$

$$D = \sqrt{(x_{sat} - x_{ue}) \cdot x_{ue} + (y_{sat} - y_{ue}) \cdot y_{ue} + (z_{sat} - z_{ue}) \cdot z_{ue}} \quad (12)$$

EIRP calculations:

In NetSim's satellite model, the method of computing EIRP depends on the link direction:

Forward Link

- In the Forward Link, the satellite transmits toward the user terminal (UT).
- The EIRP is defined based on the EIRP Density and the allocated bandwidth of the carrier

$$EIRP \text{ [dBW]} = \text{EIRPDensity [dBW/MHz]} + 10 \log_{10}(BW \text{ [MHz]}) \quad (13)$$

Return link

- In the Return Link, the user terminal (UT) transmits toward the satellite.
- The EIRP is computed from the transmit power and the Receive antenna gain of the UT.

$$EIRP \text{ [dBW]} = P_{tx} \text{ [dBm]} - 30 + G_{Rx} \text{ [dBi]} \quad (14)$$

SNR - BER Calculation The Signal-to-Noise Ratio (SNR) is calculated separately for each hop of every link.

SNR-based Bit Error Rate (BER) computation is applied only for the UT-Satellite and Satellite-UT links.

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.

3.8.4 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 mathematical expression for free-space path loss is given by the Friis Free-Space Equation:

$$PL_{FS} = 20 \log_{10} \left(\frac{4\pi d}{\lambda} \right) \tag{15}$$

Where $\lambda = \frac{c}{f}$,

d is the slant height in meters,

λ is the wavelength in meters.

3.8.5 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 denote respective channel states, P_{ij} is the probability the Markov process goes from state i to state j .

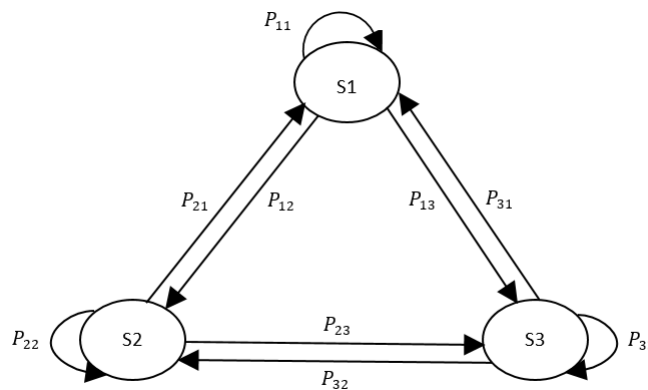


Figure 3-4: Switching of three-state Markov process.

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

$$P = \begin{pmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{pmatrix} \quad (16)$$

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.

$$N(\mu, \sigma^2) + R \quad (17)$$

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 the 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.

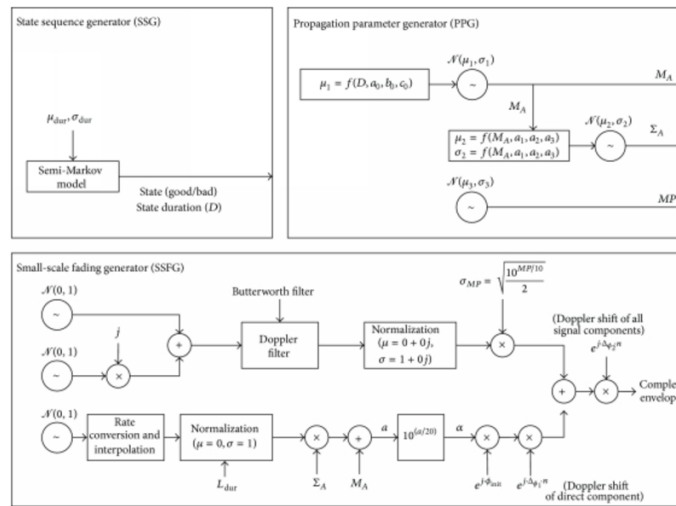


Figure 3-5: The Satellite LMS channel Model.

3.8.6 Antenna Models

TR 38.811 Antenna model The normalized antenna gain pattern, corresponding to a typical reflector antenna with a circular aperture, is considered

$$G(\theta) = \begin{cases} 1 & \text{for } \theta = 0 \\ 4 \left| \frac{J_1(ka \sin \theta)}{ka \sin \theta} \right|^2 & \text{for } 0 < |\theta| \leq 90^\circ \end{cases} \quad (18)$$

where $J_1(x)$ is the Bessel function of the first kind and first order with argument x , a is the radius of the antenna's circular aperture, $k = \frac{2\pi f}{c}$ is the wave number, f is the frequency of operation, c is the speed

of light in a vacuum and θ is the angle measured from the boresight of the antenna’s main beam. Note that ka equals the number of wavelengths on the circumference of the aperture and is independent of the operating frequency. The above expression provides the gain in linear scale and it needs to be converted to dB scale. The normalized gain pattern for $a = 10\frac{c}{f}$ (aperture radius of 10 wavelengths) is shown below

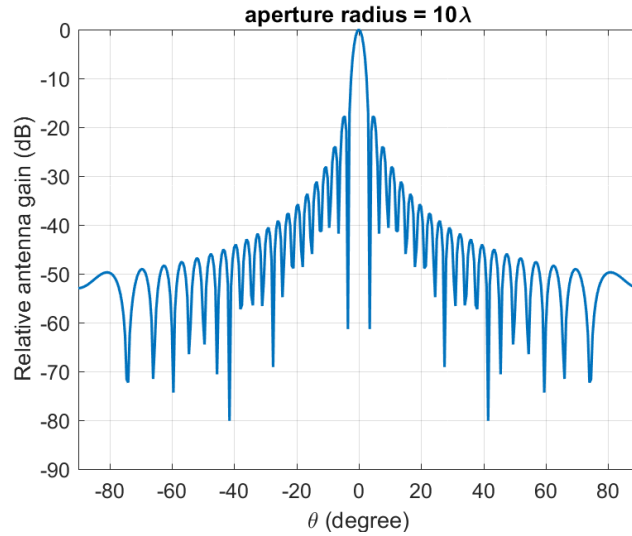


Figure 3-6: Antenna gain pattern for aperture radius 10 wavelengths, $a = 10\frac{c}{f}$.

ITU-R S.672 Antenna model To model the off-axis behavior of satellite antennas, the ITU-R S.672 recommendation specifies that, for single-feed circular or elliptical beam spacecraft antennas operating in the fixed-satellite service (FSS), the following radiation pattern should be used as the design objective outside the coverage area.

$$G(\psi) = G_m - 3 \left(\frac{\psi}{\psi_b} \right)^\alpha \text{ [dBi]} \quad \text{for } \psi_b \leq \psi \leq a\psi_b \quad (19)$$

$$G(\psi) = G_m + LN + 20 \log(z) \text{ [dBi]} \quad \text{for } a\psi_b < \psi \leq 0.5b\psi_b \quad (20)$$

$$G(\psi) = G_m + LN \text{ [dBi]} \quad \text{for } 0.5b\psi_b < \psi \leq b\psi_b \quad (21)$$

$$G(\psi) = X - 25 \log \psi \text{ [dBi]} \quad \text{for } b\psi_b < \psi \leq Y \quad (22)$$

$$G(\psi) = LF \text{ [dBi]} \quad \text{for } Y < \psi \leq 90^\circ \quad (23)$$

$$G(\psi) = LB \text{ [dBi]} \quad \text{for } 90^\circ < \psi \leq 180^\circ \quad (24)$$

Where:

$$X = G_m + LN + 25 \log(b\psi_b) \quad \text{and} \quad Y = b\psi_b \cdot 10^{0.04(G_m + LN - LF)} \quad (25)$$

- $G(\psi)$: gain at the angle ψ from the main beam direction (dBi)
- G_m : maximum gain in the main lobe (dBi)
- ψ_b : one-half the 3 dB beamwidth in the plane of interest (3 dB below G_m) (degrees)
- LN : near-in-side-lobe level in dB relative to the peak gain required by the system design
- $LF = 0$ dBi: far side-lobe level (dBi)
- z : (major axis/minor axis) for the radiated beam
- LB : $15 + LN + 0.25G_m + 5 \log z$ dBi or 0 dBi whichever is higher

LN (dB)	a	b	α
-20	$2.58 \cdot \sqrt{(1 - \log(z))}$	6.32	2
-25	$2.58 \cdot \sqrt{(1 - 0.8 \cdot \log(z))}$	6.32	2

Figure 3-8: LN selection to get a, b and α .

The numeric values of a , b , and α for $LN = -20$ dB and -25 dB side-lobe levels are given in the above table.

3.8.7 Off Boresight Angle Calculation

Conceptually, the off-boresight angle, θ , in the antenna gain formula is defined as the angle between two vectors: one along the boresight of the beam (i.e., from the satellite to the beam centre, which corresponds to the sub-satellite nadir point), and the other from the satellite to the UE. In NetSim, θ is computed as the arccosine of the normalized dot product of these two vectors.

Standard ENU-Based Look Angle Computation (Satellite to Earth)

This section describes the standard ENU (East–North–Up) method for computing satellite look angles (azimuth and elevation) as seen from an earth station (user terminal).

Notation

φ_t : Latitude of earth station (degrees)

λ_t : Longitude of earth station (degrees)

H_t : Altitude of earth station above sea level (km)

φ_s : Latitude of satellite (degrees)

λ_s : Longitude of satellite (degrees)

H_s : Altitude of satellite above sea level (km)

Step 1: Convert Geodetic Coordinates to ECEF

Convert both earth station and satellite geodetic coordinates to Earth-Centered Earth-Fixed (ECEF) Cartesian coordinates.

- WGS-84 ellipsoid constants
- WGS-84 defines the Earth as an oblate ellipsoid with:
- Semi-major axis (equatorial radius):

$$a = 6378137.0 \text{ m}$$

- Flattening:

$$f = \frac{1}{298.257223563}$$

- First eccentricity squared:

$$e^2 = 2f - f^2$$

- Numerically:

$$e^2 \approx 0.00669437999014$$

- Prime vertical radius of curvature

$$N(\phi) = \frac{a}{\sqrt{1 - e^2 \sin^2(\phi)}}$$

- This is to compensate for Earth's flattening.
- ECEF Conversion formulas (WGS-84)

$$X = (N + h) \cos(\phi) \cos(\lambda)$$

$$Y = (N + h) \cos(\phi) \sin(\lambda)$$

$$Z = (N(1 - e^2) + h) \sin(\phi)$$

This gives Earth-Centered Earth-Fixed (ECEF) coordinates:

- X axis: intersection of equator and Greenwich meridian
- Y axis: 90° east on equator
- Z axis: North pole

Step 2: Line-of-Sight Vector in ECEF

Compute the line-of-sight (LOS) vector from the earth station to the satellite:

$$\Delta r = r_s - r_t = (\Delta X, \Delta Y, \Delta Z)$$

Step 3: Rotate LOS Vector into Local ENU Frame

Define the standard ECEF-to-ENU rotation matrix at the earth station latitude φ_t and longitude λ_t :

$$\begin{bmatrix} E \\ N \\ U \end{bmatrix} = \begin{bmatrix} -\sin(\lambda_t) & \cos(\lambda_t) & 0 \\ -\sin(\phi_t) \cos(\lambda_t) & -\sin(\phi_t) \sin(\lambda_t) & \cos(\phi_t) \\ \cos(\phi_t) \cos(\lambda_t) & \cos(\phi_t) \sin(\lambda_t) & \sin(\phi_t) \end{bmatrix} \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} \quad (26)$$

This yields the local ENU components (E, N, U) of the satellite relative to the earth station.

Step 4: Slant Range

The straight-line distance between the earth station and the satellite is:

$$D_{ts} = \sqrt{E^2 + N^2 + U^2} \quad (27)$$

Step 5: Elevation Angle

The elevation angle (above the local horizontal plane) is computed as:

$$el = \text{atan2}\left(U, \sqrt{E^2 + N^2}\right) \quad (28)$$

Elevation is in the range -90° to $+90^\circ$.

Step 6: Azimuth Angle

The azimuth angle, measured clockwise from true North, is:

$$az = \text{atan2}(E, N) \quad (29)$$

The result should be wrapped to the range 0° – 360° .

Step 7: Visibility Check

Given a minimum elevation mask angle (maskAngle):

$$\text{visible} = 1 \quad \text{if } el \geq \text{maskAngle}$$

$$\text{visible} = 0 \quad \text{otherwise}$$

If $\sqrt{E^2 + N^2} \approx 0$ (satellite directly overhead), the azimuth is indeterminate.

3.8.8 Frequency Reuse

NetSim supports FR1 ($N_{reuse} = 1$), FR2 ($N_{reuse} = 2$), FR3 ($N_{reuse} = 3$) and FR4 ($N_{reuse} = 4$) configurations.

With NetSim GUI, users can configure the number of beams (1, 7, and 19) and select the frequency reuse factor (FRF) accordingly. When $N_{reuse} > 1$, NetSim assigns virtual “channel IDs” to the beams. The available resources and bandwidth are then equally divided among the channels. The bandwidth per channel is calculated per the following expression

$$BW_{channel} = \frac{BW_{Total}}{N_{channels}} \quad (30)$$

3.8.9 Interference models

Exact Geometric Interference Geometric interference arises when multiple beams sharing the same channel ID overlap, leading to co-channel interference at user terminals. The level of interference is influenced by the number of beams and the configured frequency reuse factor. In FR1, interference occurs from all available beams, whereas in FR2, FR3 and FR4 it is limited to beams using the same channel ID.

CIR-based Interference Per TR 38.821 section 6.1.3.1 the Carrier-to-noise-and-interference ratio (CNIR) of the transmission link between satellite and UE can be derived by carrier-to-noise ratio (CNR) and carrier-to-interference ratio (CIR) as follows

$$CNIR \text{ [dB]} = -10 \log_{10} \left(10^{-0.1 \cdot CNR \text{ [dB]}} + 10^{-0.1 \cdot CIR \text{ [dB]}} \right) \quad (31)$$

Carrier-to-Interference Ratio (CIR) is the user input and

CNR (dB) is computed from the link budget, based on EIRP, G/T, path loss and the antenna gain.

Interference power calculations for CIR based Interference

$$\text{Interference [mW]} = \text{Noise [mW]} \times \left(\frac{CNR \text{ [mW]}}{CNIR \text{ [mW]}} - 1 \right) \quad (32)$$

$$\text{Interference [dB]} = 10 \times \log_{10}(\text{Interference [mW]}) \quad (33)$$

3.9 Results

Please refer to the NetSim User Manual, section 8, for Results and Analysis.

3.9.1 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:

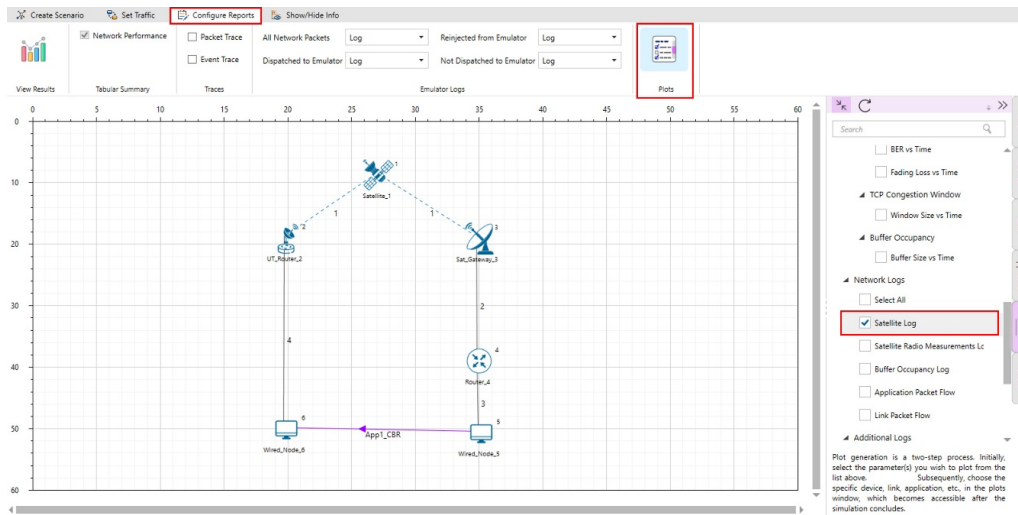


Figure 3-7: Enabling Satellite Log file.

A log file specific to satellite communication, is generated post-simulation as shown in the screenshot below.

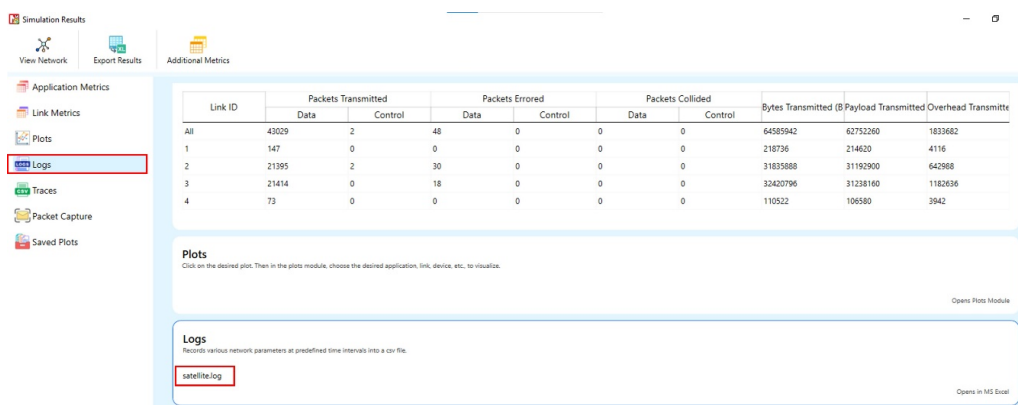


Figure 3-8: Result Window.

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 frequency = 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 frequency = 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 3-9: 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

3.9.2 Satellite Radio Measurements Log

NetSim Satellite Radio Measurements Log file records Time (ms), Transmitter name, Receiver name, Slant height (km), EIRP (dBW), Elevation Angle (°), RXG_T, Pathloss (dB), Fading loss (dB), Additional loss (dB), Total loss (dB), Angular gain (dB), Rx power (dBm), SNR (dB), Thermal noise (dBm), Channel Id, Beam Id, MCS Index and Coding rate. 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:

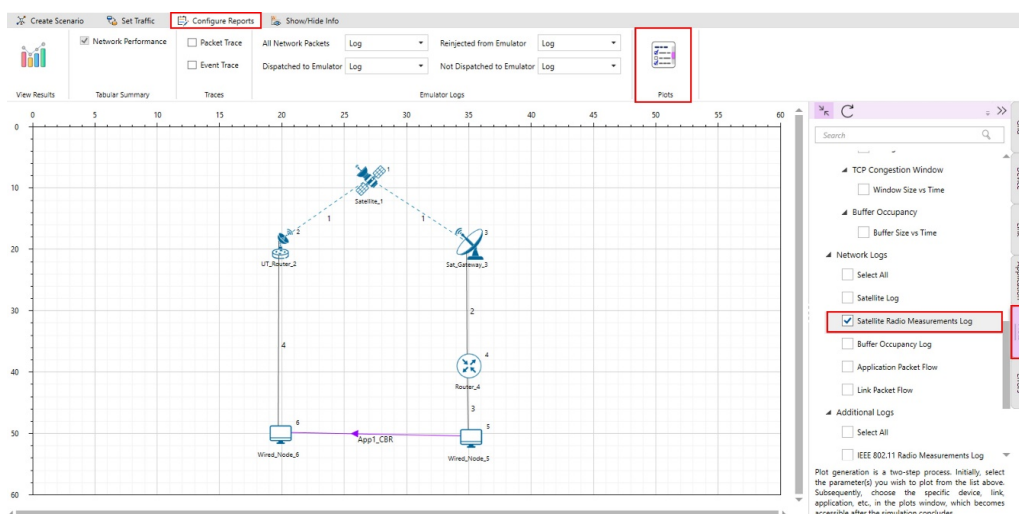


Figure 3-10: Enabling Satellite Radio Measurements Log file.

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

- Time in Milliseconds
- Transmitter Name
- Receiver Name
- Slant height (km)
- EIRP (dBW)
- Elevation Angle (°)
- RXG-T
- Pathloss (dB)
- Fading loss (dB)
- Additional loss (dB)
- Total loss (dB)
- Angular gain (dB)
- Rx power (dBm)
- SNR (dB)
- Interference (dBm)
- Thermal noise (dBm)
- Channel Id
- Beam Id
- MCS Index and
- Coding rate

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

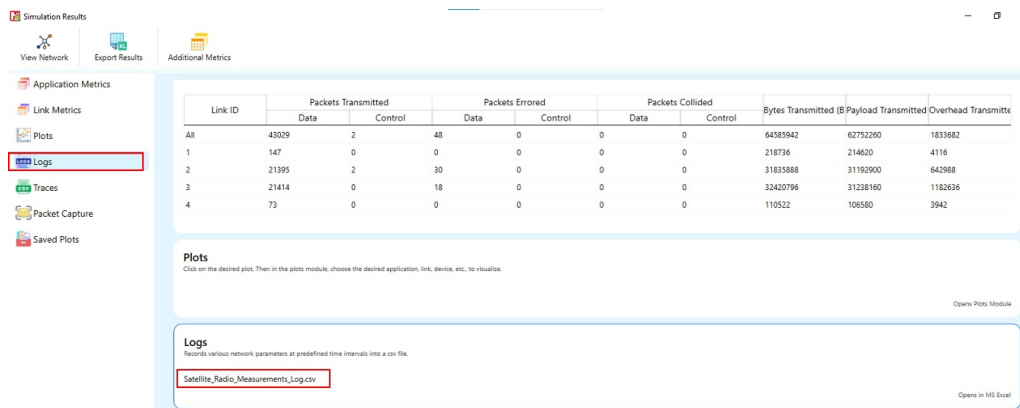


Figure 3-11: Result Window.

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

Time(ms)	Transmitter	Receiver	Slant height	EIRP(dBW)	Elevation Angle	RSG	PathLoss(dB)	FadingLoss(dB)	Additional	TotalLoss	AngularGain	Rx Power(dBm)	SNR(dB)	SNR(dB)	Interference	Channel	Beam	ThermalNoise	MCS Index	Coding rate
1289.781517	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	0.297712	0	212.805075	-61.379054	-131.229304	-31.374508	-31.375059	-1000	1	1	-119.848566	2	0.333333
1289.781517	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	-0.588759	0	201.235323	-61.379054	-141.425523	-21.275107	-21.548422	-1000	1	1	-119.848566	2	0.333333
1289.781517	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	-7.8998	0	205.484462	-61.379054	-141.915502	-24.988996	-24.972576	-1000	1	1	-119.848566	2	0.333333
1289.781517	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	-5.342912	0	207.44162	-61.379054	-145.675144	-21.622664	-25.671475	-1000	1	1	-119.848566	2	0.333333
1813.247137	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	2.425911	0	215.299922	-61.379054	-134.448962	-31.588496	-32.932651	-1000	1	1	-119.848566	2	0.333333
1813.247137	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	-0.180973	0	204.654209	-61.379054	-142.832279	-22.588723	-22.953821	-1000	1	1	-119.848566	2	0.333333
1813.247137	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	-4.462478	0	201.211894	-61.379054	-140.262873	-26.264817	-26.957088	-1000	1	1	-119.848566	2	0.333333
1813.247137	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	-1.762438	0	211.021354	-61.379054	-149.252544	-29.464388	-29.403962	-1000	1	1	-119.848566	2	0.333333
2046.781517	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	3.798446	0	222.245448	-61.379054	-142.775158	-31.648462	-31.655463	-1000	1	1	-119.848566	2	0.333333
2046.781517	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	6.225251	0	219.017163	-61.379054	-157.248603	-37.480207	-37.480207	-1000	1	1	-119.848566	2	0.333333
2046.781517	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	3.788879	0	216.372841	-61.379054	-154.882811	-34.952579	-34.952579	-1000	1	1	-119.848566	2	0.333333
2046.781517	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	4.948862	0	212.618264	-61.379054	-151.650514	-31.287298	-31.287298	-1000	1	1	-119.848566	2	0.333333
2078.271137	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	2.822134	0	215.695496	-61.379054	-153.837486	-35.981893	-35.981478	-1000	1	1	-119.848566	2	0.333333
2078.271137	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	2.442878	0	215.135354	-61.379054	-153.530033	-33.728774	-33.311059	-1000	1	1	-119.848566	2	0.333333
2078.271137	UF_NICK_3	SATELLITE_1	40318.35447	48	15.39059	20.37802	212.78430	-15.377451	0	193.486811	-61.379054	-131.637961	-11.788540	-11.879360	-1000	1	1	-119.848566	2	0.333333

Figure 3-12: Satellite Radio Measurements log file.

3.9.3 Satellite Beam Association Log

The NetSim Satellite Beam Association Log file is useful for observing the values recorded for each beam, including Time (ms), TX Name, RX Name, EIRP (dBW), Beam Id, Channel Id, Theta (°), Angular Gain, RXG-T (dB), FSPL (dB), Total loss (dB), SNR (dB), Interference (dBm), Interfering Beam Count, MCS Index, and Coding rate. This log can be enabled/disabled by going to Logs option

and checking/unchecking the Satellite Beam Association Log option under the Network Logs section as shown below:

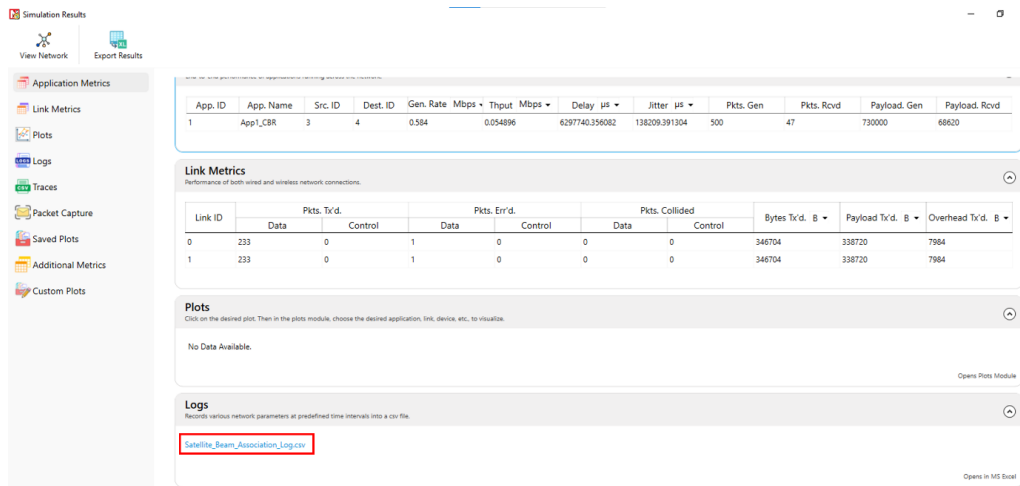


Figure 3-13: Results window.

Users can see Angular Gain, Interference and SNR values in the Log files for each forward and return link. These parameters are logged separately for each beam.

Time(ms)	TxName	RxName	BeamId	ChannelId	Theta(deg)	AngularGain(dB)	FSP(LdB)	RoG_T(dB)	EIRP(dBW)	TotalLoss(dB)	SNR(dB)	Interference(dBm)	InterferingBeamCount	MCS Index	CodingRate
0	SATELLITE_UT_NODE_3	UT_NODE_4	1	1	52.670359	-61.271775	212.784361	20.37602	48	214.940011	-33.217386	-1000	0	2	0.333
0	UT_NODE_4	SATELLITE_UT_NODE_3	1	1	81.472399	-60.305575	212.948314	20.37602	48	210.248995	-27.548995	-1000	0	2	0.333
0	SATELLITE_UT_NODE_4	UT_NODE_3	1	1	81.472399	-60.305575	212.948314	20.37602	48	210.248995	-27.548995	-1000	0	2	0.333
1260.734	UT_NODE_3	SATELLITE_UT_NODE_4	1	1	52.670359	-61.271775	212.784361	20.37602	48	212.952073	-31.267228	-1000	0	2	0.333
1260.734	UT_NODE_4	SATELLITE_UT_NODE_3	1	1	81.472399	-60.305575	212.948314	20.37602	48	203.192831	-21.467786	-1000	0	2	0.333
1260.734	UT_NODE_3	SATELLITE_UT_NODE_4	1	1	52.670359	-61.271775	212.784361	20.37602	48	205.684561	-23.689186	-1000	0	2	0.333
1260.734	UT_NODE_4	SATELLITE_UT_NODE_3	1	1	81.472399	-60.305575	212.948314	20.37602	48	207.441449	-25.716604	-1000	0	2	0.333
1813.246	UT_NODE_3	SATELLITE_UT_NODE_4	1	1	52.670359	-61.271775	212.784361	20.37602	48	215.208971	-33.485126	-1000	0	2	0.333
1813.246	UT_NODE_4	SATELLITE_UT_NODE_3	1	1	81.472399	-60.305575	212.948314	20.37602	48	204.654288	-22.679443	-1000	0	2	0.333
1813.246	UT_NODE_3	SATELLITE_UT_NODE_4	1	1	52.670359	-61.271775	212.784361	20.37602	48	208.123893	-26.397017	-1000	0	2	0.333
1813.246	UT_NODE_4	SATELLITE_UT_NODE_3	1	1	81.472399	-60.305575	212.948314	20.37602	48	211.021953	-29.297108	-1000	0	2	0.333
2345.798	UT_NODE_3	SATELLITE_UT_NODE_4	1	1	52.670359	-61.271775	212.784361	20.37602	48	213.545346	-31.817701	-1000	0	2	0.333
2345.798	UT_NODE_4	SATELLITE_UT_NODE_3	1	1	81.472399	-60.305575	212.948314	20.37602	48	219.191912	-37.250767	-1000	0	2	0.333
2345.798	UT_NODE_3	SATELLITE_UT_NODE_4	1	1	52.670359	-61.271775	212.784361	20.37602	48	216.572884	-34.847995	-1000	0	2	0.333
2345.798	UT_NODE_4	SATELLITE_UT_NODE_3	1	1	81.472399	-60.305575	212.948314	20.37602	48	212.824823	-31.099978	-1000	0	2	0.333
2878.27	UT_NODE_3	SATELLITE_UT_NODE_4	1	1	52.670359	-61.271775	212.784361	20.37602	48	215.688495	-33.80185	-1000	0	2	0.333

Figure 3-14: Satellite Beam Association log file.

3.10 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 India region coverage with 16-Beam GEO Satellite with frequency reuse

Open NetSim, Select Examples → Satellite Communication → India region coverage with 16-Beam GEO Satellite with frequency reuse then click on the tile in the middle panel to load the example as shown below.

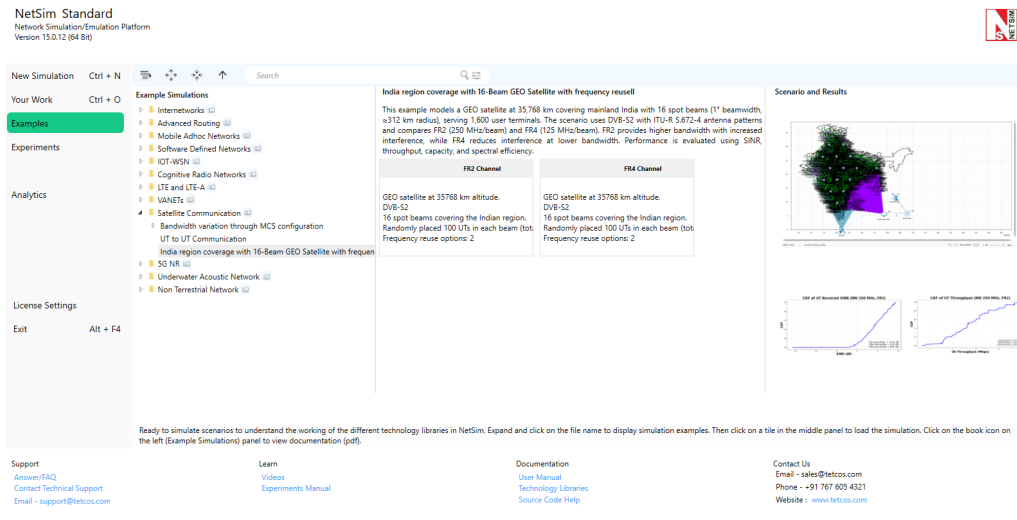


Figure 4-1: List of scenarios for the example of India region coverage with 16-Beam GEO Satellite with frequency reuse.

This example models a GEO satellite at 35,768 km altitude providing coverage over the mainland Indian region (North-East, Andaman & Nicobar & Lakshadweep will be covered in our next iteration) using 16 spot beams. Each beam spans a 1° beamwidth (≈312 km radius) and serves 100 randomly placed user terminals, for a total of 1600 UTs across the coverage area. The scenario uses the DVB-S2 protocol with ITU-R S.672-4 antenna patterns. Two frequency reuse configurations are compared: FR2 (250 MHz per beam) and FR4 (125 MHz per beam). FR2 offers higher per-beam bandwidth but increased inter-beam interference; FR4 reduces interference at the cost of bandwidth per beam.

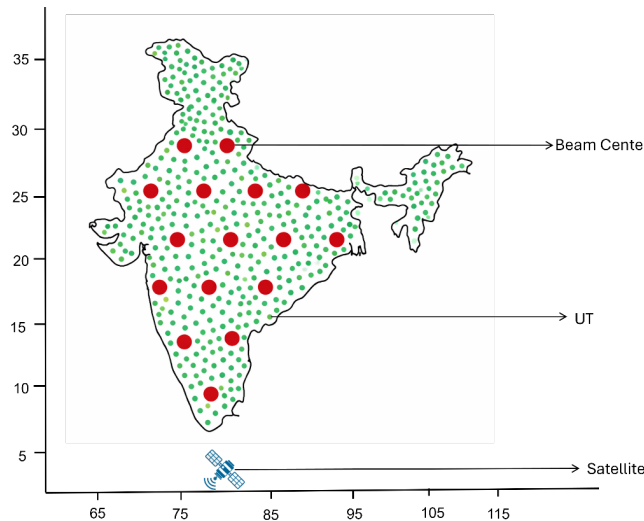


Figure 4-2: India covered using 16 spot beams. Each beam spans a 1° beamwidth (≈312 km radius) and serves 100 randomly placed user terminals (UTs), for a total of 1600 UTs across the coverage area. Beam centres are red dots while UTs are green dots.

The objective is to evaluate the trade-off between these configurations by measuring SINR and throughput distributions, satellite capacity, and spectral efficiency.

4.1.1 Network Scenario

The following network diagram illustrates what the NetSim UI displays when you open the example configuration file. When the example configuration file is opened, NetSim would take some time to load this large scenario. During this time, the UI displays progress information such as the number of devices and applications being loaded.

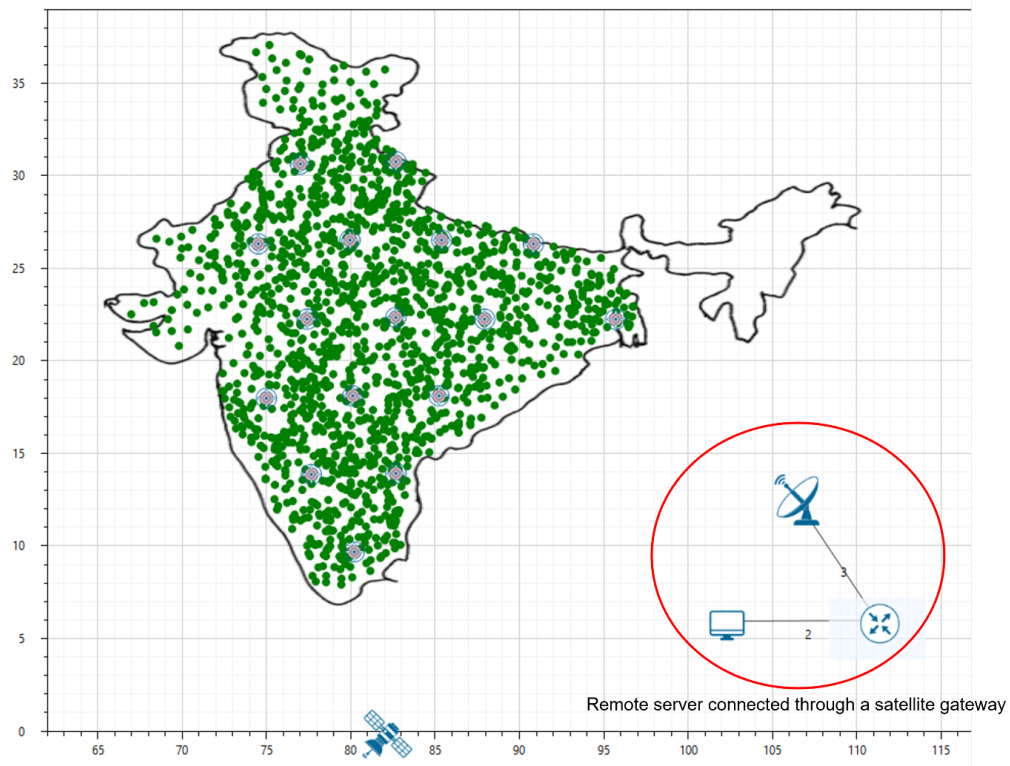


Figure 4-3: Network set up for studying the GEO Satellite, 16 Spot Beams on Indian Region, ITU S.672 Antenna.

Orbit

- GEO satellite at 35768 km altitude.

Protocol and Beams

- DVB-S2
- 16 spot beams covering the Indian region.
- Randomly placed 100 UTs in each beam (total of 1600UTs).
- Frequency reuse options: 2 and 4

Antenna

- Pattern: ITU S.672-4
- EIRP: 54 dBW

Traffic

- Unicast downlink traffic to each UT

Objective

- Measure the distributions and percentiles of SINR and throughput
- Obtain satellite capacity and spectral efficiency

4.1.2 Simulation Setup in NetSim

- The satellite is positioned at 82°E, 0° latitude in GEO orbit.
- Remote Server, Router, and Gateway are logical constructs for enabling traffic flow; their positions are not physical.

Table 4-1: *Simulation settings.*

System Model

Satellite orbit	GEO 35678 km
EIRP (dBW)	54
Frequency Reuse	FR2, FR4
Frequency Band	11 GHz
Bandwidth (MHz)	250 MHz for each FR2 beam / 125 MHz for each FR4 beam
Traffic	Unicast traffic to each UT
Antenna pattern	ITU-R S.672-4
Protocol	DVB-S2
UT Height (m)	1.2
UT RX Antenna Gain (dB)	40
Number of beams	16
Beam width	1°
MCS selection	Adaptive MCS
UT Density	100 UTs per beam
Frame size (bits)	64,800

- Simulation time is set to 10 seconds.
- Application is configured from the Wired node to each UT with the generation rate set to 5 Mbps per application.

4.1.3 Beam Positions and Frequency Coloring

Table 4-2: *Beam Positions.*

Beam ID	Longitude	Latitude
1	82.50	22.50
2	79.94	18.27
3	85.06	18.27
4	77.24	22.41
5	87.76	22.41
6	79.78	26.68
7	85.22	26.68
8	82.50	14.08
9	74.82	18.14
10	80.04	9.84
11	82.50	30.92
12	74.35	26.48
13	90.65	26.48
14	77.49	14.03
15	95.53	22.41
16	76.84	30.80

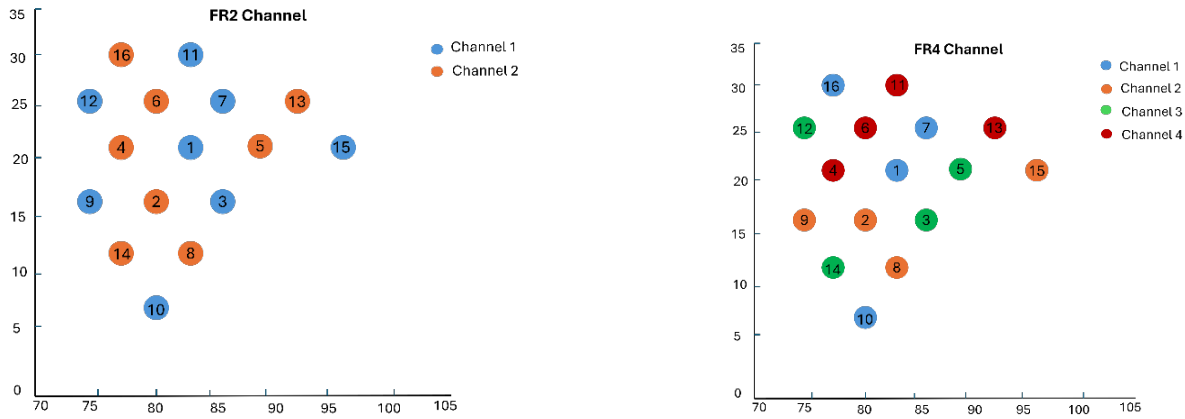


Figure 4-4: Frequency Coloring.

$$R_{beam} = h \times \tan\left(\frac{\theta}{2}\right), \quad h = 35,768 \text{ km}, \quad \theta = 1^\circ \tag{34}$$

$$R_{beam} = 312 \text{ km}, \quad \text{InterBeamDist} = \sqrt{3} \cdot R_{beam} = 540.57 \text{ km} \tag{35}$$

4.1.4 Results Summary

Results: FR2

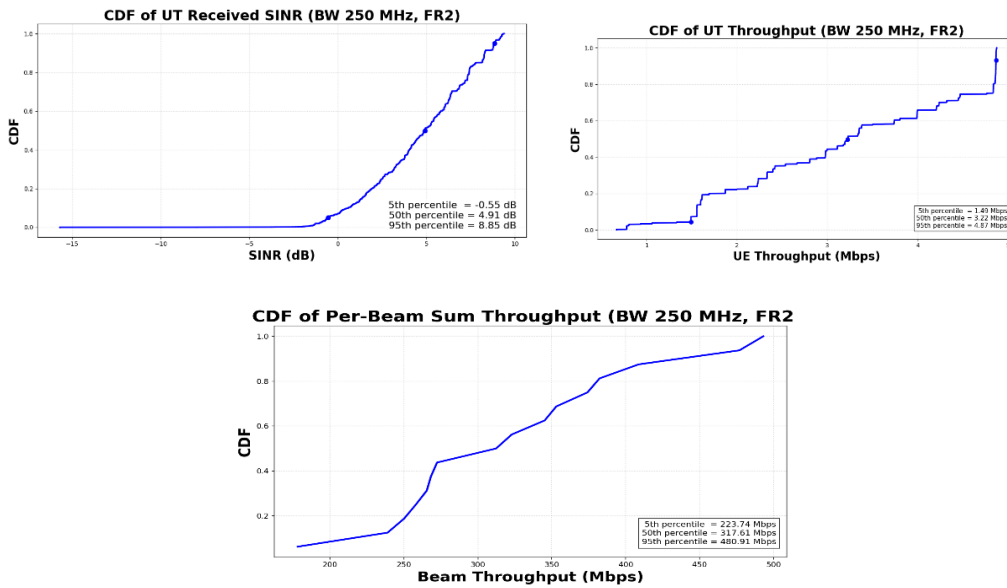


Table 4-3: FR2 Results summary.

	5%	50%	95%
SINR (dB)	-0.55	4.91	8.85
UE Thput. (Mbps)	1.49	3.22	4.87
Beam Thput. (Mbps)	223.74	317.61	480.91

Capacity and Efficiency Metrics (FR2):

Satellite capacity = 5199.75 Mbps

Area Traffic capacity:

Number of beams = 16

Beam radius, $R = 312.3$ km

Area per beam (A) = $\frac{3\sqrt{3}}{2}R^2 = 253424.62$ km²

Total coverage area = 253424.62 km² × 16 = 4054793.9 km²

- Area Traffic Capacity = 1.28 kbps/km²

Average Spectral efficiency (FR2)

System Bandwidth = 500 MHz

Spectral Efficiency

$$\eta_{system} = \frac{\text{Aggregate Throughput (bps)}}{\text{System Bandwidth (Hz)}} = \frac{5199.75 \times 10^6}{500 \times 10^6} = 10.39 \text{ bits/s/Hz} \quad (36)$$

Results: FR4

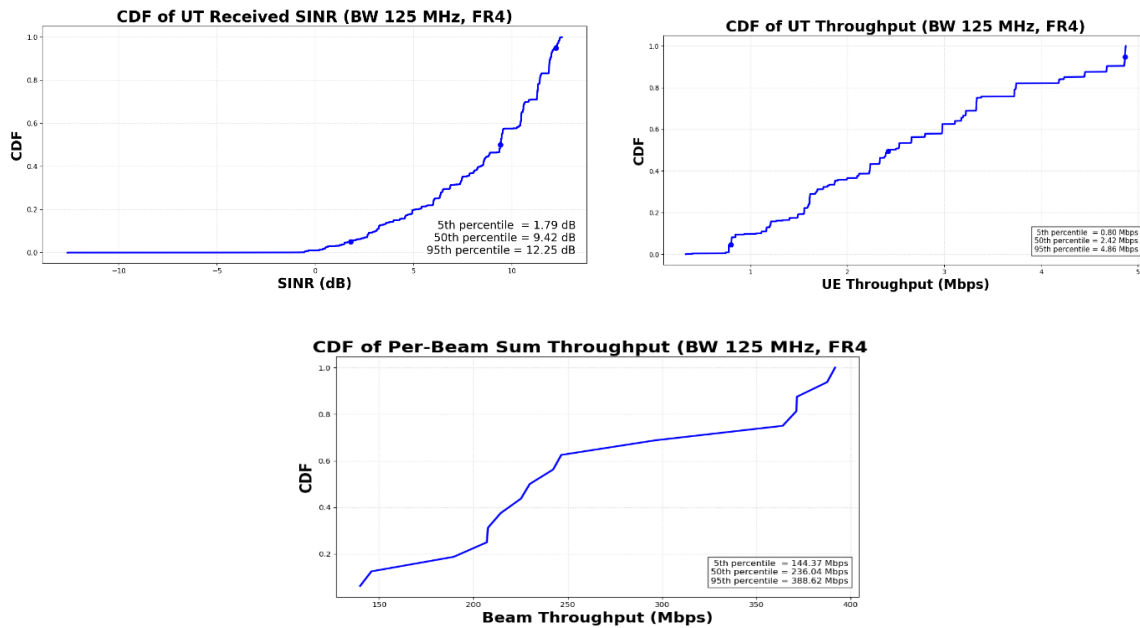


Table 4-4: FR4 Results summary.

	5%	50%	95%
SINR (dB)	1.79	9.42	12.25
UE Thput. (Mbps)	0.80	2.42	4.86
Beam Thput. (Mbps)	144.37	236.04	388.62

Capacity and Efficiency Metrics (FR4):

Satellite capacity = 4230.56 Mbps

Area Traffic capacity:

Number of beams = 16

Beam radius, $R = 312.3 \text{ km}$

Area per beam (A) = $\frac{3\sqrt{3}}{2}R^2 = 253424.62 \text{ km}^2$

Total coverage area = $253424.62 \text{ km}^2 \times 16 = 4054793.92 \text{ km}^2$

Area Traffic Capacity = 1.04 kbps/km^2

Average Spectral efficiency (FR4)

System Bandwidth = 500 MHz

$$\eta_{system} = \frac{\text{Aggregate Throughput (bps)}}{\text{System Bandwidth (Hz)}} = \frac{4230.56 \times 10^6}{500 \times 10^6} = 8.46 \text{ bits/s/Hz} \quad (37)$$

4.1.5 5th, 50th, 95th percentile UTs

(FR 2 case)	5th percentile	50th percentile	95th percentile
Received Signal (dBm)	-80.84	-80.80	-80.26
CNR (dB) or C/N	9.15	9.19	9.72
Interference Power (dBm)	-80.78	-87.74	-96.51
CIR (dB) or C/I	-0.07	6.95	16.25
CINR (dB) or C/(N+I)	-0.55	4.91	8.85
Throughput (Mbps)	1.49	3.22	4.87

- The 5% UT is located at the beam edge and subject to interference from other beams.
- The 95% UT is near the beam center with very low interference from other beams.

To plot the CDF of SINR per UT and per beam, we considered the metrics.xml file and the Radio Measurements log file.

4.2 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 below.

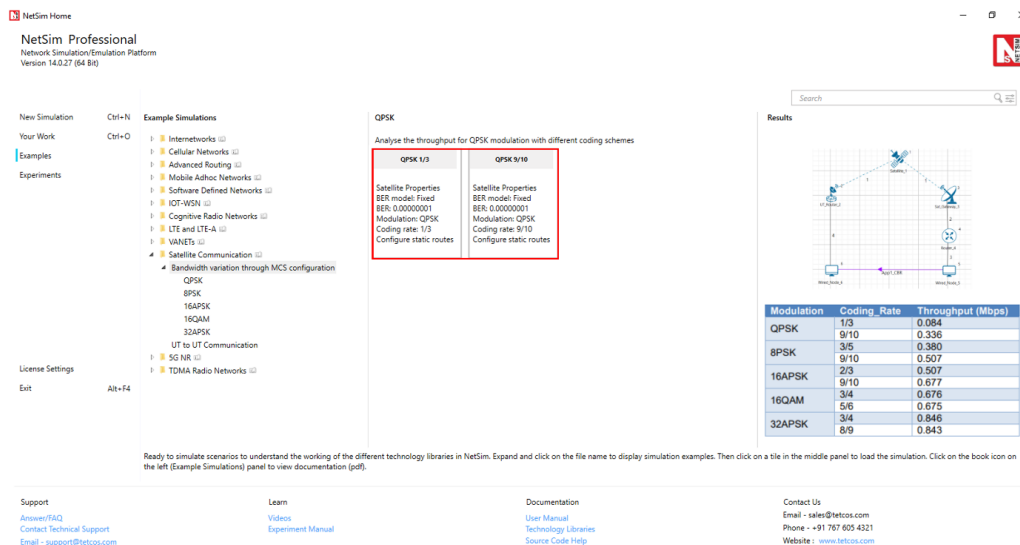


Figure 4-5: List of scenarios for the example of Bandwidth variation through MCS configuration.

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

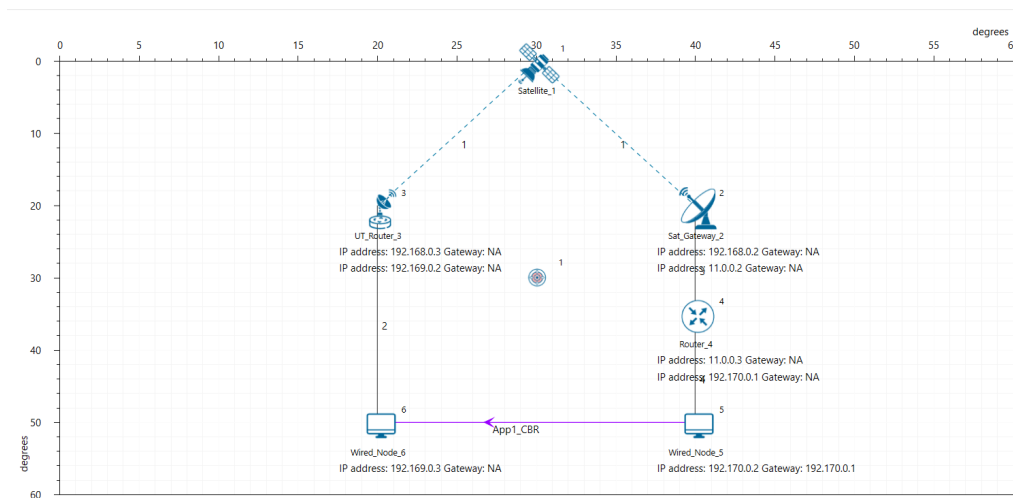


Figure 4-6: Network set up for studying the Bandwidth variation through MCS configuration.

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.

Table 4-5: Satellite Properties → Interface (Satellite) → Physical Layer → Forward.

Satellite Properties → Interface (Satellite) → Physical Layer → Forward

BER Model	Fixed
BER	0.00000001

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

Table 4-6: UT Router Properties → Interface (Satellite) → Datalink Layer.

UT Router Properties → Interface (Satellite) → Datalink Layer

Gateway	Sat Gateway 2
---------	---------------

NOTE: For manually configured scenario, the user needs 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.

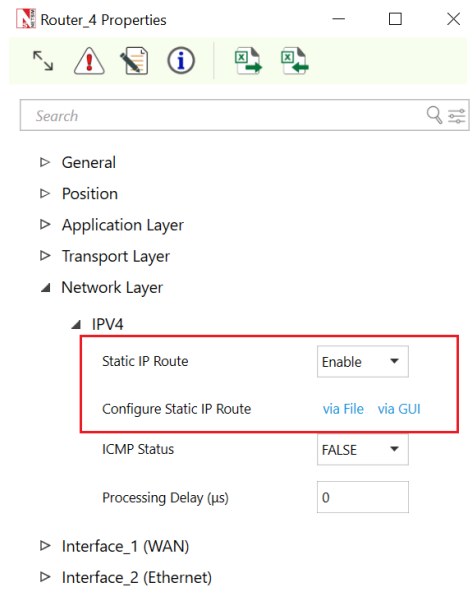


Figure 4-7: Router Network layer properties window.

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

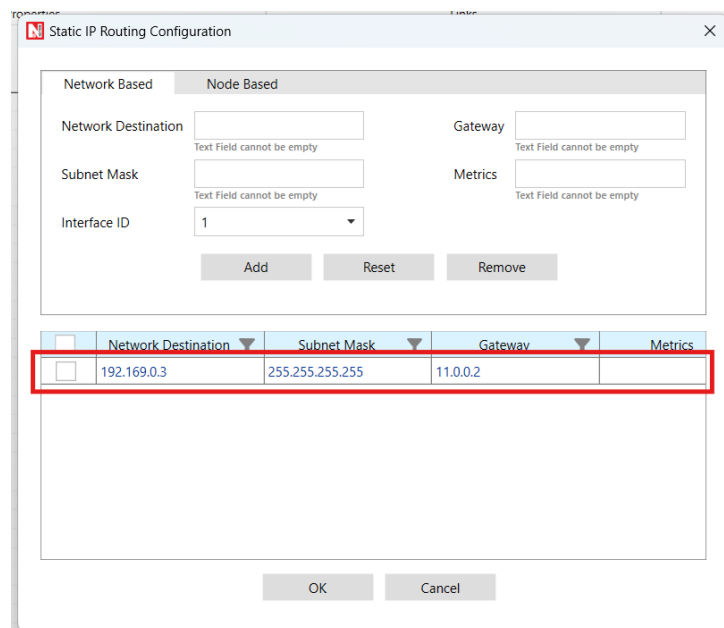


Figure 4-8: Configuring Static route window for router.

5. Go to Sat Gateway 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.

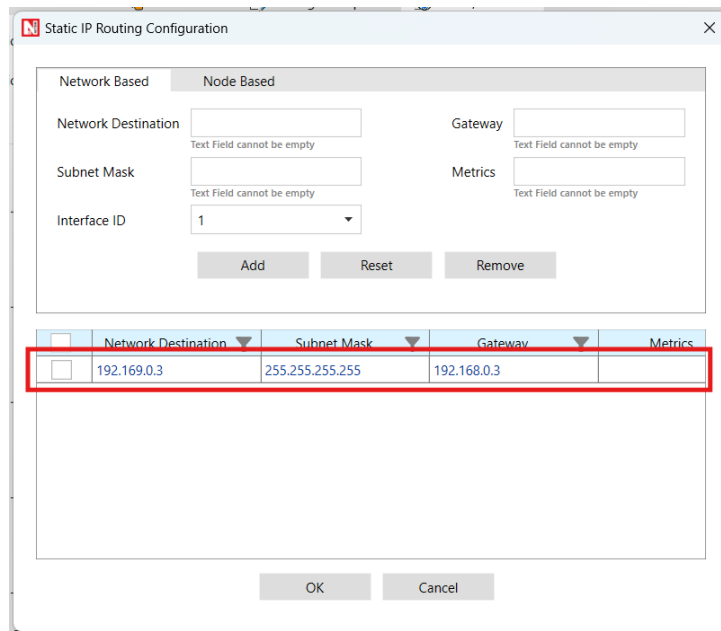


Figure 4-9: *Configuring Static route window for Sat_Gateway_3.*

6. Go to UT Router 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.

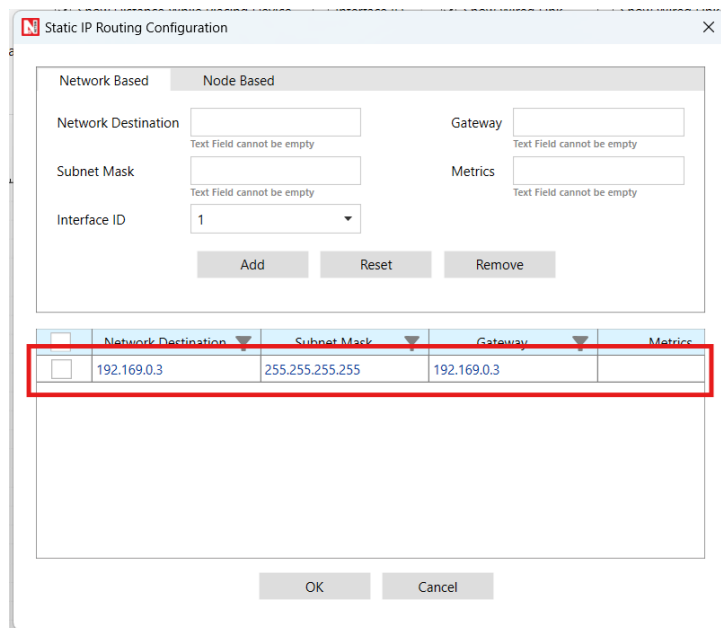


Figure 4-10: *Configuring Static route window for UT_Router_2.*

7. 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 1460 Bytes and Inter Arrival time as 467 μ s (Generation Rate = 25 Mbps). Transport Protocol is set to UDP.
8. Change the Satellite Properties → Interface (Satellite) → Physical Layer → Forward → Modulation and respective coding rates as shown in below Table but the return link uses fixed Modulation → 32APSK and Coding Rate → 3/4.
9. Run simulation for 10 seconds and observe the result.

NOTE: Satellite physical layer changes are 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).

Table 4-7: Compare the different Modulation Scheme and Coding Rate vs. Throughput.

Modulation	Coding Rate	Throughput (Mbps)
QPSK	1/3	0.087
	9/10	0.355
8PSK	3/5	0.399
	9/10	0.532
16APSK	2/3	0.534
	9/10	0.713
16QAM	3/4	0.712
	5/6	0.713
32APSK	3/4	0.891
	8/9	0.892

4.3 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 the screenshot below.

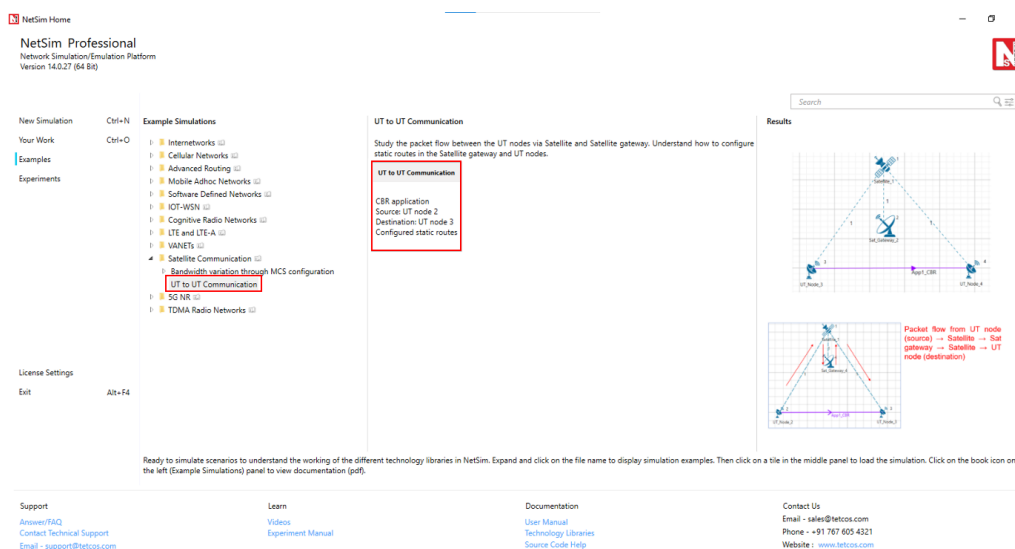


Figure 4-11: List of scenarios for the example of UT to UT Communication.

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

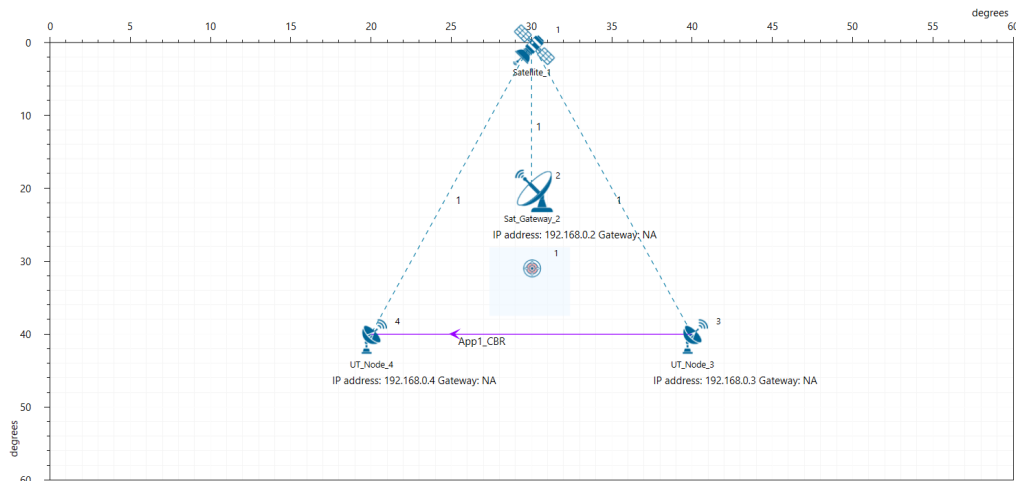


Figure 4-12: Network set up for studying the UT-to-UT Communication.

Settings done in example config file

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

Table 4-8: UT Node Properties → Interface (Satellite) → DataLink Layer.

UT Node Properties → Interface (Satellite) → DataLink Layer

Gateway	Sat Gateway 2
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- Similarly, go to UT Node 3 properties → Network Layer → Enable – Static IP Route → Configure Static Route IP.

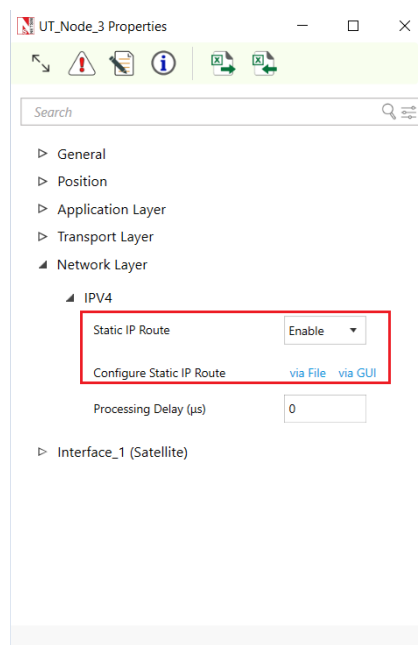


Figure 4-13: Network layer properties window for UT Node 3.

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

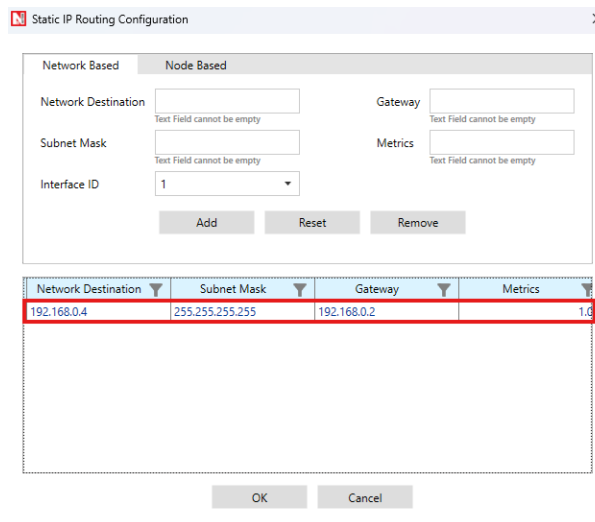


Figure 4-14: Configure static route for UT Node 3.

2. Go to Sat Gateway 2 properties → Network Layer → Enable – Static IP Route → Configure Static Route IP via GUI.

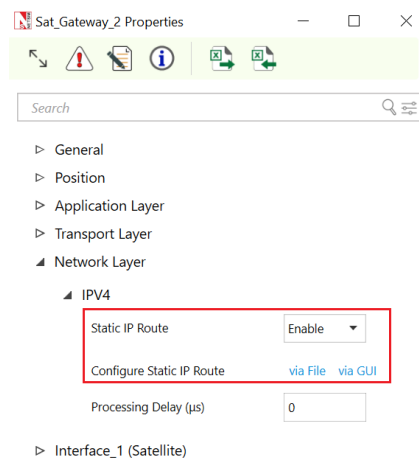


Figure 4-15: Network layer properties window for Sat Gateway 2.

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

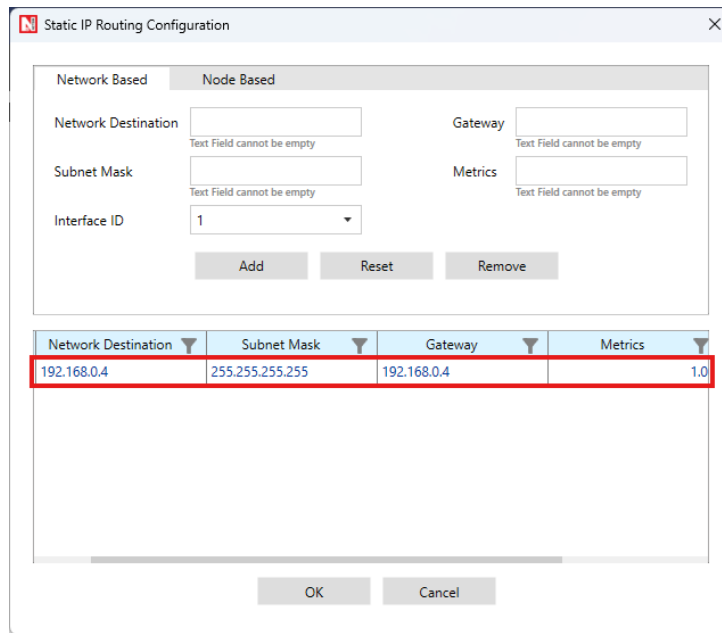


Figure 4-16: Configure static route for Satellite Gateway 2.

4. 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 μ s)
5. Click on application and set Transport Protocol to UDP in property panel.
6. Set the Link model to Abstract Link under Physical layer of satellite device.
7. Enable Packet Trace and Plots from the configure report tab.
8. 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)

	A	B	C	D	E	F	G	H
	PACKET_ID	SEGMENT_ID	PACKET_TYPE	CONTROL_PACKET_TYPE/APP_NAME	SOURCE_ID	DESTINATION_ID	TRANSMITTER_ID	RECEIVER_ID
1	1	0	CBR	App1_CBR	SATELLITE_UT-1	SATELLITE_UT-4	SATELLITE_UT-3	SATELLITE-1
2	1	0	CBR	App1_CBR	SATELLITE_UT-1	SATELLITE_UT-4	SATELLITE-1	SATELLITE_GW-2

Figure 4-17: 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.