

# NetSim<sup>®</sup>

Accelerate Network R & D

## 5G NTN

A Network Simulation & Emulation Software

By



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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](mailto:sales@tetcos.com)

Visit: [www.tetcos.com](http://www.tetcos.com)

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# 1 Introduction

The 5G NTN library supports end-to-end, full-stack, packet-level simulation of 5G NTN based LEO/MEO satellite networks. The features supported include:

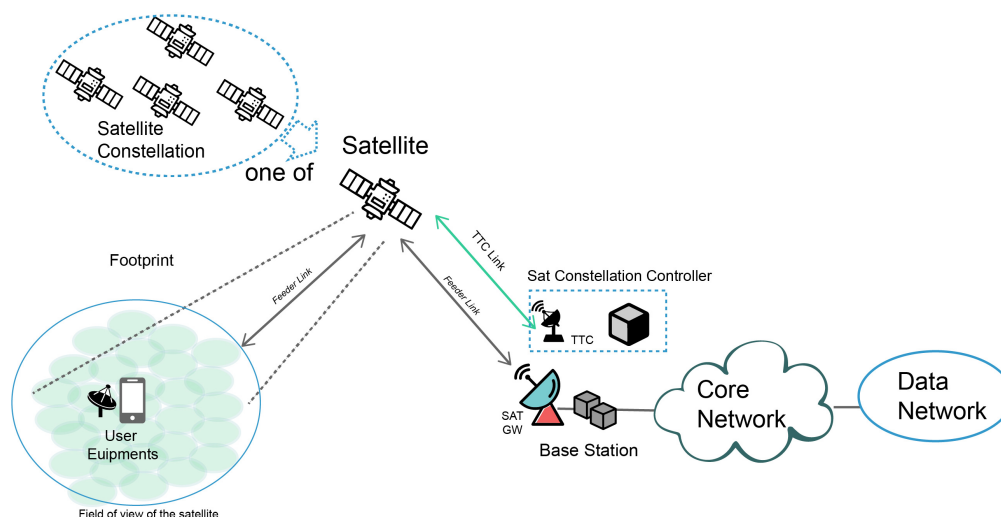
- LEO satellite orbits
  - Altitude: User configurable from 160 to 2000 km.
  - Standard options: LEO 600, LEO 1200
- MEO satellite orbits
  - Altitude: User configurable from 2000 to 35876 km.
  - Standard options: MEO 10000, MEO 20000
- GEO satellite orbits
  - Altitude: 35786 km.
  - Standard option: GEO 35786
- Bands
  - S-band and L-band: n254, n255, n256 (FR1 bands released in 3GPP standards)
  - Ka Band, Ku Band: n510, n511, n512 (FR2 bands proposed in 3GPP standards)
- Earth satellite link and satellite earth link
- Channel model and path losses (per TR 38.811)
- Propagation delay based on slant distance
- Devices
  - UEs
    - \* VSAT with directive antennas
    - \* Handhelds (or informally mobiles)
  - Ground stations, gNBs
  - 5G core and remote servers
- Downlink transmissions (Remote server > gNB > Satellite > UE)
- Uplink transmissions (UE > Satellite > gNB > Remote server)
- Antenna models
  - Omnidirectional antenna for Handheld UEs
  - Circular aperture antenna for VSATs and Satellites
- Satellite spot beams with earth fixed cells (explained later)
- Architecture
  - Transparent satellite (also termed “bent pipe” operation)

Similar to the NetSim (terrestrial) 5G library, the NTN satellite library allows users to simulate the transmission of data, voice, video, etc., over a LEO/MEO satellite network. After simulation, users can assess key output metrics such as delay, latency, and errors. These results can be viewed in both tabular and graphical formats, from a network-wide overview down to individual links and devices. For in-depth studies, NetSim can log detailed radio measurements and resource allocations as well as trace individual packet flow and individual event execution.

## Single transparent satellite fixed in a LEO orbit with terrestrial UEs and gNB

- Single satellite simulation per 3GPP TR 38.821
- The satellite remains fixed in orbit; users can configure the orbital height.
- UE elevation angle is computed per the UE's position.
- Fixed-earth spot beams. UEs will connect to the beam with the highest PDSCH SNR.
- Ground station and gNB are located at an arbitrary point outside the service beams and communicate with the satellite via a feeder link.
- UEs transmit/receive data from remote servers and the connectivity is UE ↔ Satellite ↔ Gateway ↔ gNB ↔ 5G Core ↔ Remote servers.
- UEs can be mobile and inter-beam handovers can occur.
- UEs are handheld devices (e.g., Power Class 3) operating in FR1, i.e., the S or L band. VSAT terminals can connect in FR1 or FR2 bands.
- The UE terminals are assumed to be equipped with a GNSS receiver, thus able to estimate their location.

**RAN Architecture with a transparent satellite (NTN A1 mode)** The diagrams below show a typical satellite NTN scenario based on transparent payload architecture



**Figure 1-1:** Architecture of 5G Non terrestrial network with LEO/MEO satellites. The satellite communication with the ground station is over a feeder link having 1-spot beam and communication with the UEs is over a service link having multiple spot beams. UEs can be placed within these beams (or cells). The telemetry and telecommand (TTC) link is out of scope of 3GPP realm. (source TR 38.821).

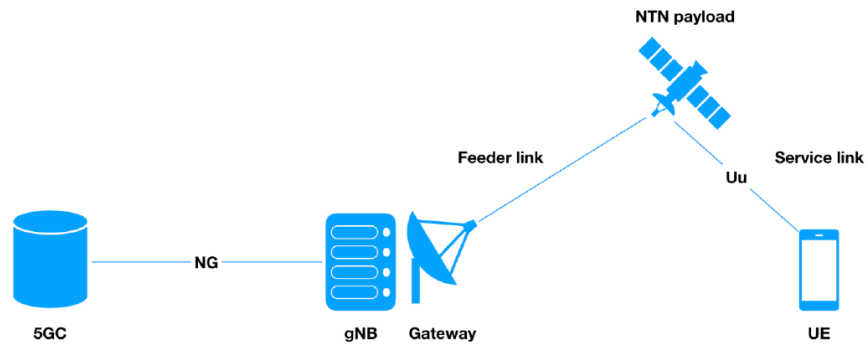
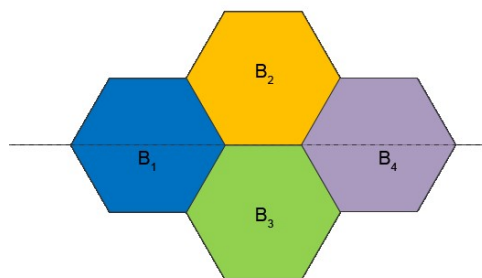


Figure 3: NTN architecture with transparent payload.

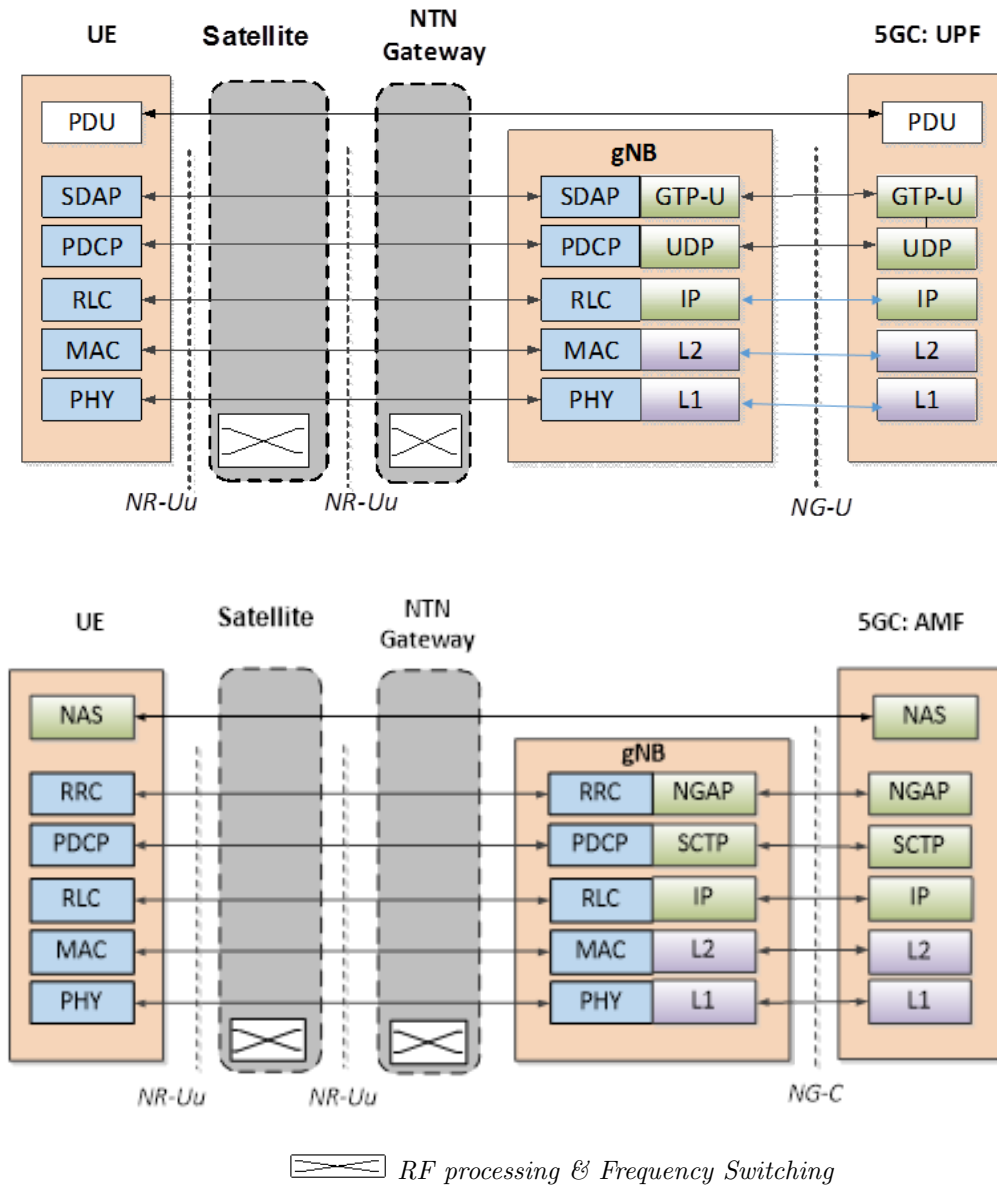
**Figure 1-2:** A simplified illustration of the transparent payload architecture. In Phase-1 the satellite is assumed fixed in the LEO/MEO orbit, and the UE is assumed to be stationary on earth.

- A feeder link is a radio communication link between a gateway and the satellite. It is a single beam of full bandwidth.
- A service link is a radio communication link between the user equipment and the satellite. The service link comprises multiple spot beams that cover a given area. The bandwidth of the beams depends on the frequency reuse factor.



**Figure 1-3:** Top view of four tessellated spot beams on the service link. In NetSim, UEs will associate to the beam which provides the highest signal strength. Per 3GPP standards, the mapping of satellite beams to terrestrial cells is one-to-one. Each beam is one physical cell. Thus, we will refer to cells and spot beams interchangeably.

- A satellite, which implements a transparent payload, performs radio frequency filtering, frequency conversion and amplification; hence, the waveform signal repeated by the payload is unchanged except for frequency translation and transmit power.



**Figure 1-4:** 5G NTN User plane and control plane protocol stacks. Source TR 38.821.

### 1.1 Earth fixed spot beams and cells

The satellite beams point towards the ground in a hexagonal manner similar to the canonical evaluation setup with hexagonal tessellation used for terrestrial cellular networks. NetSim supports earth-fixed beams.

- In earth-fixed beams, the satellite beams are steered such that they always point to the same location on earth.
- The ability to adjust these beams is constrained by the satellite’s elevation angle. It must stay above a specified minimum value on either side of the horizon for uninterrupted connectivity. Practically, when the elevation hits its limit, the beams shift to another Earth location. The beams stay fixed on that location for a set duration before moving to another, and this cycle repeats.
- The adjustment of these beams is limited by the satellite’s beam radius and the number of beams configured by the user.

- The fixed-beam scenario yields the maximum time a UE may remain under the coverage area of the same satellite. This time is the time the satellite remains above the horizon relative to the UE location. This is usually of the order of 7 to 10 minutes.
- Unlike fixed beams, “Moving beams” follow the motion of the satellite and move over the Earth’s surface. This is not currently supported in NetSim.
- Mapping of satellite beams to terrestrial cells is one-to-one. Each beam is one physical cell.
- Number of spot beams.
  - NetSim can presently support configurations of 1, 7, or 19 spot beams with custom placement. Users can drop an arbitrary number of beams based on their requirement.
  - 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 automatically computes the tessellated beams (cells) based on the number of spot beams.
- NetSim supports the NR-Uu radio interface on the service link between the satellite and the UE.

**Cell/Beam Layouts** NetSim supports 1 cell, 7 cell and 19 cell layouts. The beam diameter which is also the inter-beam distance on earth is a user input. The beams would be circular, but the tessellation would be hexagonal. The centre of all the cells can be calculated from basic trigonometry.

**Beam diameter to inter-cell distance** Let the beam diameter be  $D$ , which is a user input. Then the distance between the centre of two adjacent hexagons whose circumcircle has a diameter  $D$  can be obtained from basic trigonometry. Since  $\frac{ISD}{\frac{D}{2}} = \cos(30)$ , we obtain  $ISD = \frac{\sqrt{3} \times D}{2}$ .

**Feeder Link** The feeder link is used for communication between the satellite and the terrestrial gNB. The frequency reuse options discussed are pertinent to the service link. For the feeder link, NetSim models a single spot beam of full bandwidth pointed towards the terrestrial gNB. NetSim supports Satellite Radio Interface (SRI) on the feeder link between the NTN gateway and the satellite. The SRI transports the F1 protocol.

Per TR 38821, Table 6.1.1.1-5, NOTE 1, “Typical impairment values (additional frequency error, SNR loss) due to the feeder link except for delay can be considered to be negligible”. Therefore, in NetSim, we assume the feeder link to have NIL SNR losses. The only factor we consider and model over this link is latency.

**Bent pipe operation** Bent pipe satellites are typically used to relay information. Data received by the satellite on its reception interface is simply transmitted by the satellite on its transmission interface without modifying the data. Given that we model NIL SNR loss on the feeder link the link budget computations are only carried out on the service link.

**Angle between the antenna boresight to the line joining the UE and the satellite** The cell diameter  $D$  is a user-defined parameter. The beam positions are based on the cell diameter and the number of beams configured.  $\theta$  is defined as the angle subtended between the selected beam and the UE from the satellite. It is computed by forming vectors:

Satellite-to-Beam (centre) vector  $\hat{\rho}_c$

Satellite-to-UE vector  $\hat{\rho}_u$

The angle  $\theta$  is determined using the dot product formula:

$$\theta = \cos^{-1} \left( \frac{\hat{\rho}_c \cdot \hat{\rho}_u}{\|\hat{\rho}_c\| \|\hat{\rho}_u\|} \right) \quad (1)$$

where:

$\hat{\rho}_c \cdot \hat{\rho}_u$  is the dot product of the vectors, and

$\|\hat{\rho}_c\|, \|\hat{\rho}_u\|$  are the magnitude of the respective vectors.

## 1.2 Bands

Release 17 has three new bands for LEO NTN.

- n256 (S-Band): UL 1980 – 2010 MHz, DL: 2170 – 2200 MHz. FDD
- n255 (L-Band): UL 1626.5 – 1660.5 MHz, DL: 1525 – 1559 MHz. FDD
- n254: UL 1610 – 1626.5 MHz, DL: 2483.5–2500 MHz. FDD

Release 18 NTN bands in FR2

- n512: UL 27.5–30.0 GHz; DL 17.3–20.2 GHz FDD
- n511: UL 28.35–30.0 GHz; DL 17.3–20.2 GHz FDD
- n510: UL 27.5–28.35 GHz; DL 17.3–20.2 GHz FDD

With 3GPP Rel-18, additional spectrum in Ka band offers much higher speed – to the order of hundreds of Mbps – to non-handheld devices using small dish antennas, similar to that offered by SpaceX’s Starlink service.

Note that:

- UEs can connect only on FR1 bands
- VSAT terminals can connect on FR1 and FR2 bands

### Sub carrier spacing

- Rel 17 allows for SCS of UL signals lower than 60 kHz (in FR1)

### GUI parameters

- Grid size:
  - Min: 50km × 50 km
  - Max: 150 km × 150 km
  - Square or rectangular configurations
- Satellite type:
  - Options: LEO, MEO
  - Altitude (per Table 4.5.1, 38.811)
    - \* LEO: 160 km to 2000 km. Standard options: 600 km, 1200 km.
    - \* MEO: 2000 km to 35876 km. Standard options: 10000 km, 20000 km.
- Service link
  - Number of beams on the service link
    - \* Options: 1, 7, 19
  - Frequency reuse factor

- \* Options: 1, 3
- Beam diameter // Reference Table 4.6.1, 38.811
  - \* LEO: 5km to 200 km. Default: 50 km
  - \* MEO: 100 km to 500 km. Default: 200 km.
- $EIRP$  is the effective isotropic radiated power in dBW
- $\frac{G_{rx}}{T}$  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. Fixed.
- Channel
  - Pathloss model. Fixed to Free Space. Using this model we obtain,  $PL_{FS}$  the free space path loss (FSPL) in dB.
  - Shadow Margin,  $PL_{SM}$  in dB. Enable and disable options in the GUI. If enabled then the log normal shadowing model is applied; the standard deviation of the distribution is obtained from tables available at section 6.6.2 of 3GPP 38.811, based on the LOS probability, elevation angle, and scenario type (urban, rural, or dense urban).
  - Scintillation loss,  $PL_{SL}$  in dB. Range [0.0, 10.0]. Default [1.1]
  - Additional loss,  $PL_{AD}$  in dB. Range [0.0, 10.0]. Default [8]
  - Interference. Enable and disable options in the GUI. If enabled then Carrier to Interference Ratio, CIR in dB. Range [-30, +50]. Default [5]
- Channel bandwidth,  $BW$  in Hz from which we obtain  $B$ , is the channel bandwidth in dBHz (i.e.,  $10 \log_{10}(BW)$ , where  $BW$  is bandwidth in Hz). Options
  - FR1 – 5, 10, 15, 20, 30 (MHz)
  - FR2 – 50, 100, 200, 400 (MHz)
- Antenna
  - Satellite Max Receive Gain
  - Note that transmit gain is assumed to be included in the EIRP
- UE Transmit power: 23 dBm
- Terrestrial environment: Dense urban, urban, rural
- Frequency Reuse
  - In the NETSIM GUI, users can configure the number of beams and select the frequency reuse factor accordingly. This selection determines the channel ID assignment for all beams.
  - Once configured, the NetSim GUI generates a csv file containing the beam ID, beam centre coordinates, and assigned channel ID. This file is then passed to the NTN simulation engine. An option is available for the user to directly modify this csv file through the GUI.

### 1.3 Band Frequency Information

**Table 1-1:** Frequency Bands with Uplink/Downlink Allocations.

NR operating band	Uplink (UL) operating band BS receive / UE transmit $F_{UL,low} - F_{UL,high}$	Downlink (DL) operating band BS transmit / UE receive $F_{DL,low} - F_{DL,high}$	Duplex Mode
n256	1980 MHz – 2010 MHz	2170 MHz – 2200 MHz	FDD
n255	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD
n254	1610 MHz – 1626.5 MHz	2483.5 MHz – 2500 MHz	FDD
n512	27500 MHz – 30000 MHz	17300 MHz – 20200 MHz	FDD
n511	28350 MHz – 30000 MHz	17300 MHz – 20200 MHz	FDD
n510	27500 MHz – 28350 MHz	17300 MHz – 20200 MHz	FDD

**Maximum transmission bandwidth configuration** The maximum transmission bandwidth configuration  $N_{RB}$  for each UE channel bandwidth and subcarrier spacing is specified below.

**Table 1-2:** *Maximum transmission bandwidth configuration for FR1.*

SCS (kHz)	5 MHz $N_{RB}$	10 MHz $N_{RB}$	15 MHz $N_{RB}$	20 MHz $N_{RB}$	30 MHz $N_{RB}$
15	25	52	79	106	160
30	11	24	38	51	78

**Table 1-3:** *Maximum transmission bandwidth configuration for FR2.*

SCS (kHz)	50 MHz $N_{RB}$	100 MHz $N_{RB}$	200 MHz $N_{RB}$	400 MHz $N_{RB}$
60	66	132	264	N/A
120	32	66	132	264

### Minimum guard band and transmission bandwidth configuration

**Table 1-4:** *Minimum guard band for each UE channel bandwidth and SCS (kHz) – FR1.*

SCS (kHz)	5 MHz	10 MHz	15 MHz	20 MHz	30 MHz
15	242.5	312.5	382.5	452.5	592.5
30	505	665	645	805	945
60	N/A	1010	990	1330	1290

**Table 1-5:** *Minimum guard band for each UE channel bandwidth and SCS (kHz) – FR2.*

SCS (kHz)	50 MHz	100 MHz	200 MHz	400 MHz
60	1210	2450	4930	945
120	1900	2420	4900	9860

## 1.4 Simulation GUI

In the New simulation window select New Simulation ▷ Non-Terrestrial Networks

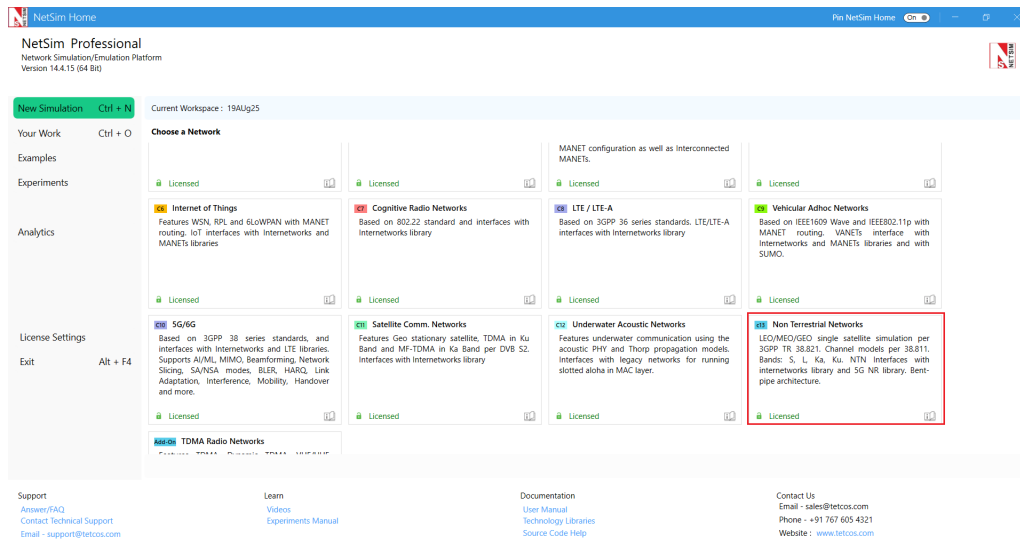


Figure 1-5: NTN in New simulation window.

### 1.4.1 Configure Non-Terrestrial Networks

Users can choose how the beam parameters can be configured.

- Standard Setup: Allows you to create a scenario with predefined parameters based on 3GPP standards.
- Custom Excel/CSV File: Allows you to define the beam configuration in your own Excel or CSV file.
- Manual Placement: Allows you to manually place devices and beams. In this mode, no devices are automatically placed.

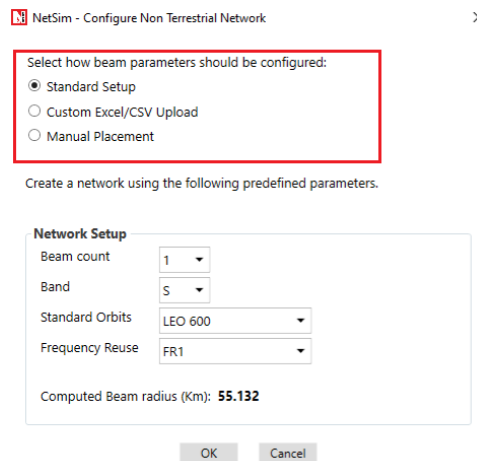
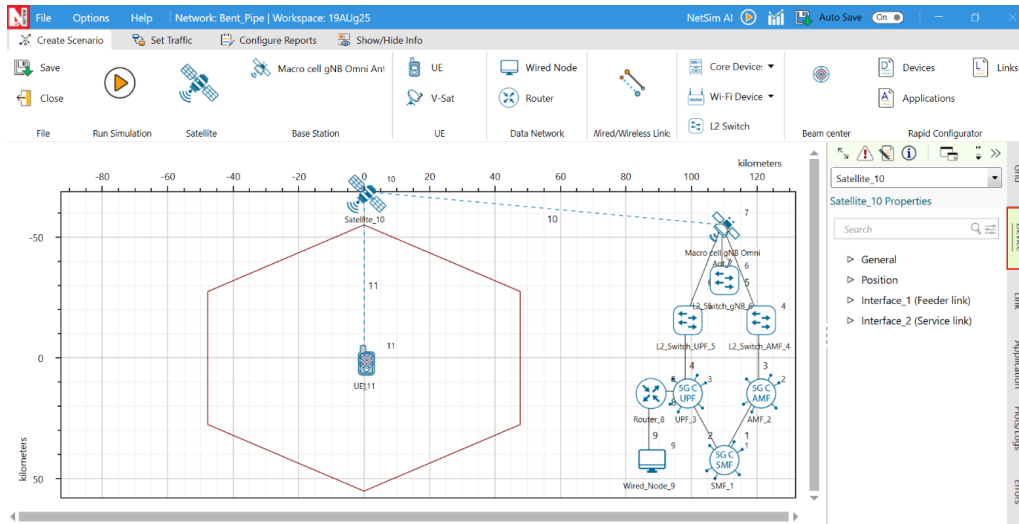


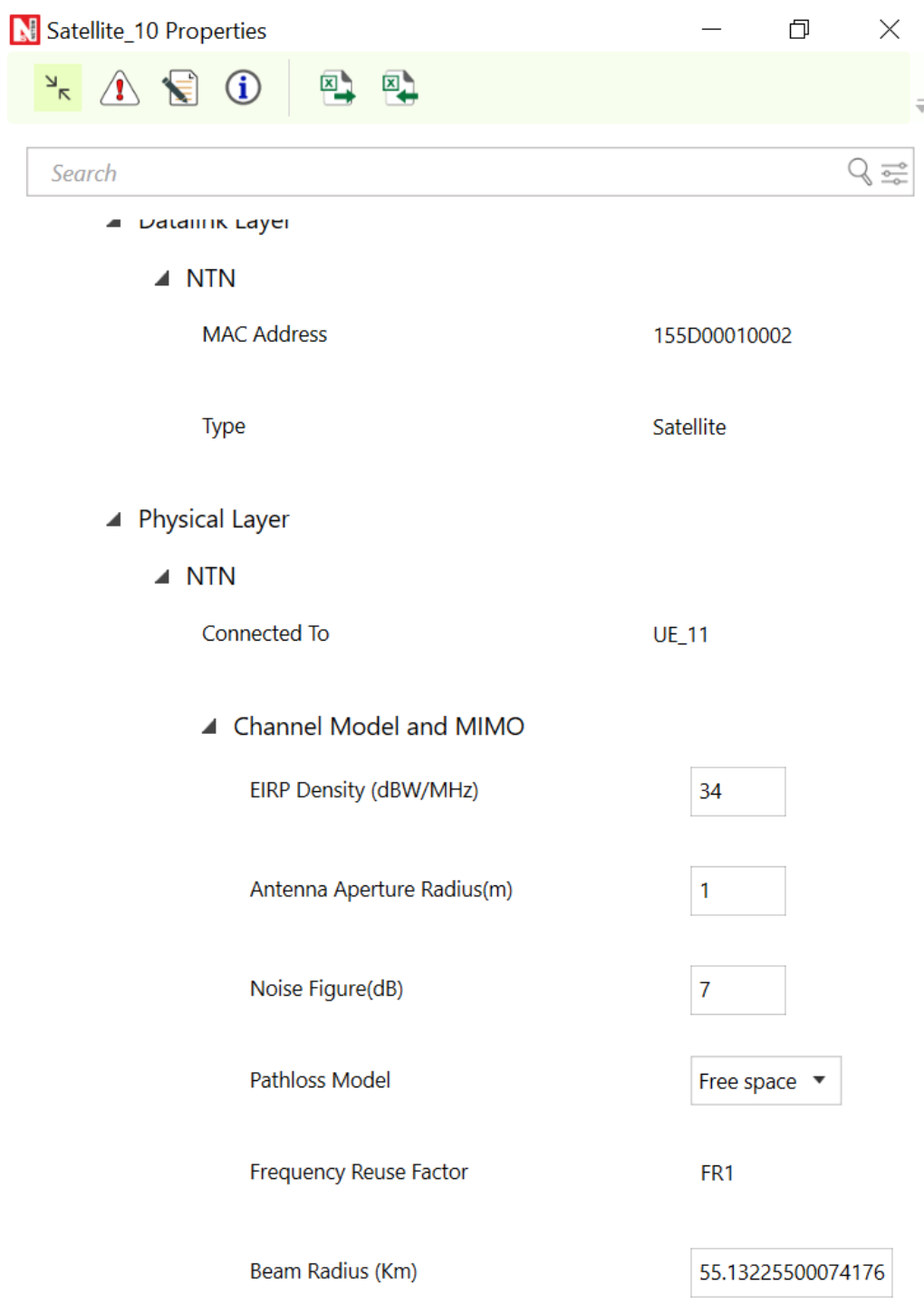
Figure 1-6: Configuring the Non-Terrestrial Network.

### 1.4.2 Set device properties



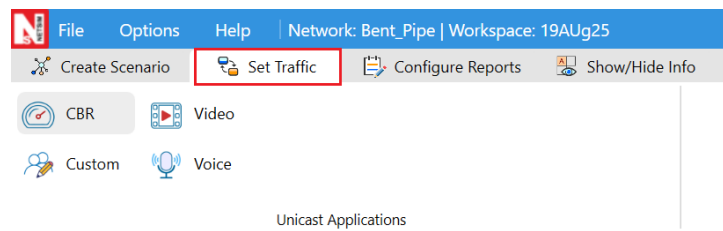
**Figure 1-7:** Network scenario created using Standard set up.

The following are main properties of Satellite device in PHY and MAC layer. To configure any properties in device, click on the device, expand the property panel on change the properties.



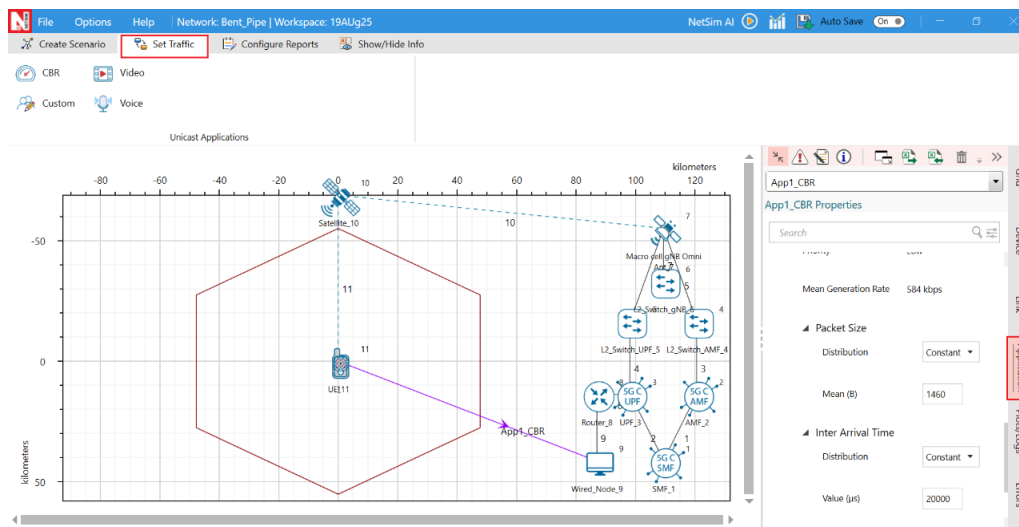
**Figure 1-8:** PHY layer properties of Satellite (Feeder link).

Configure an application by clicking on set traffic tab on top ribbon.



**Figure 1-9:** Set traffic tab from top ribbon.

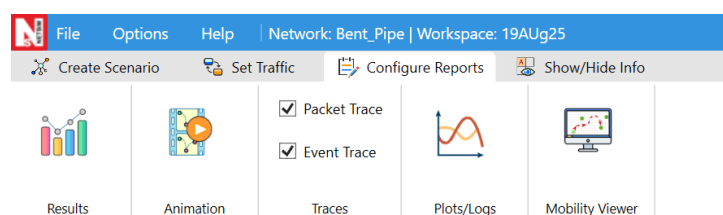
Application settings can be modified from Application properties tab on right panel.



**Figure 1-10:** Application settings from right panel.

### 1.4.3 Configure reports

Check Packet Trace / Event Trace option from the Configure Reports tab. To get detailed help, please refer to sections 8.4 and 8.5 in User Manual.



**Figure 1-11:** Enabling Packet trace and Event trace from Configure reports tab.

Enable protocol-specific logs such as NTN Radio Measurement Logs, NTN UE Beam Association Logs, NTN Resource Allocation Logs, and others. Additionally, view NTN Radio Measurement plots such as MCS Index vs Time, Shadow Fading Loss vs Time, SNR vs Time, Total Loss vs Time, and more.

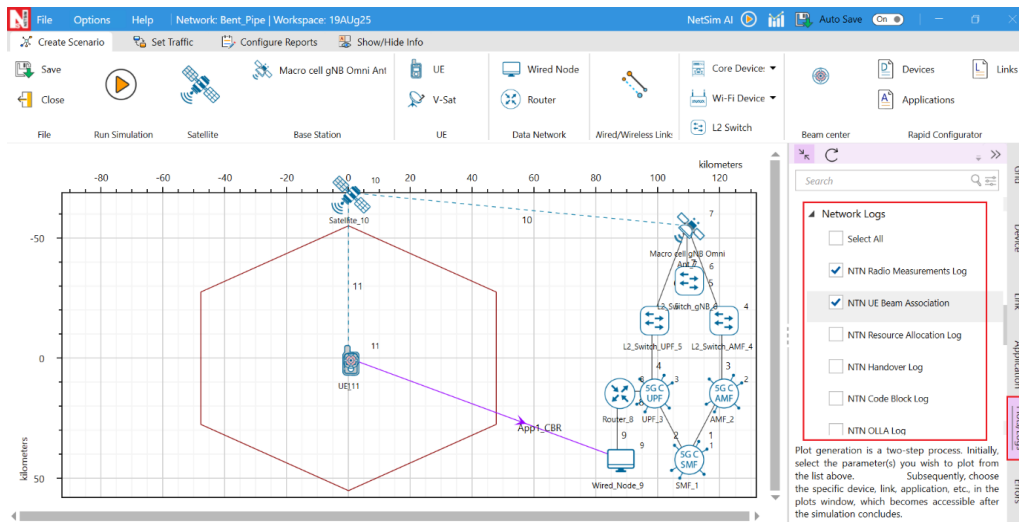


Figure 1-12: Enable NTN Radio Measurements logs.

### 1.4.4 GUI Parameters

Table 1-6: GUI configuration parameters.

Parameter	Type	Range	Description
<b>Interface (Feeder link) – Physical Layer</b>			
Frame Duration (ms)	Fixed	10ms	The length of the frame in milliseconds. The FRAME DURATION is a non-editable parameter whose value is fixed at 10 ms.
Sub Frame Duration (ms)	Fixed	1ms	The length of the frame in milliseconds. The SUBFRAME DURATION is a non-editable parameter whose value is fixed at 1 ms.
Subcarrier Number Per PRB	Fixed	12	The number of Subcarriers per PRB is a non-editable parameter whose value is fixed at 12.
Duplex Mode	Local	FDD	Frequency Division Duplexing: There are different frequency bands for UL and for DL. Hence UL and DL transmissions can occur simultaneously. As per 3GPP document, NetSim supports FDD bands and various CA configurations and Operating bands, FR1 and FR2 are available.
CA Type	Local	SINGLE_BAND	The single band drop-down options are per TS 38.101-5.
CA Configuration	Local	Depends on CA Type	The drop shows the frequency band options for the user to choose from.
CA Count	Fixed	Depends on CA Type and CA Configurations	This is a non-editable parameter that shows the number of component carriers based on the CA configuration. CA count would be 1 for Single Band configuration.

*Continued on next page*

Parameter	Type	Range	Description
<b>NOTE:</b> For detailed information to Frequency Range (FR1 & FR2), Please, refer PHY Layer			
Slot Type	Local	Downlink, Uplink	Slot type can be Uplink, or Downlink. Uplink: In uplink slot type, there are only uplink slots, and the DL:UL ratio will be fixed by NetSim as 0:1. Downlink: In downlink slot type, there are only downlink slots and the DL:UL ratio will be fixed by NetSim as 1:0.
Frequency Range	Local	FR1 & FR2	The frequency bands for NTN is separated into two frequency ranges. First, is Frequency Range 1 (FR1) which includes sub-6 GHz frequency bands. The other is Frequency Range 2 (FR2) which includes frequency bands in the mmWave range. FR1: 1525 MHz – 2500 MHz. FR2: 17300 MHz – 30000 MHz. NetSim supports both FR1 and FR2. This is a non-editable parameter shown by NetSim based on the CA configuration chosen by the user.
DL/UL Ratio	Local	a:b	Represents the ratio in which slots are assigned to downlink and uplink transmissions. The value is in the form of a:b::DL:UL. Note that the ratio 1:0 or 0:1 might lead to NIL data transmissions since the initial attachment procedures require both UL and DL control packet transmissions.
Operating Band	Fixed	n254 n255, n256, n510, n511, n512	The operating band whose numbering is defined by 3GPP. This is a non-editable parameter (except for custom band) that is shown by NetSim based on the CA configuration chosen by the user.
F Low (MHz)	Fixed	1525–28350 MHz	The lowest frequency of the Uplink/Downlink operating band. This is a non-editable parameter (except for custom band) shown by NetSim based on the CA configuration chosen by the user.
F High (MHz)	Fixed	1559–30000 MHz	The highest frequency of the Uplink/Downlink operating band. This is a non-editable parameter shown by NetSim based on the CA configuration chosen by the user.

*Continued on next page*

Parameter	Type	Range	Description
Numerology	Local	$\mu = 0, 1, 2, 3$	Sub carrier spacing is derived from numerology per the expression $\Delta f = 2^\mu \times 15 \text{ kHz}$ . Thus, Numerology = 0 means subcarrier spacing 15 kHz. Numerology = 1 means subcarrier spacing 30 kHz. Numerology = 2 means subcarrier spacing 60 kHz. Numerology = 3 means subcarrier spacing 120 kHz.
Channel Bandwidth (MHz)	Local	5–400 MHz	The bandwidth can vary from 5 MHz to 30 MHz for bands in FR1 frequency range and 50 MHz to 400 MHz for bands in FR2 frequency range. Unit is MHz.
PRB Count	Local		PRB stands for physical resource block. The PRB count is dependent on Channel Bandwidth and automatically determined by NetSim. It cannot be edited in the GUI.
Guard Band (KHz)	Local	0, Standard Table (242.5–9860 kHz)	Guard band is the unused part of the radio spectrum between radio bands, for the purpose of preventing interference. The minimum guard bands are calculated using the following equation: $(BW_{Channel} \times 1000 \text{ (kHz)} - N_{RB} \times SCS \times 12)/2 - SCS/2$ . Unit is kHz.
Subcarrier Spacing	Local	15 – 120 kHz	In 5G NR, subcarrier spacing of 15, 30, 60, 120 kHz are supported. Subcarrier spacing = 15 kHz ( $\mu = 0$ ) Subcarrier spacing = 30 kHz ( $\mu = 1$ ) Subcarrier spacing = 60 kHz ( $\mu = 2$ ) Subcarrier spacing = 120 kHz ( $\mu = 3$ )
Bandwidth PRB	Local	180 – 1440 kHz	The PRB bandwidth is dependent on numerology ( $\mu$ ) as shown below. <i>Unit = kHz</i> . Bandwidth= 180 kHz ( $\mu = 0$ ) Bandwidth= 360 kHz ( $\mu = 1$ ) Bandwidth= 720 kHz ( $\mu = 2$ ) Bandwidth= 1440 kHz ( $\mu = 3$ )
Slot per Frame	Local	10, 20, 40, 80	This represents the number of slots in a frame and is a non-editable parameter. NetSim determines the slots per frame, based on the selected numerology, in the following way: When $\mu = 0$ , a subframe has only one slot, and frame has 10 slots. When $\mu = 1$ , a subframe has 2 slots, and a radio frame has 20 slots. When $\mu = 2$ , a subframe has 4 slots in it, meaning a radio frame contains 40 slots. When $\mu = 3$ , a subframe has 8 slots in it, meaning a radio frame contains 80 slots.

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Parameter	Type	Range	Description
Slot per Subframe	Local	1, 2, 4, 8	This represents the number of slots in a sub-frame and is a non-editable parameter. NetSim determines the slots per sub-frame, based on the selected numerology, in the following way: When $\mu=0$ , a subframe has only one slot. When $\mu=1$ , a subframe has 2 slots. When $\mu=2$ , a subframe has 4 slots. When $\mu=3$ , a subframe has 8 slots.
Slot Duration ( $\mu\text{s}$ )	Local	1000, 500, 250, 125 $\mu\text{s}$	Slot duration is a non-editable parameter that depends on numerology selected. $\mu=0$ , Slot Duration = 1000 $\mu\text{s}$ . $\mu=1$ , Slot Duration = 500 $\mu\text{s}$ . $\mu=2$ , Slot Duration = 250 $\mu\text{s}$ . $\mu=3$ , Slot Duration = 125 $\mu\text{s}$ .
Cyclic Prefix	Local	Normal	If the cyclic prefix is set to “normal” then the number of symbols per slot is 14, if it is set to “extended” then the number of symbols per slot is 12. All carriers have the “normal” option while only certain carriers have the “extended” option.

**NOTE:** Cyclic Prefix is Extended only for few CA types.

Overhead (%) per DL slot	Local	0.01–0.99	This represents the fraction of symbols in a slot used for control signalling. The remaining fraction is used for data transmission. In NetSim calculations are done over aggregated PRBs per the formula given below: Data PRB available = Total PRB available – Ceil(Total PRB available $\times$ Overhead Fraction) DL Fraction range 0.01 to 0.99. Default: 0.14 for FR1, 0.18 for FR2.
Overhead (%) per UL slot	Local	0.01–0.99	This represents the fraction of symbols in a slot used for control signalling. The remaining fraction is used for data transmission. In NetSim calculations are done over aggregated PRBs per the formula given below: Data PRB available = Total PRB available – Ceil(Total PRB available $\times$ Overhead Fraction) UL Fraction range 0.01 to 0.99. Default: 0.08 for FR1, 0.10 for FR2. In 4G Network the default value is 0.25 for both FR1 and FR2.

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Parameter	Type	Range	Description
Symbol Duration ( $\mu$ s)	Local	71.43, 35.71, 17.86, 8.93	Symbol duration is a non-editable parameter that depends on the numerology selected. When $\mu = 0$ , symbol duration = 71.43 $\mu$ s. When $\mu = 1$ , symbol duration = 35.71 $\mu$ s. When $\mu = 2$ , symbol duration = 17.86 $\mu$ s. When $\mu = 3$ , symbol duration = 8.93 $\mu$ s.
<b>Antenna</b>			
TX Antenna Count	Local	1	The number of transmit antennas.
RX Antenna Count	Local	1	The number of receive antennas.
<b>PDSCH CONFIG</b>			
MCS Table	Local	QAM64, QAM256, QAM64LOWSE	MCS Table stands for modulation and coding scheme Table. The selection options are QAM64, QAM 256, and QAM64LOWSE. We recommend users set the same MCS table for PDSCH and PUSCH. The appropriate CQI table setting would be as follows: For QAM64 – Table1. For QAM256 – Table 2. For QAM64LOWSE – Table 3.
X Overhead	Local	XOH0, XOH6, XOH12, XOH18	Accounts for overhead from CSI-RS, CORESET, etc. If the xOverhead in PDSCH-ServingCellconfig is not configured (a value from 0, 6, 12, or 18), $N_{oh}^{PRB}$ is set to 0.
<b>PUSCH CONFIG</b>			
MCS Table	Local	QAM64, QAM256, QAM64LOWSE	MCS Table stands for modulation and coding scheme Table. The selection options are QAM64, QAM 256, and QAM64LOWSE. We recommend users set the same MCS table for PDSCH and PUSCH. The appropriate CQI table setting would be as follows: For QAM64 – Table1. For QAM256 – Table 2. For QAM64LOWSE – Table 3.
Transform Precoding	Local	Enable/Disable	Transform Precoding is the first step to create DFT-s-OFDM waveform. Transform Precoding is to spread UL data in a special way to reduce PAPR (Peak-to-Average Power Ratio) of the waveform. In terms of mathematics, Transform Precoding is just a form of DFT(Digital Fourier Transform).
<b>CSI REPORT CONFIG</b>			

*Continued on next page*

Parameter	Type	Range	Description
CQI Table	Local	Table1, Table2, Table3	The CQI indices and their interpretations are chosen from Table 1 or Table 3 for reporting CQI based on QPSK, 16QAM, and 64QAM. The CQI indices and their interpretations are chosen from Table 2 for reporting CQI based on QPSK, 16QAM, 64QAM and 256QAM. This is based on 3GPP Table 5.2.2.1-2, Table 1, Table 2 and Table 3. Users must set the MCS and CQI tables in the following combination: QAM64: CQI Table 1. QAM 256: CQI Table 2. QAM 64 LOWSE: CQI Table 3.

### CHANNEL MODEL

Pathloss Model	Local	None	In the current NTN implementation, only None is available. This is because the satellite-to-gNB link is a perfect link. It is assumed that the signal reaches the gNB without experiencing any degradation due to pathloss.
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### ERROR MODEL AND MCS SELECTION

MCS Selection Model	Global	IDEAL_SHANNON_THEOREM_BASED_RATE, SHANNON_RATE_WITH_ATTENUATION_FACTOR	NetSim determines the modulation and coding scheme in 5G and LTE, based on received SINR, per the following models: Ideal Shannon Theorem-Based Rate: Spectral Efficiency is computed as $Spectral\ Efficiency = \log(1 + SINR)$ Shannon Rate with Attenuation Factor ( $\alpha$ ): Spectral Efficiency is computed as $Spectral\ Efficiency = \alpha \times \log(1 + SINR)$ Then the 3GPP standards Spectral Efficiency vs MCS Table is looked up to select the MCS. This could be the 64QAM table, 256 QAM table, or the 64QAM-LOWSE table depending on what was chosen by the user.
Attenuation Factor	Global	0.5–1	Attenuation factor ( $\alpha$ ) takes value between 0.5 and 1 with the default value of 0.75.

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Parameter	Type	Range	Description
BLER Model	Global	ZERO_BLER, BLER_ENABLE	Block Error Rate Model (BLER) is used to decide code block and transport block error in 5G and LTE. If set to true then NetSim looks up the SINR-CBS-MCS vs. BLER tables to decide on the code block errors rate for the chosen MCS. Here MCS will be chosen as explained in the MCS selection section. If OLLA is enabled then MCS bump up/down will be based on HARQ ACKs/NACKs. <b>Note:</b> In NTN scenarios, BLER is always set to ZERO_BLER by default and should remain so, since HARQ re-transmissions are disabled. Enabling BLER without HARQ would cause errored blocks to be dropped with no recovery.
Outer loop link adaptation	Global	TRUE, FALSE	The Outer Loop Link Adaptation (OLLA) technique, if enabled, can improve the channel quality estimation by adjusting the value of SINR by an offset dependent on whether previous transmissions were decoded successfully or not, as captured by Hybrid Automatic Repeat Request (HARQ) feedback.
Target BLER	Global	0–1	The OLLA algorithm in NetSim is designed to converge the transport BLER to the set value of the target BLER. Range: 0 to 1.

## UE Properties

### Interface (Service link) – Physical Layer

TX Antenna Count	Local	1	The number of transmit antennas.
RX Antenna Count	Local	1	The number of receive antennas.
TX Power (dBm)	Local	23	UE total transmit power for the uplink EIRP computation. Default is 23 dBm (Power Class 3 handheld UE). $EIRP_{UE} = P_{Tx,UE} + G_{UE,Tx}$ .
Tx/Rx Antenna Gain (dB)	Local	0	UE Tx/Rx antenna gain in dBi. For omnidirectional handheld UEs this is 0 dBi. Used together with TX Power to compute the uplink EIRP. Additionally used as Rx Antenna Gain in the downlink G/T computation for the UE receiver.
UE Noise Figure (dB)	Local	7	UE receiver noise figure in dB. Used in the downlink G/T computation for the UE receiver.

## NTN Logs

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Parameter	Type	Range	Description
NTN UE Beam Association Log	Global	Enable or Disable	The NTN UE Beam Association log file records Time, UE Pos, Elevation Angle, Slant height, Theta, EIRP, PathLoss, ShadowLoss, Additional Loss, Clutter Loss, Angular Antenna Gain, Rx Power, Interference Power, SNR, SINR, CQI, MCS Index, Associated Beam flag, measurements are logged at association and at UE mobility.
NTN Radio Measurements Log	Global	Enable or Disable	The NTN Radio measurements csv log file records Timestamp, Slant height, Elevation Angle, EIRP, PathLoss, ShadowFadingLoss, AdditionalLoss, ClutterLoss, TotalLoss, BeamFormingGain, Angular Antenna Gain, UE Rx Antenna Gain, Rx Power, SNR, SINR, and more, for each carrier on the PDSCH, and are logged every sub-frame.
NTN Resource Allocation Log	Global	Enable or Disable	The NTN Radio Resource Allocation csv log file records information related to physical resource block (PRB) allocation such as the Total PRBs, Slot Start Time(ms), Slot End, BitsPerPRB, BufferFill, Allocated PRBs, Rank (scheduling metric) and more, in the DL and in the UL. All these parameters are written in every slot.
NTN Code Block Log	Global	Enable or Disable	Records parameters associated with Code Block segmentation such as Process ID, TB size, Modulation, Code Rate, CBS, BLER, CBG ID, etc. along with remarks on events associated with HARQ and PRB allocation. This will be useful to understand BLER model and Code Block segmentation in 5G.

### Satellite Properties > Service link

#### CHANNEL MODEL

EIRP Density (dBW/MHz)	Local	Editable based on band and satellite height	Editable based on the frequency band and satellite altitude. This parameter defines the effective isotropic radiated power per unit bandwidth.
Antenna Aperture Radius (m)	Local	Editable based on frequency band and satellite altitude	Editable based on the band and the scenario. For the standard scenarios, a pre-calculated value is provided. The aperture radius determines the beamwidth and, in turn, the beam radius on the Earth's surface.
Noise Figure (dB)	Local	0.1 to 12 dB	Represents the satellite receiver's internal noise contribution. A lower noise figure indicates a more sensitive receiver capable of detecting weaker signals. Used in the uplink satellite G/T computation.

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Parameter	Type	Range	Description
Max Antenna Gain (dB)	Local	30	Peak antenna gain of the satellite in dBi. Used in the uplink satellite G/T computation: $G/T _{sat} = G_{sat,abs}(\theta) - 10 \log_{10}(T_{sys}) - NF_{sat}$ , where $G_{sat,abs}(\theta) = G_{max} + G_{rel}(\theta)$ .
Satellite Rx Antenna Temperature (K)	Local	290	System noise temperature of the satellite receiver in Kelvin. Used in the uplink satellite G/T computation. LEO satellites may have 150–600 K depending on antenna pointing direction.
Frequency Reuse Factor	Local	FR1, FR3	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	Editable based on band and scenario	The beam radius is calculated based on the frequency band, satellite altitude, and aperture radius for the selected scenario, and is defined at the point where the beam power drops to half of its maximum value (i.e., 3 dB beamwidth).
Beam Count	Local	1, 7, 19	Refers to the number of beams formed in the coverage area. A single central beam corresponds to 1. The 7-beam configuration includes one central beam surrounded by a single hexagonal ring, while the 19-beam configuration includes the central beam with two hexagonal layers of surrounding beams.
Pathloss Model	Local	Free Space	NetSim computes signal attenuation per the mean pathloss model. The option available is Free space.
Outdoor Scenario	Local	Rural, Urban, Dense Urban	There are three types of outdoor scenarios possible namely: Rural, Urban, and Dense Urban, as defined in the 3GPP TR38.811 standard section 6.1.2. The propagation characteristics of these scenarios are provided in the NTN Technology library manual.
LOS/NLOS Selection	Fixed	3GPP TR38.811, USER DEFINED	3GPP TR38.811-Table 6.6.1-1: The LOS mode, either Line-of-sight or Non-Line-of-sight is based on LOS probability calculated per the TR 38.811 Standard Table 6.6.1-1. User Defined: LOS probability is not per standard but is based on user input. NetSim will determine whether a device is in line-of-sight or non-line-of-sight based on the LOS probability value set by the user.

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Parameter	Type	Range	Description
LOS Probability	Local	0 to 1	LOS Probability defines the LOS mode. If LOS Probability=1, the LOS mode is set to Line-of-Sight explicitly and if the LOS Probability=0, the LOS mode is set to Non-Line-of-Sight explicitly. For any value between 0–1, LOS mode is set per the given probability, by tossing a biased coin.
Fading and Beamforming	Local	NO FADING MIMO UNIT GAIN, RAYLEIGH WITH EIGEN BEAMFORMING	RAYLEIGH WITH EIGEN BEAMFORMING: When fading and beamforming is enabled, NetSim uses the rich scattering in the channel to form spatial channels. The number of spatial channels is equal to the number of layers (in turn equal to $Min(N_t, N_r)$ ). The beamforming gains in the spatial channel is equal to the eigen values of the channel covariance (Wishart) matrix. When running in SISO ( $N_t = N_r = 1$ ) this simply simulates Rayleigh fading. NO FADING MIMO UNIT GAIN: No fading with gain equal to unity (0 dB).
Additional Loss Model	Local	0 to 10 dB	Additional loss can be set from 0 to 10 dB to account for atmospheric and scintillation losses as per the configured scenario.
Shadowing Model	Local	None, Log Normal	Constant: A shadowing model is used to represent the signal attenuation caused by obstructions along the propagation path. The constant shadowing model is suitable for the scenarios without mobility where the obstructions along the propagation paths remain unchanged. Log Normal: The lognormal shadowing model is suitable for a scenario with mobility and obstructions within the propagation environment. In this model, the shadowing value follows a log-normal distribution with a user specified standard deviation.
Standard Deviation Selection (dB)	Local	User Defined (5 to 12 dB), 3GPPTR38.811	Shadowing is caused mainly by terrain features of the radio propagation environment. The mathematical model for shadowing is a log-normal distribution. The standard deviation can be selected from the 3GPPTR38.811 Table 6.6.2, based on the elevation angle and the chosen outdoor scenario. User Defined: users can specify the standard deviation values in the range of 5 to 12 dB.

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## INTERFERENCE MODEL

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Parameter	Type	Range	Description
Downlink Interference Model	Global	None, CIR Based, Exact geometric model	DL interference options are No interference, CIR Based, and Exact geometric model. If no interference is chosen then in the SINR calculations, the value of I is set to $-1000$ . CIR Based, the User enters Carrier-to-Interference ratio, that value is used to calculate the interference. (CIR Ratio: $-20$ to $20$ dB). Geometric models compute the exact interference.
Uplink Interference Model	Global	None, CIR Based	UL interference options. If None, interference is not considered in the uplink SINR calculation. If CIR Based, the user-specified UL C/I ratio is used to compute uplink interference.
UL C/I Ratio (dB)	Global	$-20$ to $20$	Carrier-to-Interference ratio for the uplink, used when the UL interference model is set to CIR Based. Default: $20$ dB.

#### UL SCHEDULING

UL Scheduling Type	Fixed	Configured Grant	Read-only. In NTN scenarios, the uplink uses Configured Grant Type 1 scheduling. The gNB pre-allocates periodic UL resources to each UE via cyclic round-robin, eliminating per-transmission grant signaling.
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#### 1.4.5 Mobility model in NTN

Satellite and UE devices support file-based mobility in NTN.

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 UE. Then properties  $\triangleright$  Position Properties  $\triangleright$  Mobility model as File Based Mobility and click on Open Mobility file.

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

```
<TIME IN SECONDS>,<DEVICE ID>Lat(deg),Lon(deg),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 1-13:** *Mobility.csv file with inputs added via MS Excel.*

## 2 Link budget

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

$$CNR = EIRP + Rx \frac{G}{T} - k - PL_{FS} - PL_A - PL_{SM} - PL_{SL} - PL_{AD} - B \quad (2)$$

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

$PL_A$  is the atmospheric path loss due to gases

$PL_{SM}$  is the shadowing margin in dB

$PL_{SL}$  is the scintillation loss 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

$$Rx \frac{G}{T} = G_{rx} - N_f - 10 \log_{10}(T_0 + (T_a - T_0) \times 10^{-0.1 \times N_f}) \quad (3)$$

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.

The  $CNR$  expression is used in both directions i.e., terrestrial to satellite and satellite to terrestrial. The expressions below provide the formula for  $EIRP$  if the input is provided as  $EIRPDensity$  [dBW/MHz]

$$EIRP \text{ [dBW]} = EIRPDensity \text{ [dBW/MHz]} + 10 \log_{10}(BW \text{ [MHz]}) \quad (4)$$

## 2.1 Uplink Link Budget

The uplink link budget computes the signal quality from the UE to the satellite. Per 3GPP TR 38.821 Table 6.1.2, the uplink carrier-to-noise ratio is given by

$$\left(\frac{C}{N}\right)_{UL} = EIRP_{UE} + \frac{G}{T}\Big|_{sat}(\theta) - 10 \log_{10}(k) - 10 \log_{10}(B_{Hz}) - L_{total} \quad (5)$$

where:

$EIRP_{UE} = P_{Tx,UE} + G_{UE,Tx}$  is the UE effective isotropic radiated power in dBW.  $P_{Tx,UE}$  is the UE transmit power (total power, not a density) and  $G_{UE,Tx}$  is the UE transmit antenna gain in dBi.

$G/T|_{sat}(\theta) = G_{sat,abs}(\theta) - 10 \log_{10}(T_{sys,sat}) - NF_{sat}$  is the satellite receiver gain-to-noise temperature in dB/K, where  $G_{sat,abs}(\theta) = G_{max} + G_{rel}(\theta)$  is the absolute satellite antenna gain at off-boresight angle  $\theta$ .

$B_{Hz}$  is the channel bandwidth in Hz.

$L_{total}$  is the total path loss (free-space path loss + shadow fading + clutter + additional losses) in dB, computed identically to the downlink.

The key differences between the downlink and uplink link budgets are summarized below.

Parameter	Downlink	Uplink
Transmitter	Satellite	UE
Receiver	UE	Satellite
EIRP type	Density (dBW/MHz)	Total (dBm)
Whose G/T?	UE G/T	Satellite G/T
Bandwidth in SNR	Cancels out	Remains

A key distinction is that the satellite EIRP is specified as a *density* (dBW/MHz), so the bandwidth term cancels when computing DL SNR. In contrast, the UE EIRP is a *total* power (dBm), so the UL SNR depends explicitly on the channel bandwidth.

**Example 1:** Link budget for UE at Nadir Point; No interference; 2GHz S Band.

**Table 2-1:** Simulation Parameters and Link Budget Calculation for LEO Satellite Communication at 600 km and 1200 km Altitudes. UE at Nadir Point; No interference. Calculations are explained in section 2.1.

Simulation Parameters	LEO 600km	LEO 1200km
Satellite coordinates (x, y, z) (User Input)	0, 0, 600	0, 0, 1200
UE coordinates (x, y, z) (User Input)	0, 0, 0	0, 0, 0
Frequency (User Input)	S-Band, n256	S-Band, n256

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Simulation Parameters	LEO 600km	LEO 1200km
Terrestrial environment (User Input. Default based on sec 6.1.1.3 of 38.821)	Rural	Rural
LOS probability (User Input. Per LOS probability in 3GPP TR 38.811 sec 6.6.1)	1	1
Antenna Aperture Radius(m) (User Input. Default based on Table 6.1.1.1-2 of 38.821)	1	1
EIRP density (dBW/MHz) (User Input. Default based on Table 6.1.1.1-1 of 38.821)	34	40
Bandwidth B (User Input. Default based on Table 6.1.3.2-1 of 38.821)	30	30
EIRP (dBW) $= EIRP[dBW/MHz] + 10 \log_{10} B[MHz]$ . Per TR 38.821 section 6.1.3.1-5	48.77	54.77
Elevation angle (Per Elevation angle formulas provided in 3GPP TR 38.811 sec 6.6.2)	90	90
Angular Antenna Gain $G(\theta)$ , (dB) (Per Bessel function formulas provided in 3GPP TR 38.811 sec 6.4.1)	0	0
Slant range $d$ (Km) (Per slant height formulas provided in 3GPP T1 38.811 sec 6.6.2)	600	1200
Free space pathloss (dB), $PL_{FS}$ (Per Free space pathloss formulas provided in 3GPP TR 38.811 sec 6.6.2)	154.8	160.82
Shadow loss (dB), $PL_{SM}$ (Per Shadow loss formulas provided in 3GPP TR 38.811 sec 6.6.2)	0.39	0.39
Additional Loss(dB), $PL_{AD}$ (User Input. Default based on Table 6.1.3.2-1 of 38.821)	0	0
Total Pathloss, L (dB) $L = PL_{FS} + PL_{SM} + PL_{AD}$	155.19	161.21
Rx Antenna Gain (User Input. Default based on Table 6.1.1.1-3 of 38.821)	0	0
Noise figure $N_f$ (User Input. Default based on Table 6.1.1.1-3 of 38.821)	7	7
Rx Antenna Temp $T_a$ (K) (User Input. Default based on Table 6.1.1.1-3 of 38.821)	290	290
RX equivalent antenna Temp, $T$ [dBK] (Per TR 38.821 section 6.1.3.1)	31.62	31.62
Receiver G/T (dB/K) (Per RX G/T formulas provided in 3GPP TR 38.821 sec 6.1.3.1)	-31.62	-31.62

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Simulation Parameters	LEO 600km	LEO 1200km
Boltzmann constant $k$ [dBW/K/Hz]	-228.6	-228.6
<b>Carrier to Noise Ratio, CNR (dB)</b> (Per CNR formulas provided in 3GPP TR 38.821 sec 6.1.3.1)	<b>15.78</b>	<b>15.76</b>

**Example 2:** Link budget for UE at Off Nadir Point; No interference; 2GHz S Band.

**Table 2-2:** Simulation Parameters and Link Budget Calculation for LEO Satellite Communication at 600 km and 1200 km Altitudes. UE at Off Nadir Point; No interference. Calculations are explained in section 3.1.

Simulation Parameters	LEO 600km	LEO 1200km
Satellite coordinates (x, y, z) (User Input)	0, 0, 600	0, 0, 1200
UE coordinates (x, y, z) (User Input)	17,18, 0	64,34, 0
Frequency (User Input)	S-Band, n256	S-Band, n256
Terrestrial environment (User Input. Default based on sec 6.1.1.3 of 38.821)	Rural	Rural
LOS probability (User Input. Per LOS probability in 3GPP TR 38.811 sec 6.6.1)	1	1
Antenna Aperture Radius(m) (User Input. Default based on Table 6.1.1.1-2 of 38.821)	1	1
EIRP density (dBW/MHz) (User Input. Default based on Table 6.1.1.1-1 of 38.821)	34	40
Bandwidth B (User Input. Default based on Table 6.1.3.2-1 of 38.821)	30	30
EIRP (dBW) $= EIRP[dBW/MHz] + 10 \log_{10} B[MHz]$ . Per TR 38.821 section 6.1.3.1-5	48.77	54.77
Elevation angle (Per Elevation angle formulas provided in 3GPP TR 38.811 sec 6.6.2)	87.64	86.54
Angular Antenna Gain $G(\theta)$ , (dB) (Per Bessel function formulas provided in 3GPP TR 38.811 sec 6.4.1)	-4.2	-10.26
Slant range $d$ (Km) (Per slant height formulas provided in 3GPP TR 38.811 sec 6.6.2)	600.51	1202.19
Free space pathloss (dB), $PL_{FS}$ (Per Free space pathloss formulas provided in 3GPP TR 38.811 sec 6.6.2)	154.81	160.84
Shadow loss (dB), $PL_{SM}$ (Per shadow loss formulas provided in 3GPP TR 38.811 sec 6.6.2)	0.39	0.39
Additional Loss(dB), $PL_{AD}$ (User Input. Default based on Table 6.1.3.2-1 of 38.821)	0	0

*Continued on next page*

Simulation Parameters	LEO 600km	LEO 1200km
Total Pathloss, L (dB) $L = PL_{FS} + PL_{SM} + PL_{AD}$	155.20	161.23
Rx Antenna Gain (User Input. Default based on Table 6.1.1.1-3 of 38.821)	0	0
Noise figure $N_f$ (User Input. Default based on Table 6.1.1.1-3 of 38.821)	7	7
Rx Antenna Temp $T_a$ (K) (User Input. Default based on Table 6.1.1.1-3 of 38.821)	290	290
RX equivalent antenna Temp, $T$ [dBK] (Per TR 38.821 section 6.1.3.1)	31.62	31.62
Receiver G/T (dB/K) (Per RX G/T formulas provided in 3GPP TR 38.821 sec 6.1.3.1)	-31.62	-31.62
Boltzmann constant $k$ [dBW/K/Hz]	-228.6	-228.6
<b>Carrier to Noise Ratio, CNR (dB)</b> <b>(Per CNR formulas provided in 3GPP TR 38.821 sec 6.1.3.1)</b>	<b>11.58</b>	<b>5.49</b>

**Example 3:** Link budget with UE at Off Nadir Point with Interference; 2GHz S Band.

The calculations proceed exactly per Example 2 up to CNR. Once CNR is computed, interference is added and to obtain CNIR.

**Table 2-3:** Simulation Parameters and Link Budget Calculation for LEO Satellite Communication at 600 km and 1200 km Altitudes. UE at Off Nadir Point with Interference. Interference calculations are provided in section 4.2.

Simulation Parameters	LEO 600km	LEO 1200km
Satellite coordinates (x, y, z) (User Input)	0, 0, 600	0, 0, 1200
UE coordinates (x, y, z) (User Input)	17,18, 0	64,34, 0
Frequency (User Input)	S-Band, n256	S-Band, n256
Terrestrial environment (User Input. Default based on sec 6.1.1.3 of 38.821)	Rural	Rural
LOS probability (User Input. Per LOS probability provided in 3GPP TR 38.811 sec 6.6.1)	1	1
Antenna Aperture Radius(m) (User Input. Default based on Table 6.1.1.1-2 of 38.821)	1	1
EIRP density (dBW/MHz) (User Input. Default based on Table 6.1.1.1-1 of 38.821)	34	40
Bandwidth B (User Input. Default based on Table 6.1.3.2-1 of 38.821)	30	30

*Continued on next page*

Simulation Parameters	LEO 600km	LEO 1200km
EIRP (dBW) = $EIRP[dBW/MHz] + 10 \log_{10} B[MHz]$ . Per TR 38.821 section 6.1.3.1-5	48.77	54.77
Elevation angle (Per Elevation angle formulas provided in 3GPP TR 38.811 sec 6.6.2)	87.64	86.54
Angular Antenna Gain $G(\theta)$ , (dB) (Per Bessel function formulas provided in 3GPP TR 38.811 sec 6.4.1)	-4.2	-10.26
Slant range $d$ (Km) (Per slant height formulas provided in 3GPP TR 38.811 sec 6.6.2)	600.51	1202.19
Free space pathloss (dB), $PL_{FS}$ (Per Free space pathloss formulas provided in 3GPP TR 38.811 sec 6.6.2)	154.81	160.84
Shadow loss (dB), $PL_{SM}$ (Per shadow loss formulas provided in 3GPP TR 38.811 sec 6.6.2)	0.39	0.39
Additional Loss(dB), $PL_{AD}$ (User Input. Default based on Table 6.1.3.2-1 of 38.821)	0	0
Total Pathloss, L (dB) $L = PL_{FS} + PL_{SM} + PL_{AD}$	155.20	161.23
Rx Antenna Gain (User Input. Default based on Table 6.1.1.1-3 of 38.821)	0	0
Noise figure $N_f$ (User Input. Default based on Table 6.1.1.1-3 of 38.821)	7	7
Rx Antenna Temp $T_a$ (K) (User Input. Default based on Table 6.1.1.1-3 of 38.821)	290	290
RX equivalent antenna Temp, $T$ [dBK] (Per TR 38.821 section 6.1.3.1)	31.62	31.62
Receiver G/T (dB/K) (Per RX G/T formulas provided in 3GPP TR 38.821 sec 6.1.3.1)	-31.62	-31.62
Boltzmann constant $k$ [dBW/K/Hz]	-228.6	-228.6
<b>Carrier to Noise Ratio, CNR (dB)</b> <b>(Per CNR formulas provided in 3GPP TR 38.821 sec 6.1.3.1)</b>	<b>11.58</b>	<b>5.49</b>
Carrier to Interference Ratio, CIR (dB) (User Input. Per TR 38.821 section 6.1.3.1)	5	5
Carrier to Noise plus Interference Ratio, CNIR (dB) (Per CNIR formulas provided in 3GPP TR 38.821 sec 6.1.3.1)	4.14	2.23

## 2.2 Link Budget Calculations: Example 1 LEO 600

We consider the satellite co-ordinates as (0,0,600) km, and the UE co-ordinates as (0,0,0)km. The elevation angle is calculated as arctan of the ratio of the satellite altitude to the distance between the

satellite and the UE in the XY plane.

$$\alpha = \sin^{-1}\left(\frac{D}{Ru \times L}\right) = 90^\circ \quad (6)$$

Where,

$$Ru = \sqrt{x_{ue}^2 + y_{ue}^2 + z_{ue}^2} \quad (7)$$

$$L = \sqrt{(x_{sat} - x_{ue})^2 + (y_{sat} - y_{ue})^2 + (z_{sat} - z_{ue})^2} \quad (8)$$

$$D = \sqrt{(x_{sat} - x_{ue}) \cdot x_{ue} + (y_{sat} - y_{ue}) \cdot y_{ue} + (z_{sat} - z_{ue}) \cdot z_{ue}} \quad (9)$$

$$\alpha = 90^\circ \quad (10)$$

The slant height used in NetSim is per 38.811, equation 6.6-3, i.e.

$$d = \sqrt{R_E^2 \sin^2(\alpha) + h_o^2 + 2h_o R_E - R_E \sin(\alpha)} \quad (11)$$

For a link between a ground station and a LEO satellite operating at 600 km with elevation angle  $\alpha = 90^\circ$ .

$$d = \sqrt{(6.371 \cdot 10^6)^2 \cdot \sin^2(90^\circ) + (6 \cdot 10^5)^2 + 2 \cdot (6 \cdot 10^5) (6.371 \cdot 10^6) - 6.371 \cdot 10^6 \sin(90^\circ)} \quad (12)$$

$$d = 600 \text{ km} \quad (13)$$

The free space pathloss  $PL_{FS}$  for a channel with  $d = 600$  km is

$$F_{Low} = 2170, F_{High} = 2200, f_c = \frac{2170+2200}{2} = 2.185 \text{ GHz}$$

$$PL_{FS} = 32.45 + 20 \log_{10}(f_c) + 20 \log_{10}(d) \quad (14)$$

$$32.45 + 20 \log_{10}(2.185) + 20 \log_{10}(600 \times 1000) = 154.8 \text{ dB} \quad (15)$$

The receiver antenna  $G/T$  is given by the expression

$$Rx \frac{G}{T} = G_{rx} - N_f - 10 \log_{10}(T_0 + (T_a - T_0) \times 10^{-0.1 \times N_f}) \quad (16)$$

We know  $T_0 = 290$ , and when we apply  $T_a = 290$ , we obtain

$$Rx \frac{G_{rx}}{T} = 0 - 7 - 10 \log_{10}(290) = -31.62 \text{ dB/K} \quad (17)$$

We know that bandwidth  $B$  [dBHz] =  $10 \times \log_{10}(B \text{ [Hz]}) = 10 \times \log_{10}(30 \times 10^6) = 74.77$  dBHz

The shadow margin  $PL_{SM}$  is calculated per the tables available in section 6.6.2 of 38.811. The given example is based on the Rural scenario, with a LOS probability of 1 and an elevation angle of  $90^\circ$ . The standard deviation chosen from the table is 0.72. We then generate a zero-mean Gaussian random variable with input standard deviation of 0.72. In this case, the random shadow loss drawn is 0.54 dB

Angular antenna gain,  $G(\theta) = 0$

MaxAntennaGain=0,

And finally we obtain  $CNR$  as

$$CNR = EIRP + G(\theta) - \text{MaxAntennaGain} + Rx \frac{G}{T} - k - PL_{FS} - PL_{SM} - PL_{AD} - B \quad (18)$$

Substituting we get

$$CNR = 48.77 + 0 + (-31.62) - (-228.6) - 154.8 - (0.39) - 0 - 74.77 = 15.78 \text{ dB} \quad (19)$$

### 2.3 Link Budget Calculations: Example 2 LEO 1200

We consider the satellite co-ordinates as (0, 0, 1200) km, and the UE co-ordinates as (64, 34, 0) km. The elevation angle is calculated in NetSim as follows

$$\theta = 86.54^\circ \quad (20)$$

The slant height used in NetSim is per 38.811, equation 6.6-3, i.e.

$$d = \sqrt{R_E^2 \sin^2(\alpha) + h_o^2 + 2h_o R_E - R_E \sin(\alpha)} \quad (21)$$

For a link between a ground station and a LEO satellite operating at 1200 km with elevation angle  $\alpha = 86.54^\circ$ .

$$d = \sqrt{(6.371 \cdot 10^6)^2 \cdot \sin^2(86.51^\circ) + (12 \cdot 10^5)^2 + 2 \cdot (12 \cdot 10^5) (6.371 \cdot 10^6) - 6.371 \cdot 10^6 \sin(86.51^\circ)} \quad (22)$$

$$d = 1202.19 \text{ km} \quad (23)$$

The free space pathloss  $PL_{FS}$  for a channel with  $d = 1202.19$  km is

$$F_{Low} = 2170, F_{High} = 2200, f_c = \frac{2170+2200}{2} = 2.185 \text{ GHz}$$

$$PL_{FS} = 32.45 + 20 \log_{10}(f_c) + 20 \log_{10}(d) \quad (24)$$

$$32.45 + 20 \log_{10}(2.185) + 20 \log_{10}(1202.19 \times 1000) = 160.84 \text{ dB} \quad (25)$$

The receiver antenna  $G/T$  is given by the expression

$$Rx \frac{G}{T} = G_{rx} - N_f - 10 \log_{10}(T_0 + (T_a - T_0) \times 10^{-0.1 \times N_f}) \quad (26)$$

We know  $T_0 = 290$ , and when we apply  $T_a = 290$ , we obtain

$$Rx \frac{G_{rx}}{T} = 0 - 7 - 10 \log_{10}(290) = -31.62 \text{ dB/K} \quad (27)$$

We know that bandwidth  $B$  [dBHz] =  $10 \times \log_{10}(B \text{ [Hz]}) = 10 \times \log_{10}(30 \times 10^6) = 74.77 \text{ dBHz}$

The shadow margin  $PL_{SM}$  is calculated per the tables available in section 6.6.2 of 38.811. The given example is based on the Rural scenario, with a LOS probability of 1 and an elevation angle of  $86.54^\circ$ . The standard deviation chosen from the table is 0.72. We then generate a zero-mean Gaussian random variable with input standard deviation of 0.72. In this case, the random shadow loss that we draw is 0.54 dB.

Angular antenna gain,  $G(\theta) = -10.26$

MaxAntennaGain=0,

And finally we obtain  $CNR$  as

$$CNR = EIRP + G(\theta) - \text{MaxAntennaGain} + Rx \frac{G}{T} - k - PL_{FS} - PL_{SM} - PL_{AD} - B \quad (28)$$

Substituting we get

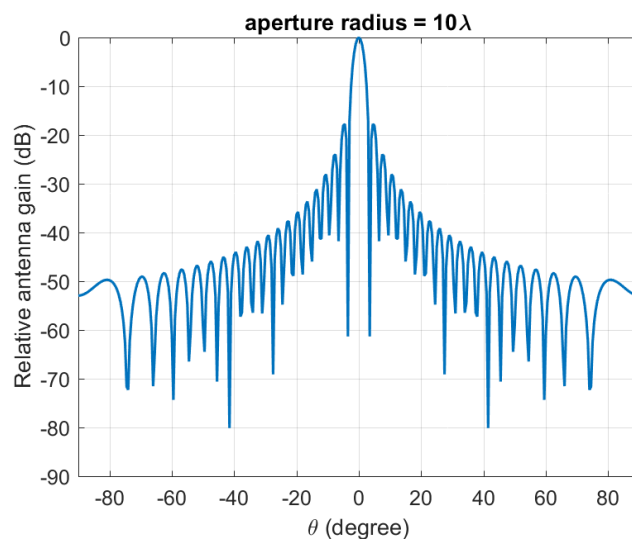
$$CNR = 54.77 - 10.26 + (-31.62) - (-228.6) - 160.84 - (0.39) - 0 - 74.77 = 5.49 \text{ dB} \quad (29)$$

### 3 Satellite Antenna Pattern

In the section above the link budgets were calculated assuming the max transmit antenna gain. However, per section 6.4.1 of TR 38.811, we know that the normalized antenna gain pattern, corresponding to a typical reflector antenna with a circular aperture, is given by

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

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  $\theta$  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 3-1:** Antenna gain pattern for aperture radius 10 wavelengths,  $a = 10 \frac{c}{f}$ .

### 3.1 Off Boresight Angle Calculation

Conceptually, the off-boresight angle,  $\theta$ , 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  $\theta$  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

$\varphi_t$  : Latitude of earth station (degrees)

$\lambda_t$  : Longitude of earth station (degrees)

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

$\varphi_s$  : Latitude of satellite (degrees)

$\lambda_s$  : 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):

$$a = 6378137.0 \text{ m} \quad (30)$$

- Flattening:

$$f = \frac{1}{298.257223563} \quad (31)$$

- First eccentricity squared:

$$e^2 = 2f - f^2 \quad (32)$$

- Numerically:

$$e^2 \approx 0.00669437999014 \quad (33)$$

- Prime vertical radius of curvature

$$N(\phi) = \frac{a}{\sqrt{1 - e^2 \sin^2(\phi)}} \quad (34)$$

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

$$X = (N + h) \cos(\phi) \cos(\lambda) \quad (35)$$

$$Y = (N + h) \cos(\phi) \sin(\lambda) \quad (36)$$

$$Z = N ((1 - e^2) + h) \sin(\phi) \quad (37)$$

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:

$$\Delta r = r_s - r_t = (\Delta X, \Delta Y, \Delta Z) \quad (38)$$

### Step 3: Rotate LOS Vector into Local ENU Frame

Define the standard ECEF-to-ENU rotation matrix at the earth station latitude  $\phi_t$  and longitude  $\lambda_t$ :

$$\begin{bmatrix} E \\ N \\ U \end{bmatrix} = \begin{bmatrix} -\sin(\lambda_t) & \cos(\lambda_t) & 0 \\ -\sin(\phi_t) \cos(\lambda_t) & -\sin(\phi_t) \sin(\lambda_t) & \cos(\phi_t) \\ \cos(\phi_t) \cos(\lambda_t) & \cos(\phi_t) \sin(\lambda_t) & \sin(\phi_t) \end{bmatrix} \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} \quad (39)$$

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:

$$D_{ts} = \sqrt{E^2 + N^2 + U^2} \quad (40)$$

### Step 5: Elevation Angle

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

$$el = \text{atan2}\left(U, \sqrt{E^2 + N^2}\right) \quad (41)$$

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

### Step 6: Azimuth Angle

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

$$az = \text{atan2}(E, N) \quad (42)$$

The result should be wrapped to the range  $0^\circ$ - $360^\circ$ .

### Step 7: Visibility Check

Given a minimum elevation mask angle (maskAngle):

$$\text{visible} = 1 \quad \text{if } el \geq \text{maskAngle} \quad (43)$$

$$\text{visible} = 0 \quad \text{otherwise} \quad (44)$$

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

### 3.2 Link Budget Calculations: Example 3 LEO 600 and LEO 1200

For the same two examples, shown earlier, if we compute the angular antenna gain based on the UE and satellite positions

Case 1:

$$f = 2.18 \text{ GHz}; \quad a = 1 \text{ m}; \quad k = \frac{2\pi f}{c} = \frac{2 \times 3.14 \times 2.18 \times 10^9}{3 \times 10^8} = 45.76 \quad (45)$$

The UE associates with beam 3, and the angle between the antenna boresight to the line joining the UE and the satellite is  $\theta = 3.33^\circ$ . This computation is carried out within NetSim. Substituting

$$4 \left| \frac{J_1(45.76 \times 1 \times \sin(3.33))}{45.76 \times 1 \times \sin(3.33)} \right|^2 = 4 \left| \frac{J_1(2.656)}{2.656} \right|^2 = 0.117 \text{ mW} = -9.31 \text{ dBm} \quad (46)$$

Case 2:

$$\theta = 6.15^\circ \quad (47)$$

$$4 \left| \frac{J_1(45.76 \times 1 \times \sin(6.15))}{45.76 \times 1 \times \sin(6.15)} \right|^2 = 4 \left| \frac{J_1(4.900)}{4.900} \right|^2 = 0.0165 \text{ mW} = -17.82 \text{ dBm} \quad (48)$$

Since EIRP includes the antenna gains, the angular gain values obtained above need to be added in the CNR calculations. The final link budget calculations are shown below. The changes as compared to the earlier table are shown in blue.

**Table 3-1:** Simulation Parameters and Link Budget Calculation for LEO Satellite Communication at 600 km and 1200 km Altitudes.

Simulation Parameters	LEO 600 km	LEO 1200 km
Antenna Aperture (m)	1	1
Beam Radius (Km)	55.13	110.24
EIRP density (dBW/MHz)	34	40
Bandwidth B	30	30
EIRP (dBW)	48.77	54.77
Elevation angle	80.58	85.26
Angular Antenna Gain, $G(\theta)$ , (dB) (Calculation provided above)	-9.31	-17.82
Slant range d (Km)	607.48	1203.46
Free space pathloss (dB), $PL_{FS}$	154.91	160.85
Shadow loss (dB), $PL_{SM}$	0.39	0.96
Additional Loss(dB), $PL_{AD}$	2	2
Total Pathloss, L(dB)	157.3	163.81
Rx Antenna Gain	0	0
Noise figure f	7	7
Rx Antenna Temp $T_a$ (K)	290	290
RX equivalent antenna Temp, $T$ [dBK]	31.62	31.62
Receiver G/T	-31.62	-31.62
Boltzmann constant $k$ $\left[\frac{dBW}{KHz}\right]$	-228.6	-228.6
CNR (Calculation provided below)	4.36	-4.66

Case 1:

$$CNR = EIRP + G(\theta) + Rx \frac{G}{T} - k - PL_{FS} - PL_{SM} - PL_{AD} - B \quad (49)$$

Substituting we get

$$CNR = 48.77 + (-9.87) + (-31.62) - (-228.6) - 154.14 - 0.57 - 8 - 74.77 = -1.6 \text{ dB} \quad (50)$$

Case 2:

$$CNR = EIRP + G(\theta) + Rx \frac{G}{T} - k - PL_{FS} - PL_{SM} - PL_{AD} - B \quad (51)$$

Substituting we get

$$CNR = 54.77 + (-12.95) + (-31.62) - (-228.6) - 160.08 - 0.57 - 8 - 74.77 = -4.62 \text{ dB} \quad (52)$$

## 4 Uplink Scheduling

In terrestrial 5G NR, uplink transmissions follow a dynamic grant procedure: the UE sends a Scheduling Request, the gNB responds with a UL Grant, the UE sends a Buffer Status Report, and the gNB allocates resources for data transmission on PUSCH. This multi-step procedure assumes sub-millisecond round-trip times. In NTN, the one-way propagation delay ranges from approximately 4 ms (LEO 600 km) to 240 ms

(GEO), resulting in round-trip delays of 8 ms to over 500 ms. A four-step dynamic grant procedure would therefore add hundreds of milliseconds of scheduling delay before data transmission can begin.

To address this, 3GPP TS 38.214 Section 6.1.2.3 and TS 38.321 Section 5.8.2 define **Configured Grant (CG)** as a mechanism where the gNB pre-configures periodic uplink transmission resources for each UE via RRC signaling. Once configured, the UE transmits autonomously on PUSCH without waiting for individual UL grants.

## 4.1 NetSim Implementation

NetSim implements **Configured Grant Type 1** as a **cyclic round-robin** scheduler operating in time-division mode (TDM):

- Each associated UE receives one dedicated UL slot per cycle.
- The cycle length equals the number of associated UEs ( $N_{UE}$ ). UE  $i$  transmits in slot  $(n \cdot N_{UE} + i)$  where  $n = 0, 1, 2, \dots$
- In each assigned slot, the scheduled UE receives **all available PRBs** (after overhead deduction).
- The available PRBs per UE per slot =  $N_{PRB} - \lceil OH_{UL} \cdot N_{PRB} \rceil$ .
- Each beam runs its own independent cyclic round-robin schedule.
- MCS is selected per-UE based on the UL link budget: UL SNR  $\rightarrow$  CQI  $\rightarrow$  MCS.
- **HARQ is disabled** in NTN by default and operates as a passthrough. Packet delivery flows through the HARQ transmit path, but no retransmissions occur.

## 5 Interference Models

### 5.1 CIR based Interference

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

$$CNIR \text{ [dB]} = -10 \log_{10} \left( 10^{-0.1 CNR \text{ [dB]}} + 10^{-0.1 CIR \text{ [dB]}} \right) \quad (53)$$

### 5.2 Link Budget Calculations: Example 4 LEO 600 and LEO 1200

Case 1:

Assuming a CIR of 5 dB, and using the CNR obtained from the earlier section we get

$$CNR \text{ [dB]} = -10 \log_{10} \left( 10^{-0.1 \times (-1.6)} + 10^{-0.1 \times 5} \right) = -2.46 \text{ dB} \quad (54)$$

Case 2:

Assuming a CIR of 5 dB, and using the CNR obtained from the earlier section we get

$$CNIR \text{ [dB]} = -10 \log_{10} \left( 10^{-0.1 CNR \text{ [dB]}} + 10^{-0.1 CIR \text{ [dB]}} \right) \quad (55)$$

$$= -10 \log_{10} \left( 10^{-0.1 \times (-4.62)} + 10^{-0.1 \times 5} \right) = -5.07 \text{ dB} \quad (56)$$

**Table 5-1:** *CNR, CIR, and CNIR Comparison for LEO 600 km and 1200 km.*

Simulation Parameters	LEO 600 km	LEO 1200 km
CNR	4.36	-4.66
CIR	5	5
CNIR	1.66	-5.11

### Interference power calculations for CIR based Interference

$$\text{Interference [mW]} = \text{Noise [mW]} \times \left( \frac{\text{CNR [mW]}}{\text{CNIR [mW]}} - 1 \right) \quad (57)$$

$$\text{Interference [dB]} = 10 \times \log_{10}(\text{Interference [mW]}) \quad (58)$$

Case 1:

Assuming a CNR of 4.36 dB, and using the CNIR of 1.66 dB obtained from the earlier section we get

$$\text{Interference [mW]} = 10^{0.1 \times (-99.05)} \times \left( \frac{10^{0.1 \times 4.36}}{10^{0.1 \times 1.66}} - 1 \right) \quad (59)$$

$$\text{Interference [mW]} = 1.073 \times 10^{-10} \quad (60)$$

$$\text{Interference [dB]} = 10 \times \log_{10}(1.073 \times 10^{-10}) = -99.69 \text{ dB} \quad (61)$$

Case 2:

Assuming a CNR of -4.62 dB, and using the CNIR of -5.07 dB obtained from the earlier section we get

$$\text{Interference [mW]} = 10^{0.1 \times (-99.05)} \times \left( \frac{10^{0.1 \times (-4.66)}}{10^{0.1 \times (-5.11)}} - 1 \right) \quad (62)$$

$$\text{Interference [mW]} = 1.3439 \times 10^{-11} \quad (63)$$

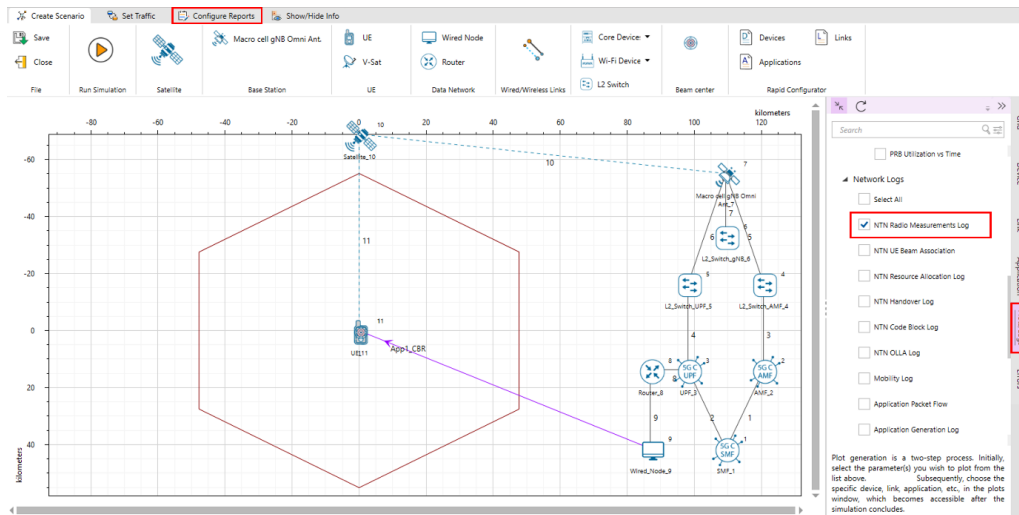
$$\text{Interference [dB]} = 10 \times \log_{10}(1.3439 \times 10^{-11}) = -108.71 \text{ dB} \quad (64)$$

Exact geometric interference: In NTN systems, 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 FR3, it is limited to beams using the same channel ID.

## 6 Radio Measurements Log

NTN's radio measurement log records signal data for all available beams and UEs. Each entry contains the measurements simulation time, UE position, Beam id, UE elevation angle, theta (angle subtended by the current beam), slant height, EIRP density, Tx Angular antenna gain, Rx Gain, Shadow fading loss, Pathloss, Shadow loss, Additional loss, Total loss, and thermal noise. CIR (carrier to interference ratio) is calculated at receiver when CIR interference is enabled, as well as SNR and SINR. These logs are useful for analysing NTN performance across beams and UEs.

The NTN Radio Measurements log can be enabled by clicking on configure reports in top ribbon > Plots/Logs > Select NTN Radio Measurements log under Network Logs as shown below.

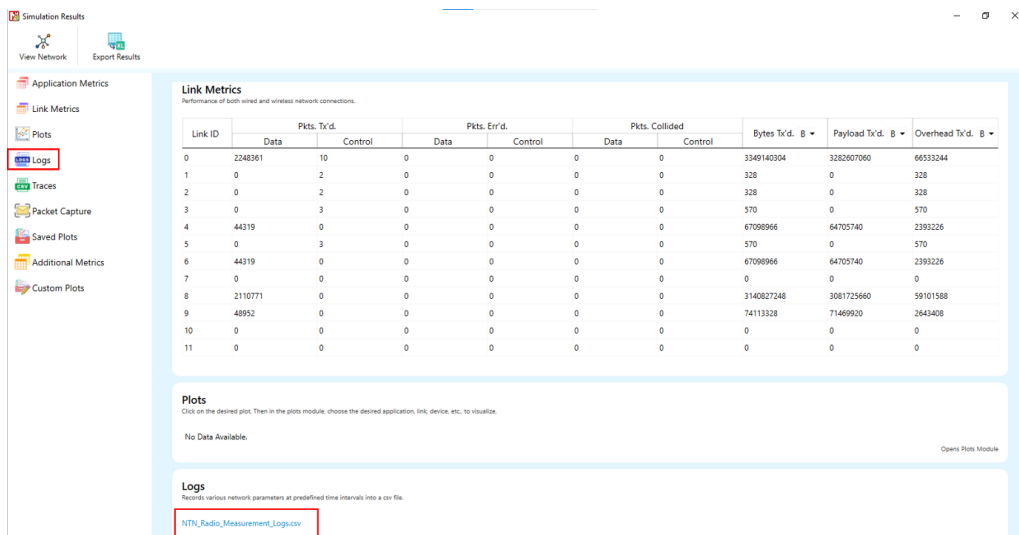


**Figure 6-1:** Enabling NTN Radio Measurement log.

The NTN Radio Measurement Log.csv file will contain the following information:

- Time(ms)
- gNB or eNB Name
- UE Name
- Slant height(km)
- Elevation angle(°)
- CC\_ID
- Band
- Channel
- Layer ID
- EIRP(dBW)
- Pathloss(dB)
- Shadow fading loss(dB)
- Additional loss(dB)
- Clutter loss(dB)
- Total loss(dB)
- Beamforming Gain(dB)
- Angular Antenna Gain(dB)
- UE Rx Antenna Gain(dB)
- Rx Power(dBm)
- SNR(dB)
- SINR(dB)
- Thermal noise(dBm)
- Interference power(dBm)
- CQI Index
- MCS Index

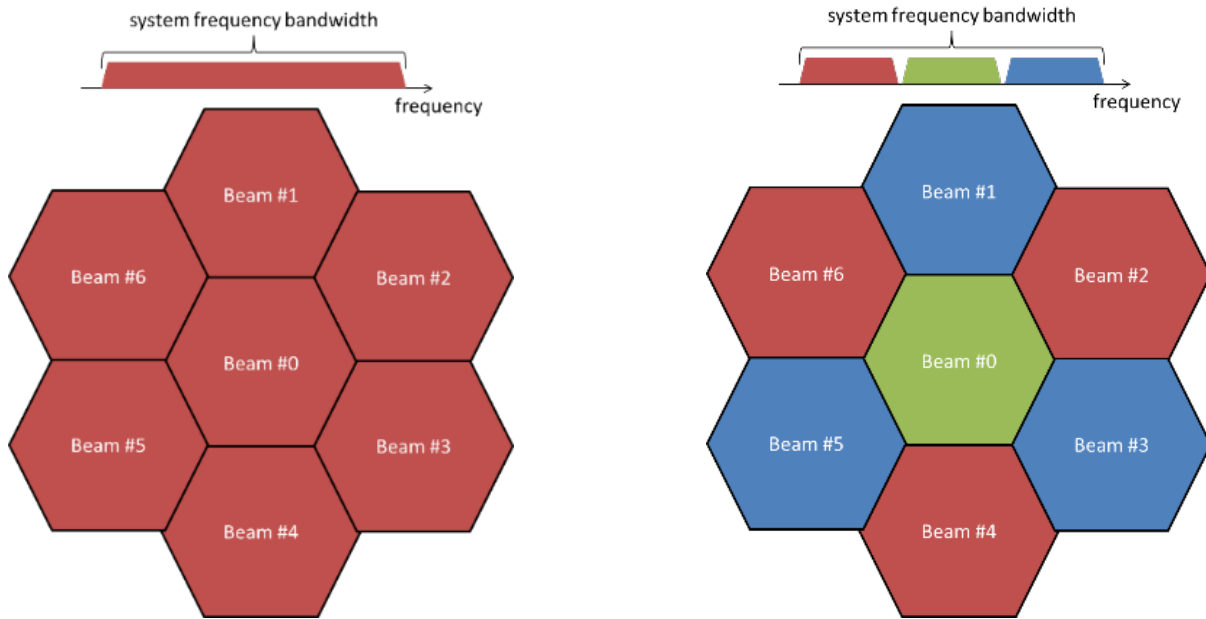
The log file can be accessed from the Simulations Results Window under the log file drop down in the left pane



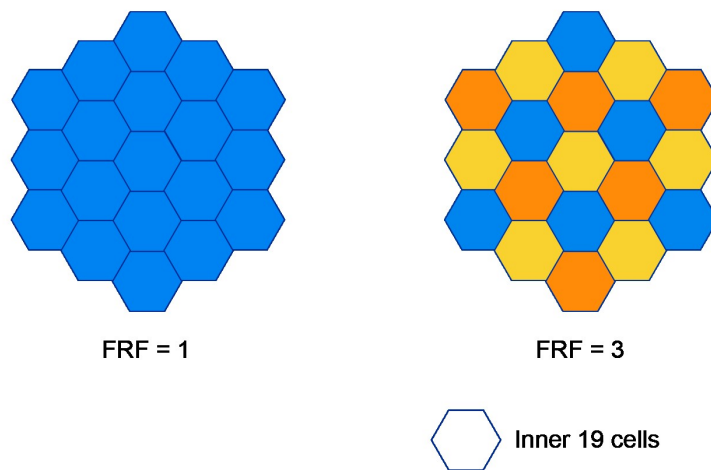
**Figure 6-2:** NTN Radio Measurement Log file highlighted in the Results window.

## 7 Frequency Reuse

NetSim supports FR1 ( $N_{reuse} = 1$ ) and FR3 ( $N_{reuse} = 3$ ) configurations.



**Figure 7-1:** Frequency reuse in a 7-beam layout. Left: FR1 – all beams share the full system bandwidth. Right: FR3 – the bandwidth is divided among three channel groups to reduce inter-beam interference.



**Figure 7-2:** The 7-cell and 19-cell cases for FR1 and FR3.

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” (colors in the figure above) to the beams. The available resources and bandwidth are then equally divided among the channels, considering the guard band for accurate resource allocation per beam. The bandwidth per channel is calculated per the following expression

$$BW_{channel} = \frac{BW_{Total} - (N_{channels} - 1) \times BW_{GuardBand}}{N_{channels}} \tag{65}$$

In NetSim, the centre frequencies of all channels remain the same, even though, in real-world deployments, each channel would have a different centre frequency.

**Example:** Consider an S-band system with a 2 GHz carrier frequency and 30 MHz bandwidth, using a frequency reuse factor (FRF) of 3. Each channel is allocated bandwidth while maintaining a 500 kHz

guard band.  $BW_{channel} = \frac{30-(3-1)\times 0}{3} = \frac{30}{3} = 10$  MHz.

Based on the number of beams and the FRF, the NetSim automatically configures the beam IDs, beam center coordinates, and assigned channel IDs.

## 8 Link Budget with Interference

**Table 8-1:** *Simulation Parameters and Performance comparison for FR1 and FR3 bands.*

Simulation Parameters	FR1	FR3
Satellite Altitude	LEO1200	LEO1200
Terrestrial environment	Rural	Rural
LOS probability	1	1
Antenna Aperture (m)	1	1
Beam Radius (Km)	110.26	110.26
EIRP density (dBW/MHz)	40	40
Guard Band (kHz)	0	0
Channel Bandwidth B (MHz)	30	10
EIRP (dBW)	54.77	50
Elevation angle	85.26	85.26
Slant range d (Km)	1203.46	1203.46
Free space pathloss (dB)	160.85	160.85
Shadow loss (dB)	0.42	0.96
Additional Loss (dB)	2	2
Total Pathloss, L(dB)	163.27	168.069
Tx Angular Antenna Gain (dBm)	-17.82	-17.82
Rx Antenna Gain	0	0
Noise figure	7	7
Rx Antenna Temp $T_a$ (K)	290	290
RX equivalent antenna Temp	31.62	31.62
Receiver G/T	-31.62	-31.62
Boltzmann constant	-228.6	-228.6
CNR (dB)	-4.12	-4.66
Noise (dBm)	-99.06	-103.83
Received Power (dBm)	-103.18	-108.49
Interference Power (dBm) (geometric model)	-106.37	-116.51
CINR (dB)	-4.86	-4.89
Throughput (Mbps)	6.57	2.15

### 8.1 Calculations for FRF 1

We consider the satellite co-ordinates as (0, 0, 1200) km, and the UE co-ordinates as (77.05, 63.0, 0)km. The elevation angle is calculated as arctan of the ratio of the satellite altitude to the distance between the satellite and the UE in the XY plane.

$$\theta = 85.26^\circ \quad (66)$$

The slant height used in NetSim is per 38.811, equation 6.6-3, i.e.

$$d = \sqrt{R_E^2 \sin^2(\alpha) + h_o^2 + 2h_o R_E \sin(\alpha)} - R_E \sin(\alpha) \quad (67)$$

For a link between a ground station and a LEO satellite operating at 1200 km with elevation angle  $\alpha = 85.26^\circ$ .

$$d = \sqrt{(6.371 \cdot 10^6)^2 \cdot \sin^2(85.26^\circ) + (12 \cdot 10^5)^2 + 2 \cdot (12 \cdot 10^5) (6.371 \cdot 10^6) - 6.371 \cdot 10^6 \sin(85.26^\circ)} \quad (68)$$

$$d = 1203.46 \text{ km} \quad (69)$$

The free space pathloss  $PL_{FS}$  for a channel with  $f_c = 2$  GHz, or  $\lambda = \frac{c}{f} = 0.15$  m, and  $d = 1203.46$  km is

$$PL_{FS} = 20 \log_{10} \left( \frac{4\pi d}{\lambda} \right) = 20 \log_{10} \left( \frac{4\pi (1203.46 \times 10^3) (2 \times 10^9)}{3 \times 10^8} \right) = 160.85 \text{ dB} \quad (70)$$

The receiver antenna  $G/T$  is given by the expression

$$Rx \frac{G}{T} = G_{rx} - N_f - 10 \log_{10}(T_0 + (T_a - T_0) \times 10^{-0.1 \times N_f}) \quad (71)$$

We know  $T_0 = 290$ , and when we apply  $T_a = 290$ , we obtain

$$Rx \frac{G}{T} = 0 - 7 - 10 \log_{10}(290) = -31.62 \text{ dB/K} \quad (72)$$

We know that bandwidth  $B$  [dBHz] =  $10 \times \log_{10}(B \text{ [Hz]}) = 10 \times \log_{10}(30 \times 10^6) = 74.77$  dBHz

And finally, we obtain  $CNR$  as

$$CNR = EIRP + G(\theta) + Rx \frac{G}{T} - k - PL_{FS} - PL_{SM} - PL_{AD} - B \quad (73)$$

$$= 54.77 + (-17.82) + (-31.62) - (-228.6) - 160.85 - 0.42 - 2 - 74.77 = -4.12 \text{ dB}$$

$$Rx \text{ Power (dBm)} = CNR + \text{Noise} = -4.12 + (-99.06) = -103.18 \text{ dBm} \quad (74)$$

Interference power,  $I$ , obtained based on the geometric interference model is  $-101.95$  dBm

$$CINR \text{ (Linear)} = \frac{Rx \text{ Power}}{\text{Noise} + \text{Interference Power}} = \frac{10^{-\frac{103.18}{10}}}{10^{-\frac{99.06}{10}} + 10^{-\frac{106.37}{10}}} \quad (75)$$

$$= \frac{4.82 \times 10^{-11}}{1.24 \times 10^{-10} + 2.31 \times 10^{-11}} = \frac{4.82 \times 10^{-11}}{1.471 \times 10^{-10}} = 0.327 \quad (76)$$

$$CINR \text{ (dBm)} = 10 \times \log_{10}(0.327) = -4.86 \text{ dB} \quad (77)$$

CINR calculated is  $-2.77$  dB

## 8.2 Calculations for FRF 3

We consider the satellite co-ordinates as (0, 0, 1200) km, and the UE co-ordinates as (77.05, 63.0, 0)km. The elevation angle is calculated as arctan of the ratio of the satellite altitude to the distance between the satellite and the UE in the XY plane.

$$\theta = 85.26^\circ \quad (78)$$

The slant height used in NetSim is per 38.811, equation 6.6-3, i.e.

$$d = \sqrt{R_E^2 \sin^2(\alpha) + h_o^2 + 2h_o R_E - R_E \sin(\alpha)} \quad (79)$$

For a link between a ground station and a LEO satellite operating at 1200 km with elevation angle  $\alpha = 85.26^\circ$ .

$$d = \sqrt{(6.371 \cdot 10^6)^2 \cdot \sin^2(85.26^\circ) + (12 \cdot 10^5)^2 + 2 \cdot (12 \cdot 10^5) (6.371 \cdot 10^6) - 6.371 \cdot 10^6 \sin(85.26^\circ)} \quad (80)$$

$$d = 1203.46 \text{ km} \quad (81)$$

The free space pathloss  $PL_{FS}$  for a channel with  $f_c = 2$  GHz, or  $\lambda = \frac{c}{f} = 0.15$  m, and  $d = 1203.46$  km is

$$PL_{FS} = 20 \log_{10} \left( \frac{4\pi d}{\lambda} \right) = 20 \log_{10} \left( \frac{4\pi (1203.46 \times 10^3) (2 \times 10^9)}{3 \times 10^8} \right) = 160.85 \text{ dB} \quad (82)$$

The receiver antenna  $G/T$  is given by the expression

$$Rx \frac{G}{T} = G_{rx} - N_f - 10 \log_{10} (T_0 + (T_a - T_0) \times 10^{-0.1 \times N_f}) \quad (83)$$

We know  $T_0 = 290$ , and when we apply  $T_a = 290$ , we obtain

$$Rx \frac{G_{rx}}{T} = 0 - 7 - 10 \log_{10}(290) = -31.62 \text{ dB/K} \quad (84)$$

$$Rx \frac{G}{T} = G_{rx} - N_f - 10 \log_{10} (T_0 + (T_a - T_0) \times 10^{-0.1 \times N_f}) \quad (85)$$

We know that bandwidth  $B$  [dBHz] =  $10 \times \log_{10}(B$  [Hz]) =  $10 \times \log_{10}(10 \times 10^6) = 70$  dBHz

And finally, we obtain  $CNR$  as

$$CNR = EIRP + G(\theta) + Rx \frac{G}{T} - k - PL_{FS} - PL_{SM} - PL_{AD} - B \quad (86)$$

$$= 50 + (-17.82) + (-31.62) - (-228.6) - 160.85 - 0.96 - 2 - 70 = -4.66 \text{ dB}$$

$$Rx \text{ Power (dBm)} = CNR + \text{Noise} = -4.66 + (-103.83) = -108.49 \text{ dBm} \quad (87)$$

Interference power,  $I$ , obtained based on the geometric interference model is  $-116.51$  dBm

$$CINR \text{ (Linear)} = \frac{Rx \text{ Power}}{\text{Noise} + \text{Interference Power}} = \frac{10^{\frac{-108.49}{10}}}{10^{\frac{-103.83}{10}} + 10^{\frac{-116.51}{10}}} \quad (88)$$

$$= \frac{1.41 \times 10^{-11}}{4.13 \times 10^{-11} + 2.33 \times 10^{-12}} = \frac{1.41}{4.353} = 0.324 \tag{89}$$

$$CINR \text{ (dBm)} = 10 \times \log_{10}(0.324) = -4.89 \text{ dB} \tag{90}$$

CINR calculated is -4.89 dB

## 9 Beam Radius Calculations

The half-power point occurs when the power drops to half of its maximum value. Mathematically, this is when

$$G(\theta_{HPBW}) = 4 \times \left| \frac{J_1(ka \sin(\theta_{HPBW}))}{ka \cdot \sin(\theta_{HPBW})} \right|^2 = \frac{1}{2} \tag{91}$$

Taking square root

$$\left| \frac{2 \cdot J_1(ka \sin(\theta_{HPBW}))}{ka \cdot \sin(\theta_{HPBW})} \right| = \frac{1}{\sqrt{2}} \tag{92}$$

Solving numerically for  $J_1(x) = \frac{x}{2\sqrt{2}}$ , we get

$$ka \sin(\theta_{HPBW}) \approx 1.616 \tag{93}$$

Substituting  $k = 2\pi/\lambda$  and  $a = \frac{D}{2}$

$$\frac{2\pi}{\lambda} \cdot \frac{D}{2} \sin(\theta_{HPBW}) \approx 1.616 \tag{94}$$

Using the fact that for small angles  $\sin(\theta) \approx \theta$ , and on converting to degrees, we get

$$\theta_{HPBW} \text{ [degrees]} \approx \frac{70\lambda}{D} \tag{95}$$

For aperture,  $a$  and wavelength  $\lambda$ , since  $2a = D$  and substituting  $\lambda = \frac{c}{f}$  we get

$$\theta_{HPBW} \text{ [degrees]} = \frac{35 \times c}{a \times f} \tag{96}$$

**Table 9-1:** Antenna and Beam Parameters for S-Band LEO, MEO, and GEO Satellite Configurations.

Parameters	LEO 1200	MEO 10000	GEO 35786
Altitude (km)	1200	10000	35786
Band	S band	S band	S band
Antenna Aperture Radius (m)	1	5	11
Channel Frequency (GHz)	2	2	2
$\theta_{3dB}$ (or $\theta_{HPBW}$ )(Calculation provided below)	5.25	1.05	0.476
Beam Radius (km)	110.26	183.28	297.31

$$\theta_{HPBW} = \frac{35 \times \lambda}{a} = \frac{35 \times c}{a \times f} \quad (97)$$

$$\text{LEO 1200: } \theta_{HPBW} = \frac{35 \times 3 \times 10^8}{1 \times 2 \times 10^9} = 5.25^\circ \quad (98)$$

$$\text{MEO 10000: } \theta_{HPBW} = \frac{35 \times 3 \times 10^8}{5 \times 2 \times 10^9} = 1.05^\circ \quad (99)$$

$$\text{GEO 35786: } \theta_{HPBW} = \frac{35 \times 3 \times 10^8}{11 \times 2 \times 10^9} = 0.476^\circ \quad (100)$$

**Table 9-2:** Antenna and Beam Parameters for K-band LEO, MEO, and GEO Satellite Configurations.

Parameters	LEO 1200	MEO 10000	GEO 35786
Altitude (km)	1200	10000	35786
Band	K band	K band	K band
Antenna Aperture Radius (m)	0.25	1	2.5
Channel Frequency (GHz)	20	20	20
$\theta_{3dB}$ (or $\theta_{HPBW}$ )(Calculation provided below)	2.1	0.525	0.21
Beam Radius (km)	44	91.63	131.16

$$\text{LEO 1200: } \theta_{HPBW} = \frac{35 \times 3 \times 10^8}{0.25 \times 20 \times 10^9} = 2.1^\circ \quad (101)$$

$$\text{MEO 10000: } \theta_{HPBW} = \frac{35 \times 3 \times 10^8}{1 \times 20 \times 10^9} = 0.525^\circ \quad (102)$$

$$\text{GEO 35786: } \theta_{HPBW} = \frac{35 \times 3 \times 10^8}{2.5 \times 20 \times 10^9} = 0.21^\circ \quad (103)$$

## 9.1 Hexagonal tessellation based on beam radius

In a hexagonal tessellation:

- Each beam is represented by a hexagon.
- The beams are arranged in a honeycomb pattern to maximize coverage and minimize overlap.
- The beam radius,  $R$  is the distance from the centre of the beam to its edge, where the power drops to a specified level (e.g., half-power or  $-3$  dB).
- In a hexagonal grid, the distance between beam centers (beam spacing) is  $\sqrt{3} \cdot R$

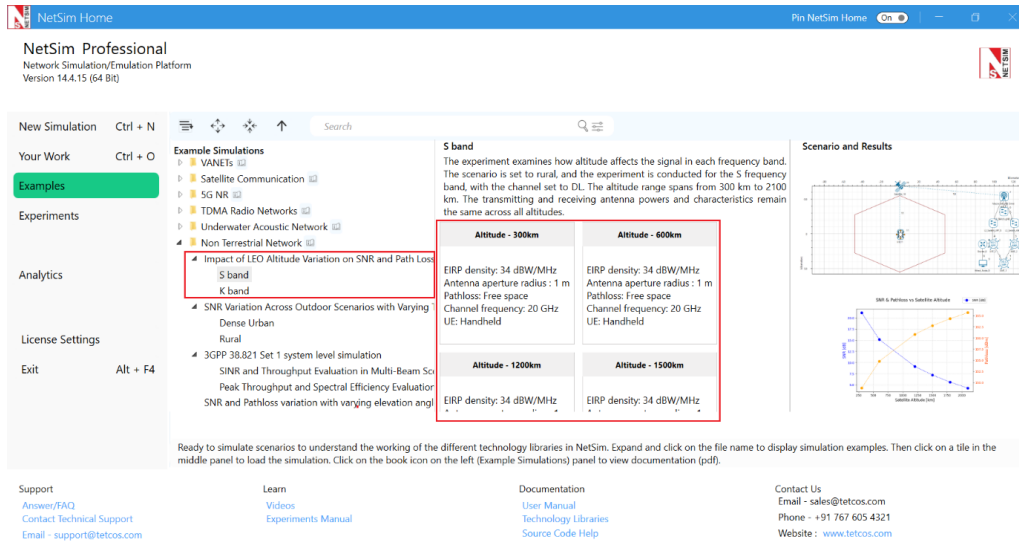
## 10 Featured Examples

### 10.1 Impact of LEO Altitude Variation on SNR and Path Loss

The experiment examines how altitude affects signal in each frequency band. The scenario is set to rural. The experiment is run for two frequency bands of interest (S and K), with the channel set to

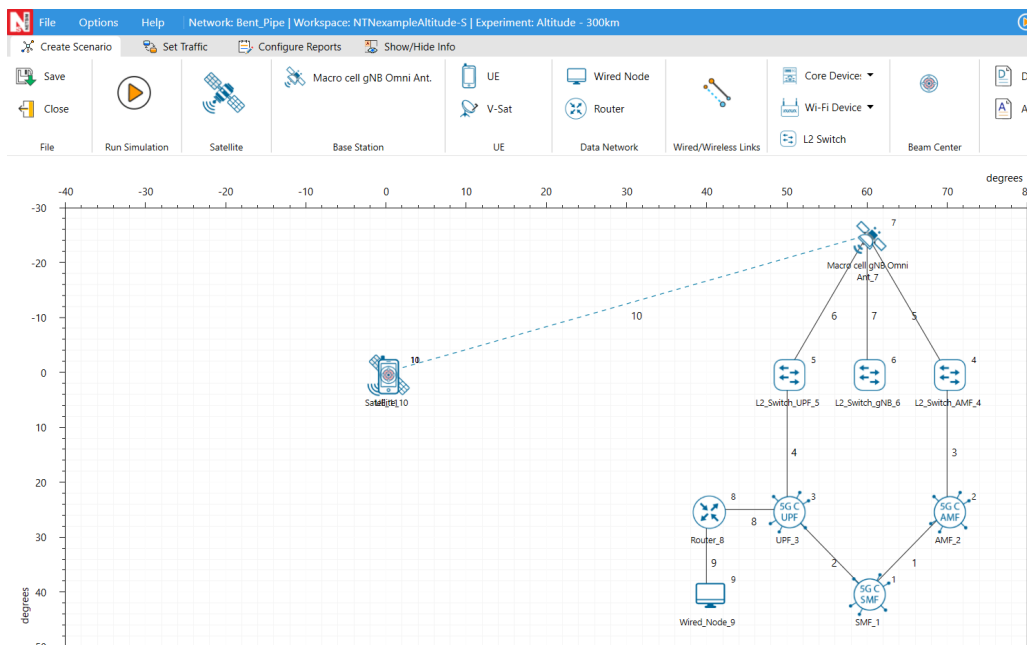
DL. The altitude range spans from 300km to 2100km. Transmitting and receiving antenna powers and characteristics are the same for each altitude.

To simulate this example in NetSim, Open NetSim, Select Examples > Non Terrestrial Network > Impact of LEO Altitude Variation on SNR and Path Loss then click on the tile in the middle panel to load the example as shown in below screenshot.



**Figure 10-1:** List of scenarios for the example of Impact of LEO Altitude Variation on SNR and Path Loss.

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



**Figure 10-2:** Network set up for studying the Impact of LEO Altitude Variation on SNR and Path Loss.

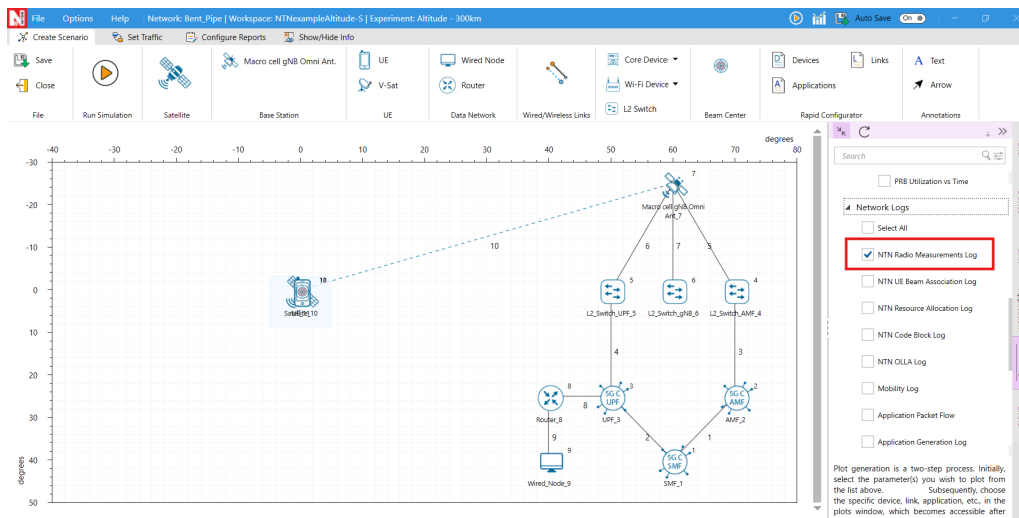
**Settings done in example config file for S band**

- Set the satellite properties as follows. To configure, click on Satellite. On the right side, expand the property panel, go to the Physical Layer of Interface\_2 (Service Link), and set the following properties:

**Table 10-1:** *Input Parameters for Link Budget Simulation Across Multiple Satellite Altitudes.*

Simulation Properties	Values
<b>Satellite ▷ Interface_2 (Service link) properties</b>	
EIRP Density (dBW/MHz)	34
Antenna Aperture Radius (m)	1
Pathloss (dBm)	Free Space
Additional Loss (dB)	0
Shadow Model	None
Outdoor Model	Rural
Altitude (km)	300, 600, 1200, 1500, 1800, 2100
<hr/>	
UE Noise Figure (dB)	7
<hr/>	
<b>gNB ▷ Interface_4 (Feeder link) properties</b>	
CA Configuration	S Band n256
Central Frequency (GHz)	2.185
Channel Bandwidth (MHz)	20

- Enable NTN UE Beam association log by clicking on plots/logs tab on the right side of the panel.



**Figure 10-3:** *Enable NTN Radio measurement log.*

**Pathloss and SINR calculation for 600 km** We consider the satellite co-ordinates as (0, 0) degree and 600 km altitude, and the UE co-ordinates as (0, 0) degree. The elevation angle is calculated as:

$$\alpha = \sin^{-1}\left(\frac{D}{Ru \times L}\right) = 90^\circ \tag{104}$$

Where,

$$Ru = \sqrt{x_{ue}^2 + y_{ue}^2 + z_{ue}^2} \tag{105}$$

$$L = \sqrt{(x_{sat} - x_{ue})^2 + (y_{sat} - y_{ue})^2 + (z_{sat} - z_{ue})^2} \tag{106}$$

$$D = \sqrt{(x_{sat} - x_{ue}) \cdot x_{ue} + (y_{sat} - y_{ue}) \cdot y_{ue} + (z_{sat} - z_{ue}) \cdot z_{ue}} \tag{107}$$

The slant height used in NetSim is per 38.811, equation 6.6-3, i.e.

$$d = \sqrt{R_E^2 \sin^2(\alpha) + h_o^2 + 2h_o R_E - R_E \sin(\alpha)} \tag{108}$$

For a link between a ground station and a LEO satellite operating at 600 km with elevation angle  $\alpha = 90^\circ$ .

$$d = \sqrt{(6.371 \cdot 10^6)^2 \cdot \sin^2(90^\circ) + (6 \cdot 10^5)^2 + 2 \cdot (6 \cdot 10^5) (6.371 \cdot 10^6) - 6.371 \cdot 10^6 \sin(90^\circ)} \tag{109}$$

$$d = 600 \text{ km} \tag{110}$$

The free space pathloss  $PL_{FS}$  for a channel with  $f_c = 2.185 \text{ GHz}$ , or  $\lambda = \frac{c}{f} = 0.15 \text{ m}$ , and  $d = 600 \text{ km}$  is

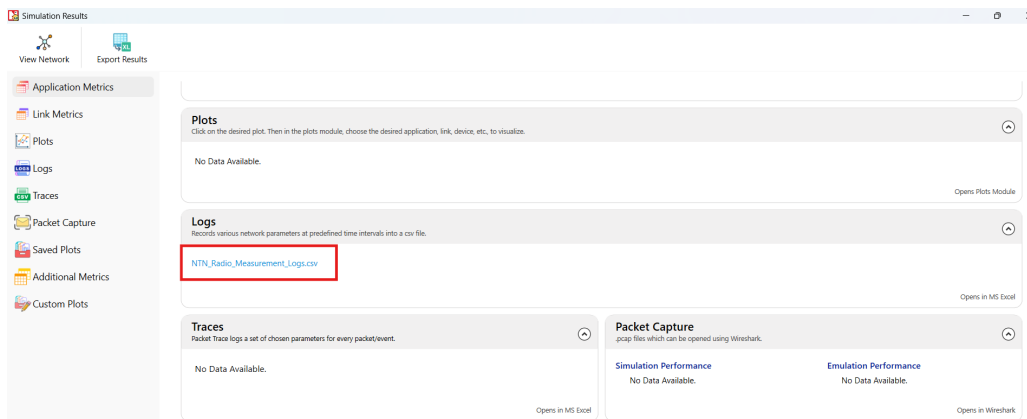
$$PL_{FS} = 20 \log_{10} \left( \frac{4\pi d}{\lambda} \right) = 20 \log_{10} \left( \frac{4\pi (600 \times 10^3) (2.185 \times 10^9)}{3 \times 10^8} \right) = 154.8 \text{ dB} \tag{111}$$

$$CNR = EIRP + G_{Tx} + Rx \frac{G}{T} - k - PL_{FS} - PL_{SM} - PL_{AD} - B \tag{112}$$

$$CNR = 47.01 + 0 + (-31.62) - (-228.6) - (154.8) - 0 - 73.01 \tag{113}$$

$$= 16.17 \text{ dB} \tag{114}$$

**Results** After the simulation, open the NTN UE Radio Measurement.csv under logs section from simulation results window and observe the SNR and pathloss value.



**Figure 10-4:** Opening NTN Radio measurement log from simulation results window.

	K	L	M	N	O	P	Q	R	S	T	U	V	
1	EIRP(dBW)	PathLoss(dB)	ShadowFadingLoss(dB)	AdditionalLoss(dB)	ClutterLoss(dB)	TotalLoss(dB)	BeamFormingGain(dB)	AngularAntennaGain(dB)	UE Rx Antenna Gain(dB)	Rx Power(dBm)	SNR(dB)	SINR(dB)	Therm
2	47.01	154.8	0	0	0	154.8 N/A	0	0	0	-84.64	16.17	16.17	
3	47.01	154.8	0	0	0	154.8 N/A	0	0	0	-84.64	16.17	16.17	
4	47.01	154.8	0	0	0	154.8 N/A	0	0	0	-84.64	16.17	16.17	
5	47.01	154.8	0	0	0	154.8 N/A	0	0	0	-84.64	16.17	16.17	
6	47.01	154.8	0	0	0	154.8 N/A	0	0	0	-84.64	16.17	16.17	
7	47.01	154.8	0	0	0	154.8 N/A	0	0	0	-84.64	16.17	16.17	
8	47.01	154.8	0	0	0	154.8 N/A	0	0	0	-84.64	16.17	16.17	
9	47.01	154.8	0	0	0	154.8 N/A	0	0	0	-84.64	16.17	16.17	
10	47.01	154.8	0	0	0	154.8 N/A	0	0	0	-84.64	16.17	16.17	
11	47.01	154.8	0	0	0	154.8 N/A	0	0	0	-84.64	16.17	16.17	
12	47.01	154.8	0	0	0	154.8 N/A	0	0	0	-84.64	16.17	16.17	
13	47.01	154.8	0	0	0	154.8 N/A	0	0	0	-84.64	16.17	16.17	
14	47.01	154.8	0	0	0	154.8 N/A	0	0	0	-84.64	16.17	16.17	

Figure 10-5: SNR and Pathloss value from NTN UE Beam Association log.

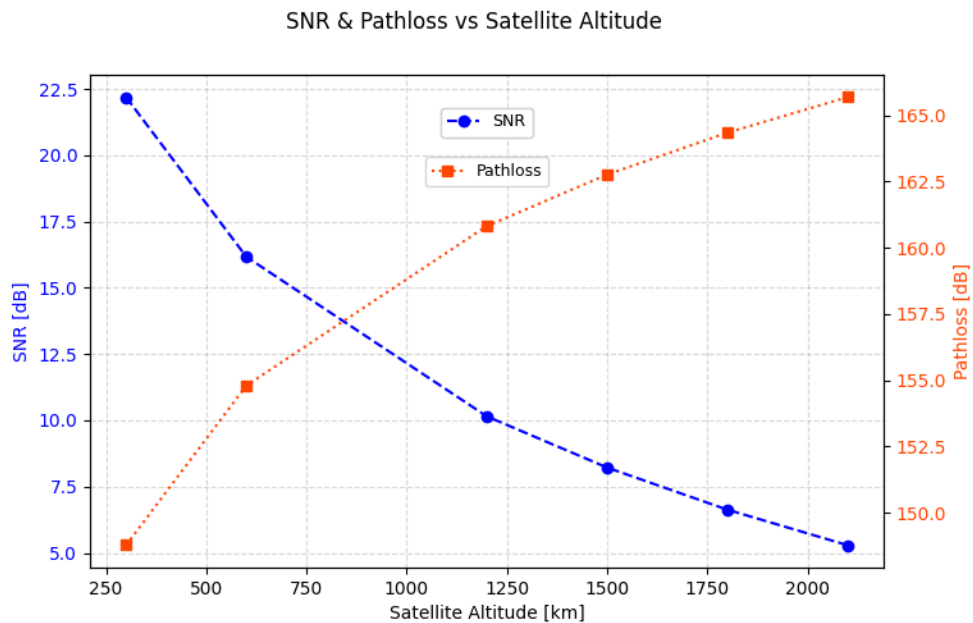


Figure 10-6: Impact of Satellite Altitude on Signal-to-Noise Ratio (SNR) and Pathloss in a Rural Outdoor Scenario.

### Settings done in example config file for K band

- Set the satellite properties as follows. To configure, click on Satellite. On the right side, expand the property panel, go to the Physical Layer of Interface\_2 (Service Link), and set the following properties:

**Table 10-2:** *Simulation settings for K-band altitude variation example.*

Simulation Properties	Values
<b>Satellite ▷ Interface_2 (Service link) properties</b>	
EIRP Density (dBW/MHz)	4
Antenna Aperture Radius (m)	0.25
Pathloss Model	Free Space
Additional Loss (dB)	0
Shadow Fading	None
Outdoor Model	Rural
Altitude	300, 600, 1200, 1500, 1800, 2100
<b>VSAT ▷ Interface_1 (Service Link) properties</b>	
UE Noise Figure (dB)	1.2
Tx/Rx Antenna Gain (dB)	35
<b>gNB ▷ Interface_4 (Feeder link) properties</b>	
CA Configuration	K Band n510
Channel Frequency (GHz)	18.75
Channel Bandwidth (MHz)	200

- Enable NTN UE Beam association log by clicking on plots/logs tab on the right side of the panel.
- Run simulation for 10 seconds.

We consider the satellite co-ordinates as (0,0) degree and 600 km altitude, and the UE co-ordinates as (0,0)degree. The elevation angle is calculated as:

$$\alpha = \sin^{-1}\left(\frac{D}{Ru \times L}\right) = 90^\circ \quad (115)$$

Where,

$$Ru = \sqrt{x_{ue}^2 + y_{ue}^2 + z_{ue}^2} \quad (116)$$

$$L = \sqrt{(x_{sat} - x_{ue})^2 + (y_{sat} - y_{ue})^2 + (z_{sat} - z_{ue})^2} \quad (117)$$

$$D = \sqrt{(x_{sat} - x_{ue}) \cdot x_{ue} + (y_{sat} - y_{ue}) \cdot y_{ue} + (z_{sat} - z_{ue}) \cdot z_{ue}} \quad (118)$$

The slant height used in NetSim is per 38.811, equation 6.6-3, i.e.

$$d = \sqrt{R_E^2 \sin^2(\alpha) + h_o^2 + 2h_o R_E - R_E \sin(\alpha)} \quad (119)$$

For a link between a ground station and a LEO satellite operating at 600 km with elevation angle  $\alpha = 90^\circ$ .

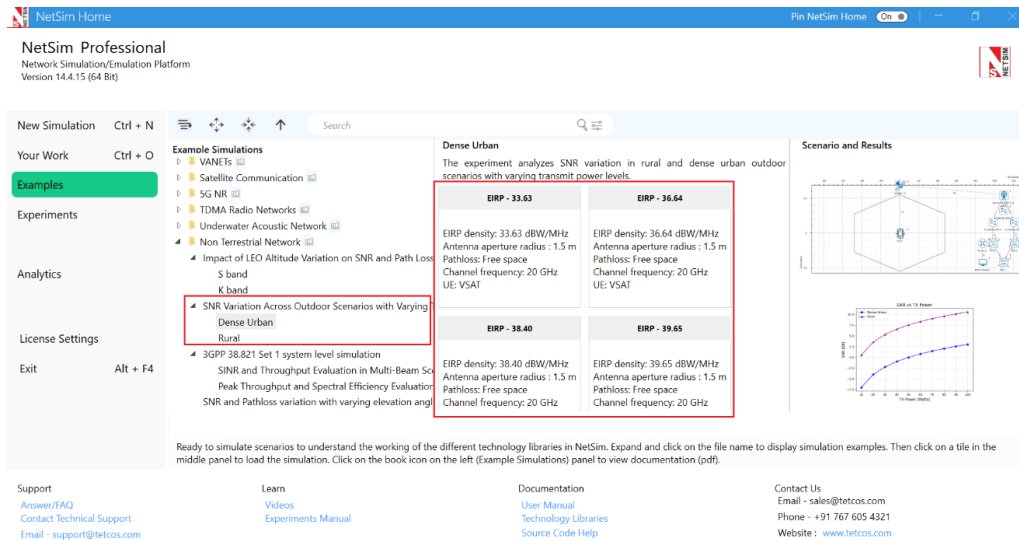
$$d = \sqrt{(6.371 \cdot 10^6)^2 \cdot \sin^2(90^\circ) + (6 \cdot 10^5)^2 + 2 \cdot (6 \cdot 10^5) (6.371 \cdot 10^6) - 6.371 \cdot 10^6 \sin(90^\circ)} \quad (120)$$



and K-band cases are comparable. Although the K-band scenario has higher path loss and lower EIRP input, the use of V-SAT antennas with a receiver gain of 35 dBi compensates for these effects, whereas the S-band scenario uses simulated handheld UEs with nil receiver gain.

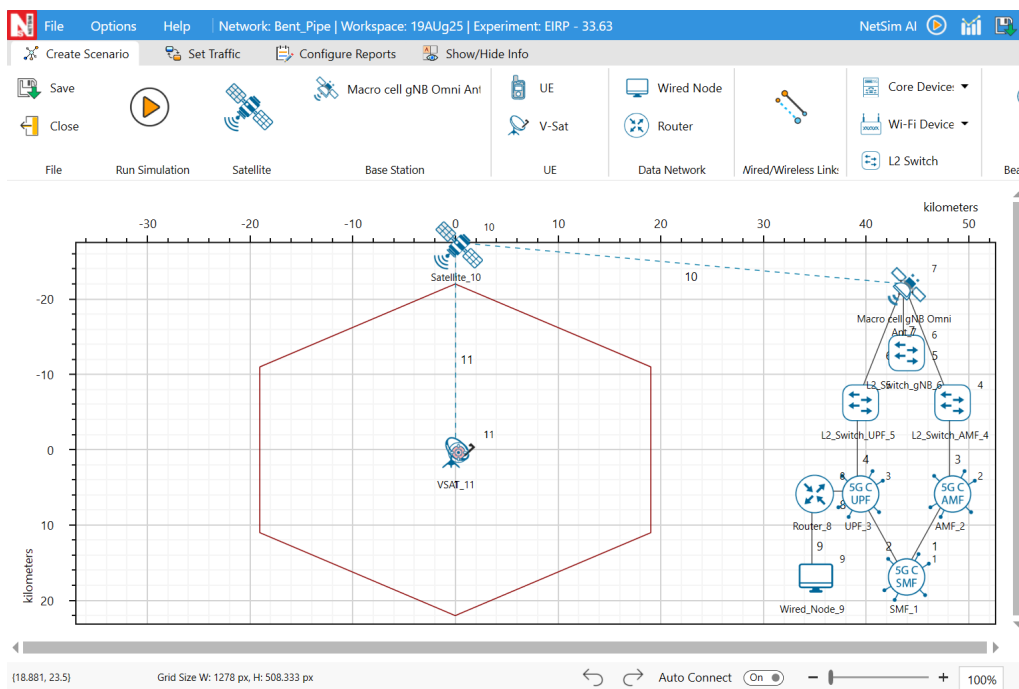
## 10.2 SNR Variation Across Outdoor Scenarios with Varying Transmit Power

To simulate this example in NetSim, Open NetSim, Select Examples > Non Terrestrial Network > SNR Variation Across Outdoor Scenarios with Varying Transmit Power then click on the tile in the middle panel to load the example as shown in below screenshot.



**Figure 10-9:** List of scenarios for the example of SNR Variation Across Outdoor Scenarios with Varying Transmit Power.

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



**Figure 10-10:** Network set up for studying the SNR Variation Across Outdoor Scenarios.

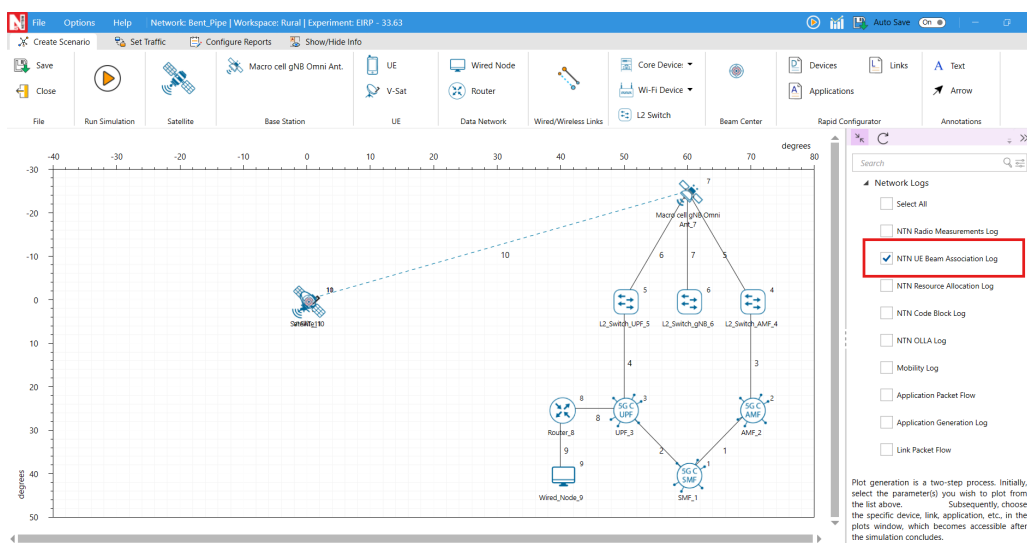
### Settings done in example config file for Dense urban and Rural scenarios

- Set the satellite properties as follows. To configure, click on Satellite. On the right side, expand the property panel, go to the Physical Layer of Interface\_2 (Service Link), and set the following properties:

**Table 10-3:** Simulation settings for SNR variation with transmit power example.

Simulation Properties	Values
<b>Satellite ▷ Interface_2 (Service link) properties</b>	
Antenna Aperture Radius (m)	1.5
Pathloss Model	Free Space
Shadow model	Log Normal
Additional Loss(dB)	0
LOS probability	0 (NLOS)
Clutterloss Model	TR38.811
EIRP Density (dBW/MHz)	33.63, 36.64, 38.40, 39.65, 40.61, 41.41, 42.08, 42.66, 43.17, 43.63
Tx Power (dBm)	40.00, 43.01, 44.77, 46.02, 46.98, 47.78, 48.45, 49.03, 49.54, 50.00
<b>VSAT ▷ Interface_1 (Service Link) properties</b>	
UE Noise Figure (dB)	1.2
Tx/Rx Antenna Gain (dB)	35
<b>gNB ▷ Interface_4 (Feeder link) properties</b>	
CA Configuration	K Band n510
Channel Frequency (GHz)	18.75
Channel Bandwidth (MHz)	400

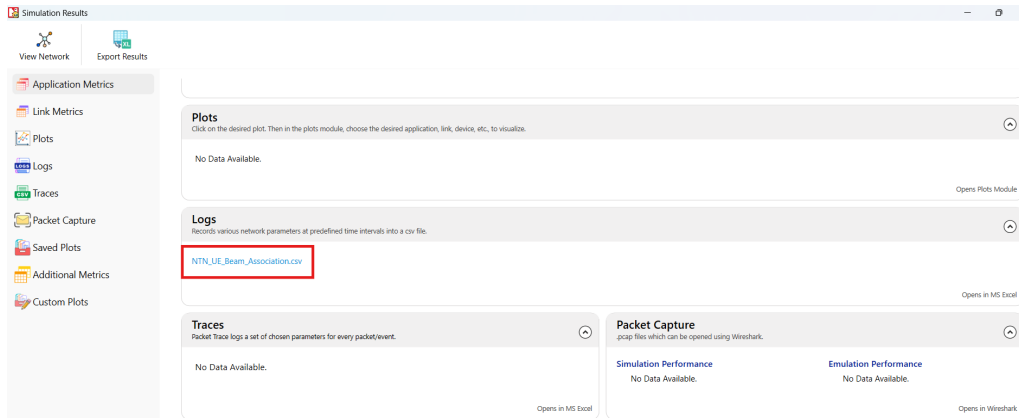
- Enable NTN UE Beam association log by clicking on plots/logs tab on the right side of the panel.



**Figure 10-11:** Enable NTN UE Beam Association log.

- Run Simulation for 10 seconds.

**Results** After the simulation, open the NTN UE Beam Association.csv under logs section from simulation results window and observe the SNR value.

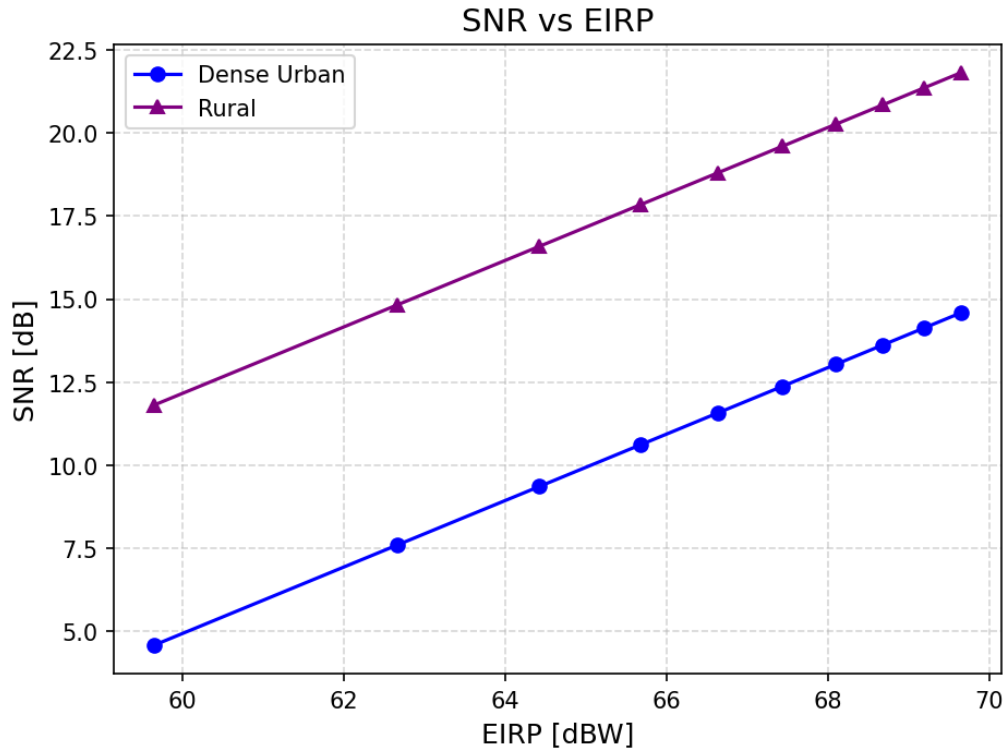


**Figure 10-12:** Opening NTN UE Beam Association log from simulation results window.

	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
	CIR (dB)	Total Loss (dB)	Noise (dBm)	Rx Power (dBm)	FR Channel Id	Channel Bandwidth (MHz)	Interference Power (dBm)	Guard Band BW (MHz)	SNR (dB)	SINR (dB)	Current Beam Id	CQI	MCS Index	Associated Beam
1	N/A	192.97	-87.81	-69.37	1	400	-1000	0	18.43	18.43	1	NA	NA	
2	N/A	192.97	-87.81	-69.37	1	400	-1000	0	18.43	18.43	1	NA	NA	TRUE
3	N/A	205.2	-87.81	-81.6	1	400	-1000	0	6.2	6.2	1	0	0	
4	N/A	205.2	-87.81	-81.6	1	400	-1000	0	6.2	6.2	1	0	0	TRUE
5	N/A	196.02	-87.81	-72.42	1	400	-1000	0	15.39	15.39	1	0	0	
6	N/A	196.02	-87.81	-72.42	1	400	-1000	0	15.39	15.39	1	0	0	TRUE
7	N/A	196.02	-87.81	-72.42	1	400	-1000	0	15.39	15.39	1	0	0	TRUE
8														
9														
10														
11														
12														
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26														

**Figure 10-13:** SNR value from NTN UE Beam Association log.

## Clutter loss enabled and NLOS



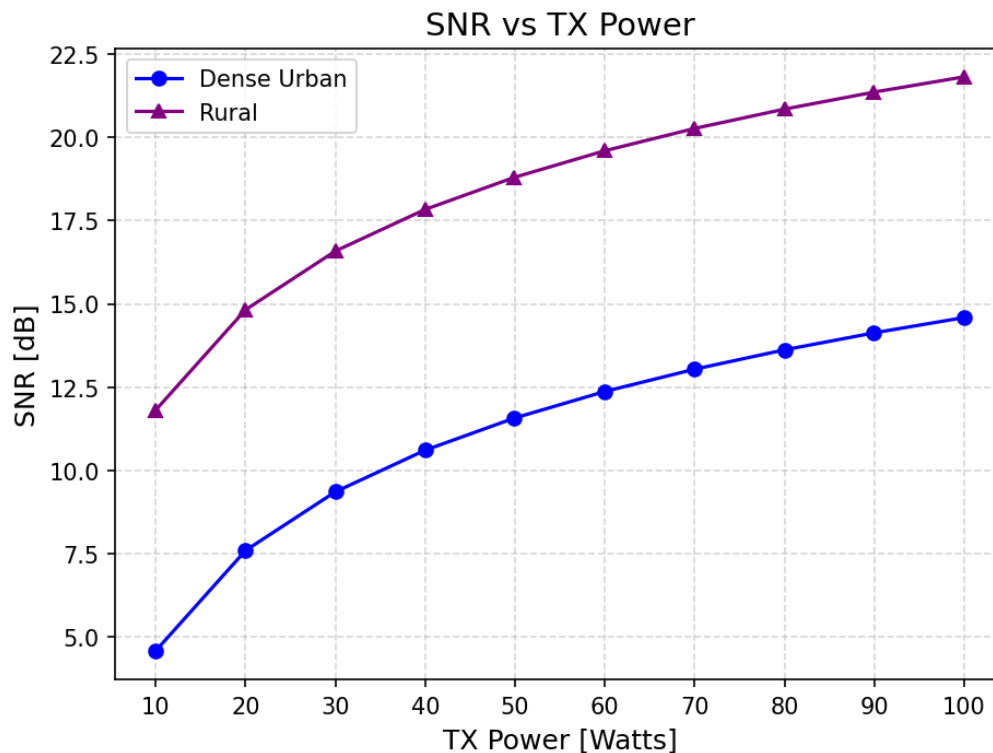
**Figure 10-14:** Effect of EIRP Density on Signal-to-Noise Ratio (SNR) in Rural and Dense Urban.

If we consider 49.65 as Tx antenna gain, and calculate the Tx power based on that,

$$EIRP \text{ [dBW]} = P_{tx} \text{ [dBm]} - 30 + G_{Tx} \text{ [dBi]} \tag{126}$$

$$59.65 = P_{tx} \text{ [dBm]} - 30 + 49.65 \tag{127}$$

$$P_{tx} \text{ [dBm]} = 40 \tag{128}$$

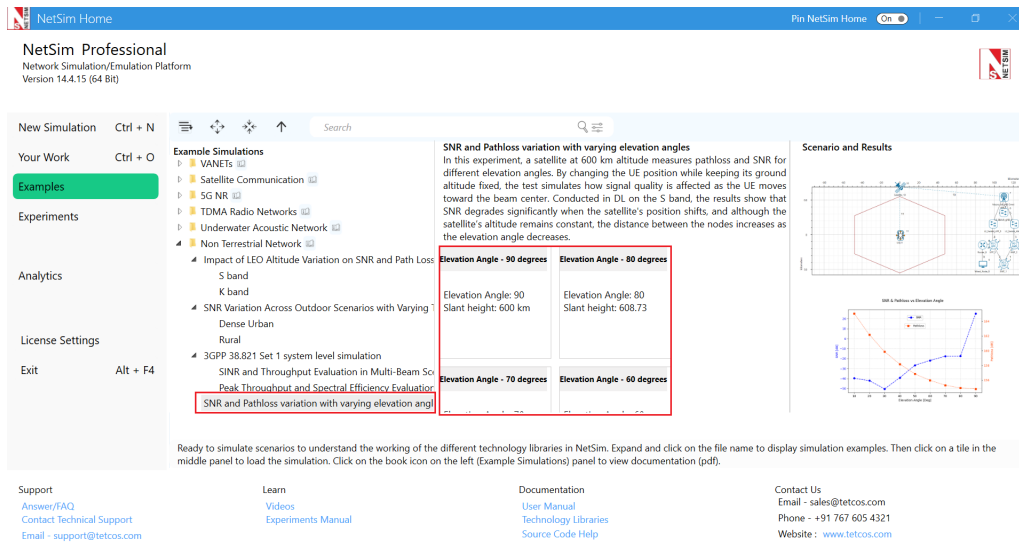


**Figure 10-15:** *Effect of Transmit Power on Signal-to-Noise Ratio (SNR) in Rural and Dense Urban.*

### 10.3 SNR and Pathloss variation with varying elevation angles

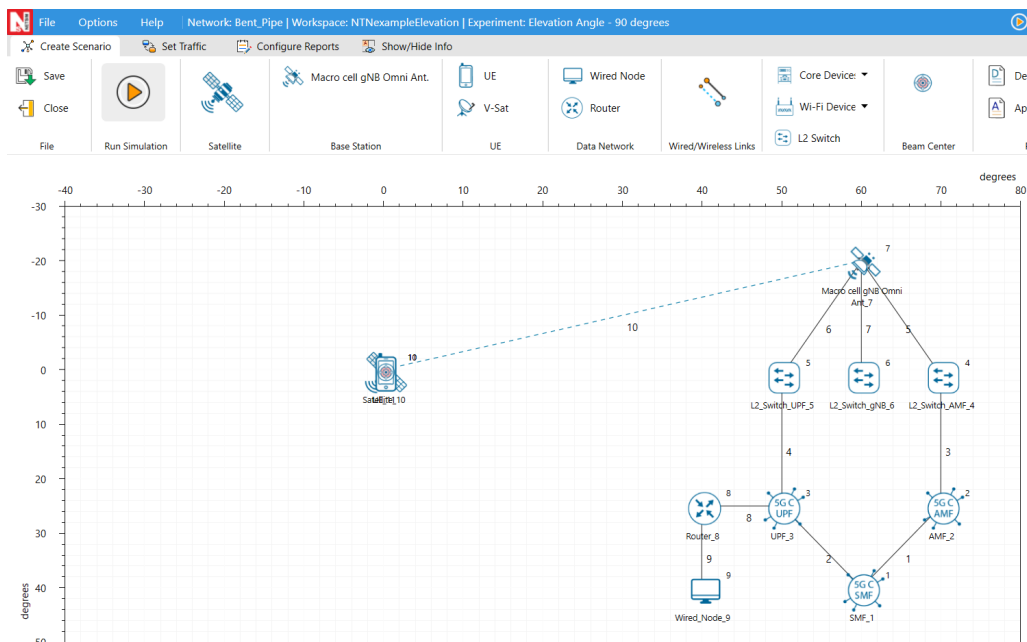
In this experiment, a satellite at an altitude of 600km is deployed to measure pathloss and SNR values for different elevation angles. Changing the UE position, but keeping its altitude from ground fixed, aims at simulating how the signal might be affected as a UE moves towards the beam center. The test is performed in DL on the S band. The simulations are performed for every scenario. The results show how dramatically the elevation angle affects the signal, with SNR values that experience an immediate degradation when going from communicating with a satellite that is perfectly positioned to one that is slightly shifted. Elevation angle however, is not the only factor that changes, since the altitude from ground of the satellite is kept the same throughout the test, the distance between the communicating nodes is increasing with the diminishing of the elevation angle.

To simulate this example in NetSim, Open NetSim, Select Examples > Non-Terrestrial Network > SNR and Pathloss variation with varying elevation angles then click on the tile in the middle panel to load the example as shown in below screenshot.



**Figure 10-16:** List of scenarios for the example of SNR and Pathloss variation with varying elevation angles.

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



**Figure 10-17:** Network set up for studying the SNR and Pathloss variation with varying elevation angles.

**Settings in the example config file**

**Table 10-4:** Slant Height vs. Elevation Angle in Satellite Geometry.

Elevation Angle	90	80	70	60	50	40	30	20	10
Slant height km	600	608.29	634.78	682.83	760.90	882.24	1073.43	1393.22	1932.84

**Results** Based on the UE position, the Elevation Angle and Slant Height (km) will change, these values can be observed from NTN UE Beam Association log.

	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
1	UE Rx Antenna Gain(dB)	CIR(dB)	TotalLoss(dB)	Noise(dBm)	Rx Power(dBm)	FR Channel Id	Channel Bandwidth(MHz)	Interference Power(dBm)	Guard Band BW(MHz)	SNR(dB)	SINR(dB)	Current Beam Id	CQI	MCS
2	0	N/A	155	-100.82	-85.84	1	20	-1000	0	14.97	14.97	1	NA	NA
3	0	N/A	155	-100.82	-85.84	1	20	-1000	0	14.97	14.97	1	NA	NA
4	0	N/A	155.77	-100.82	-86.61	1	20	-1000	0	14.21	14.21	1	NA	NA
5	0	N/A	155.77	-100.82	-86.61	1	20	-1000	0	14.21	14.21	1	0	0
6	0	N/A	155.19	-100.82	-86.03	1	20	-1000	0	14.78	14.78	1	0	0
7	0	N/A	155.19	-100.82	-86.03	1	20	-1000	0	14.78	14.78	1	0	0

Figure 10-18: Slant height and Elevation angle in NTN UE Beam Association log.

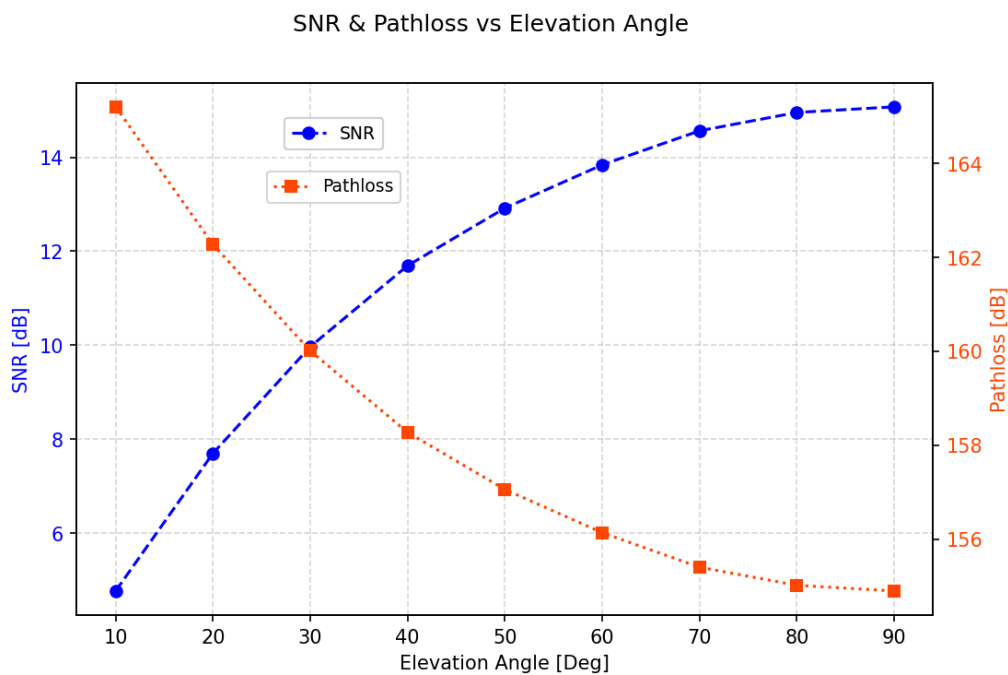


Figure 10-19: Impact of Elevation Angle on Signal-to-Noise Ratio (SNR) and Pathloss in a Satellite Link.

## 10.4 3GPP 38.821 Set 1 system level simulation

### 10.4.1 Introduction

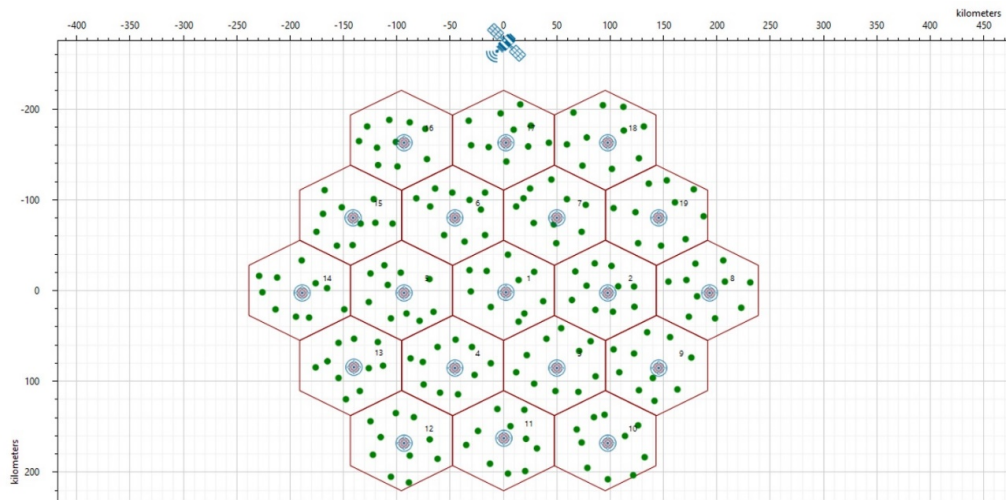
This simulation is based on the Set 1 Reference Scenario from 3GPP TR 38.821, which provides guidelines for evaluating the performance of Non-Terrestrial Networks (NTN) with Low Earth Orbit (LEO) satellites. In this setup, the satellite uses a transparent payload, meaning it acts as a relay, passing signals between the ground gateway and the User Equipment (UE).

### 10.4.2 Objective

The goal is to measure the distributions and percentiles of SINR and throughput across multiple spot beams, with each beam containing multiple UEs.

### 10.4.3 Part 1: Network Scenario

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



**Figure 10-20:** 19 beams arranged in a hexagonal layout; S-band, LEO orbit; total 190 UEs (10 UEs per beam) connected via a transparent satellite relay with full buffer DL traffic.

#### 10.4.4 Simulation Setup

To create this scenario, we have:

- Set the Grid length to  $450 \times 200$
- Dropped 19 beams in a hexagonal grid layout.
- Randomly placed 10 UEs in each beam (total of 190).
- Set the Band to S-band and Frequency reuse to FR1.
- Selected LEO 600 from the orbit options to configure a Low Earth Orbit at 600 km altitude.
- Simulation time is set to 30 seconds.

### 10.4.5 Parameter configuration

**Table 10-5:** *System simulation parameters.*

Evaluation parameters	Values
<b>Satellite &gt; Interface_2 (Service link) properties</b>	
Satellite Orbit	LEO 600
Satellite altitude	600 km
EIRP (dBW/MHz)	34
Antenna aperture (m)	1
Traffic	Full buffer DL
RU%	100%
Elevation angle	Beam centres are at elevation angle 90°. The UE's elevation angle would depend on its location within the beam.
Antenna pattern	Bessel function per section 6.4.1 of TR 38.811. All UEs are not at the Nadir point and hence antenna gains need to be computed.
Additional loss(dB)	0
Clutter loss (dB)	0
UE density	10 UEs per spot beam
Antenna temperature (k)	290
<b>UE &gt; Interface_1 (Service Link) properties</b>	
UE Noise Figure (dB)	7
UE mobility	No mobility
<b>gNB &gt; Interface_4 (Feeder link) properties</b>	
Band	S
CA Configuration	S Band n256
Central Frequency (GHz)	2.185
Bandwidth (MHz)	30 per beam
Downlink Scheduling Type	Round robin

### Application properties

- Created a CBR application from Wired Node 9 to all UEs from the set traffic tab in the ribbon on top. Click on the created application, and in the right-side property panel, set the packet size to 1460B and Interarrival time to 584  $\mu$ s, keeping the other application properties as default. This creates a generation rate of 20 Mbps ensuring full buffer at each UE.

**Table 10-6:** *Application properties.*

Application settings	
Packet size(B)	1460
Inter arrival time ( $\mu$ s)	584
Generation rate (Mbps)	20

The NTN Radio measurement log, NTN Resource allocation log and Application packet flow log files must be enabled from the design window.

Log files can be enabled by clicking on the icon in Configure Reports > Plots > Network Logs option as shown below

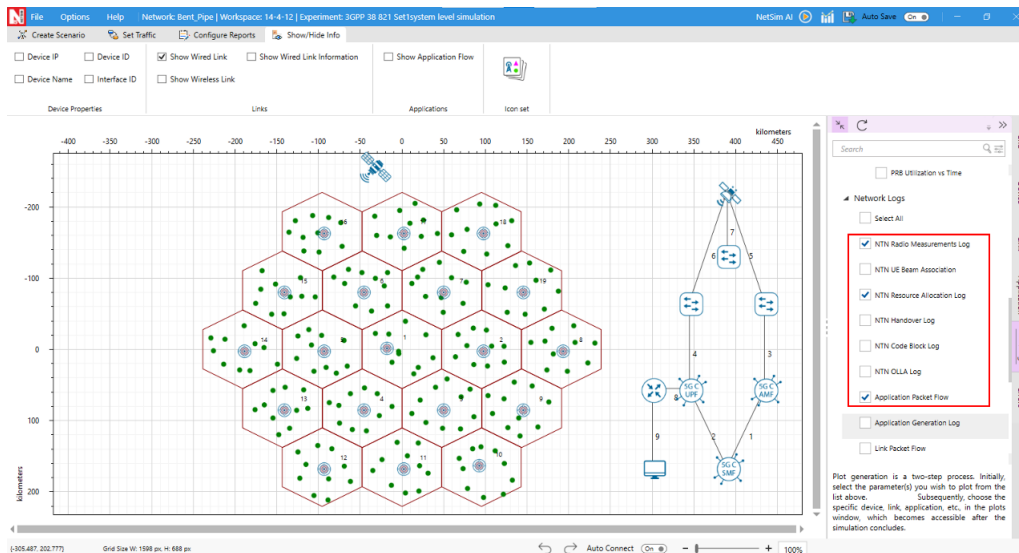


Figure 10-21: Enabling the Log files.

- Run simulation for 30s, after the simulation completes, go to results window click on logs options and open NTN Radio Measurement Log.csv, note down the SINR, and from the Application packet flow log note down the Throughput for each application.

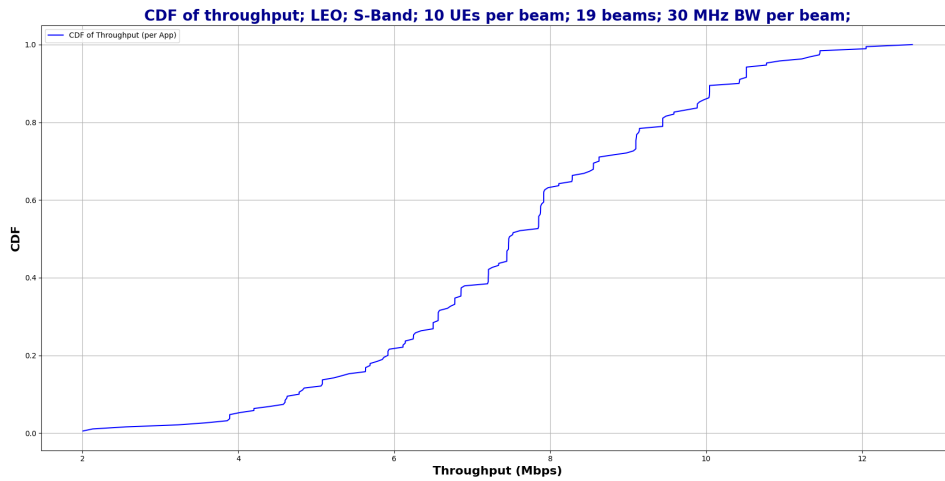
Link ID	Pkts. Tx'd.			Pkts. Err'd.			Pkts. Collided			Bytes Tx'd. B	Payload Tx'd. B	Overhead Tx'd. B
	Data	Control		Data	Control		Data	Control				
0	3760278	10	0	0	0	0	0	0	5628365510	5490005880	138359630	
1	0	2	0	0	0	0	0	0	328	0	328	
2	0	2	0	0	0	0	0	0	328	0	328	
3	0	3	0	0	0	0	0	0	570	0	570	
4	421921	0	0	0	0	0	0	0	638788394	616004660	22783734	
5	0	3	0	0	0	0	0	0	570	0	570	
6	421921	0	0	0	0	0	0	0	638788394	616004660	22783734	
7	0	0	0	0	0	0	0	0	0	0	0	
8	2488353	0	0	0	0	0	0	0	3702669264	3632995380	69673884	
9	428083	0	0	0	0	0	0	0	648117662	625001180	23110482	
10	0	0	0	0	0	0	0	0	0	0	0	
11	0	0	0	0	0	0	0	0	0	0	0	

Figure 10-22: Results window.

### 10.4.6 Results and Discussion

The results of the simulation are shown using CDF plots for SINR, UE Throughput and Beam throughput.

- To generate CDF of throughput plot, the Throughput column from the Application packet flow log file was considered, and the CDF of throughput was plotted.

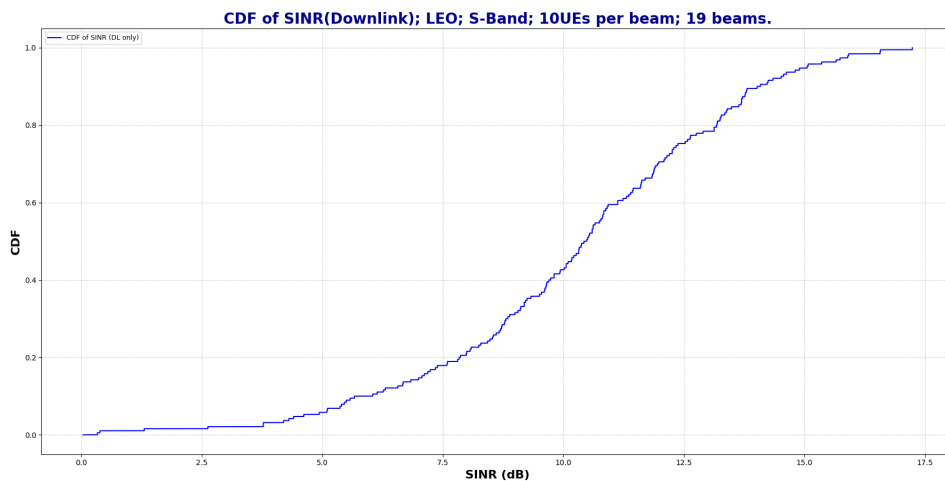


**Figure 10-23:** CDF of downlink throughput per UE; LEO satellite network using S-Band with 19 beams and 10 UEs per beam.

**Table 10-7:** Throughput percentile metrics.

Throughput percentile metrics	
5 <sup>th</sup> percentile	4.101 Mbps
50 <sup>th</sup> percentile	7.473 Mbps
95 <sup>th</sup> percentile	10.774 Mbps

To generate CDF of SINR plot, the SINR column from the radio measurement log file was considered, and the CDF of SINR was plotted.

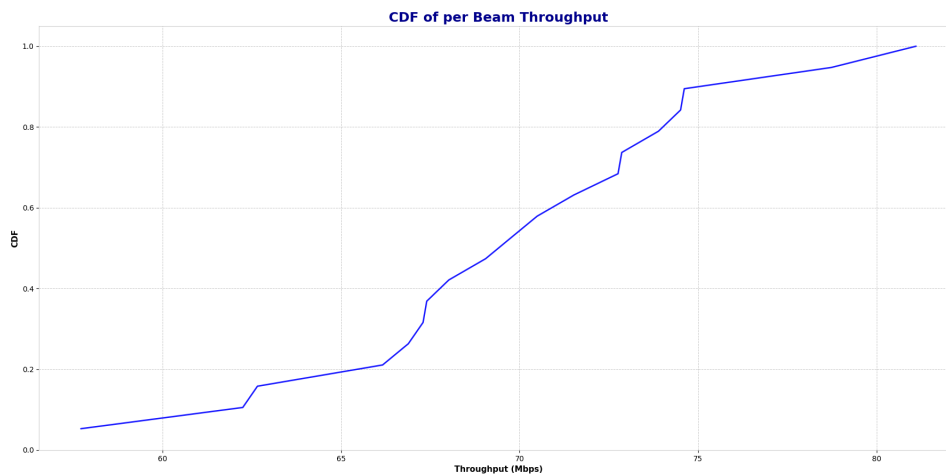


**Figure 10-24:** CDF of SINR; LEO; S-Band; 10 UEs per beam; 19 beams.

**Table 10-8:** SINR percentile metrics.

SINR percentile metrics	
5 <sup>th</sup> percentile	4.62 dB
50 <sup>th</sup> percentile	10.47 dB
95 <sup>th</sup> percentile	15.06 dB

To generate CDF of per beam throughput plot, the throughput for each application was taken from the results window. The number of UEs associated with each beam was obtained from the resource allocation log file, and the CDF of throughput per beam was then plotted.



**Figure 10-25:** CDF of Per-Beam Throughput.

**Table 10-9:** Per-Beam Throughput percentile metrics.

Per-Beam Throughput percentile metrics	
5 <sup>th</sup> percentile	61.79 Mbps
50 <sup>th</sup> percentile	69.77 Mbps
95 <sup>th</sup> percentile	78.97 Mbps

The SINR CDF shows how the signal quality changes based on the user’s location within a beam. UEs near the beam center usually have better SINR, while edge UEs see lower values due to reduced antenna gain.

The throughput CDF shows how throughput is distributed among UEs. The scheduling is Round Robin scheduling and all UEs have full buffer traffic. UEs with higher SINR achieve slightly better throughput.

The per-beam throughput CDF shows how sum throughput varies across beams. Each beam has the same bandwidth and number of UEs, but performance depends on SINR which depends on UE location within the beam. Due to randomness in the UE positions we see a distribution in the per beam throughputs.

**Satellite capacity**

- Satellite capacity = 1278.53 Mbps (Sum throughput of all 190 UEs)

**Area Traffic capacity**

- Number of beams = 19
- Beam radius,  $R = 55.13$  km
- Area per beam (A) =  $\frac{3\sqrt{3}}{2}R^2 = \frac{3\sqrt{3}}{2}(55.13)^2 = 7887.1$  km<sup>2</sup>
- Total coverage area =  $7887.1$  km<sup>2</sup>  $\times 19 = 149854.9$  km<sup>2</sup>
- Area Traffic Capacity

$$\frac{1278.53 \text{ Mbps}}{149854.9 \text{ km}^2} = 0.008531 \times 1000 \text{ kbps/km}^2 = 8.531 \text{ kbps/km}^2 \tag{129}$$

### Average Spectral efficiency

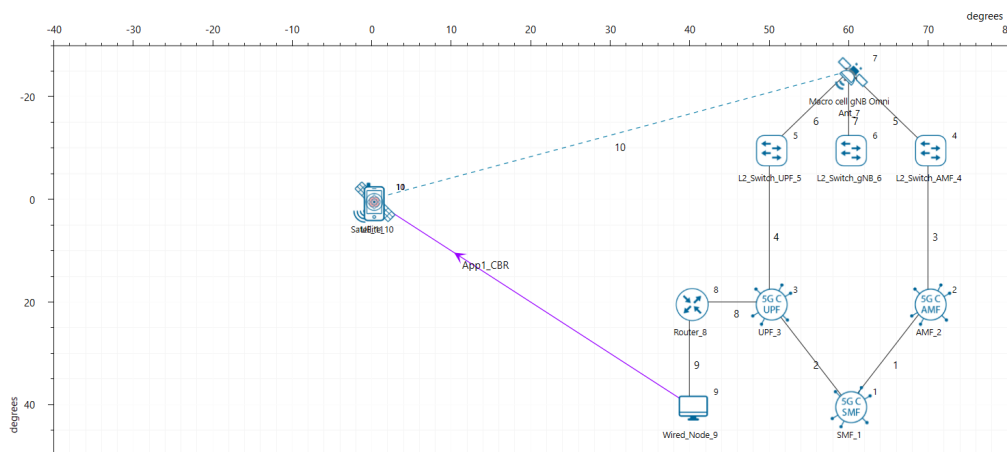
- Channel Bandwidth = 30 MHz
- Number of TRxPs = 19

$$\frac{\text{Aggregate Throughput(bps)}}{\text{Bandwidth(Hz)} \times \text{Number of TRxPs}} = \frac{1278.53 \times 10^6}{30 \cdot 10^6 \times 19} = 2.24 \text{ bits/s/Hz/TRxP.}$$

### 10.4.7 Part 2: Peak Throughput and Spectral Efficiency Evaluation

In this simulation scenario, 1 UE is placed at the nadir point, and the full system bandwidth of 30 MHz is allocated to that single user. The maximum number of Physical Resource Blocks (PRBs) supported by 30 MHz at numerology  $\mu = 0$  is 160 PRBs. A full buffer downlink traffic model is used, with a generation rate of 125 Mbps.

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



**Figure 10-26:** Network Scenario.

**Simulation Setup** To create this scenario, we have:

- Set the Grid length to  $120 \times 40$  km
- Dropped a single beam in a hexagonal grid layout.
- Placed the UE at the center of the beam footprint.
- Set the Band to S-band and Frequency reuse to FR1.

- Selected LEO 600 from the orbit options to configure a Low Earth Orbit at 600 km altitude.
- Simulation time is set to 50 seconds.

## Parameter configuration

**Table 10-10:** *Simulation parameters.*

Evaluation parameters	Values
Satellite Orbit	LEO 600
Satellite altitude	600 km
Slant height	600 km
EIRP (dBW/MHz)	34
Noise Figure (dB)	7
Antenna aperture (m)	1
Band	S
Frequency	2 GHz (S Band)
Bandwidth (MHz)	30 per beam
Downlink Scheduling Type	Round robin
Traffic	Full buffer DL
RU%	100%
Elevation angle(°)	90
Antenna pattern	Bessel function per section 6.4.1 of TR 38.811.
Pathloss (dB)	154
Additional loss (dB)	0
Clutter loss (dB)	0
UE density	1 UE
UE mobility	No mobility
Antenna temperature (k)	290
UE TX power (dBm)	23
UE RX Antenna Gain (dB)	0

## Application Properties

- Created a CBR application from Wired Node 9 to UE 11 from the set traffic tab in the ribbon on top. Click on the created application, and in the right-side property panel, set the packet size to 1460B and Interarrival time to 93.44  $\mu$ s, keeping the other application properties as default. This creates a generation rate of 125 Mbps ensuring full buffer at each UE.

**Table 10-11:** *Application settings.*

Application settings	
Packet size(B)	1460
Inter arrival time ( $\mu$ s)	93.44
Generation rate (Mbps)	125

**Theoretical Spectral Efficiency Computation** As per Annex 1 of the ITU-2020-NTN framework, the theoretical peak spectral efficiency is given by:

$$SE_p = \frac{v_{Layers} \cdot Q_m \cdot f \cdot R_{max} \cdot \frac{N_{PRB}^{BW,\mu} \times 12}{T_s^\mu} \cdot (1 - OH)}{BW} \quad (130)$$

The NTN code block log file must be enabled from the design window. MCS value can be observed from the code block log file.

Log file can be enabled by clicking on the icon in Configure Reports > Plots > Network Logs option as shown below

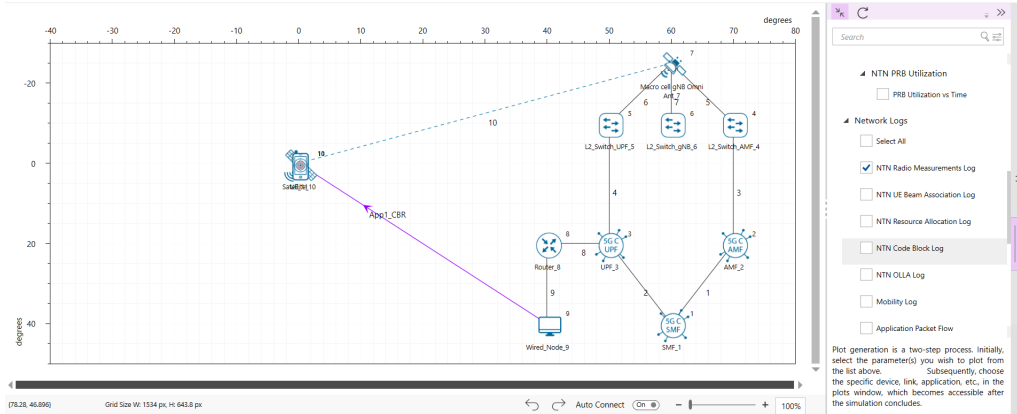


Figure 10-27: Enabling the NTN Radio measurements log file.

**Where**

Number of layer,  $\nu = 1$

Modulation order ( $Q_m$ ) = 6

Coding rate ( $R$ ) = 0.852

Numerology ( $\mu$ ) = 0

Overhead,  $OH = 0.14$

Bandwidth = 30 MHz.

$N_{PRB}^{BW,\mu}$  is the maximum Resource Block (RB) allocation in UE supported maximum bandwidth  $BW$  in a given band with numerology  $\mu$ .

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

$$T_s^\mu = \frac{10^{-3}}{14 \times 2^\mu} = \frac{0.001}{14} = 0.00007143$$

$$\frac{N_{PRB}^{BW,\mu} \times 12}{T_s^\mu} (1 - OH) = \frac{160 \times 12 \times (1 - 0.14)}{0.00007143} = 23.11 \times 10^6$$

$$SE_p = \frac{1 \times 6 \times 0.852 \times 23.11 \times 10^6}{30 \times 10^6} = \frac{5.112 \times 23.11}{30} = 3.94 \text{ b/s/Hz}$$

**Results and discussion** From the simulation results:

Achieved throughput = 105.65 Mbps

MCS Index = 21

Modulation = 64-QAM

Coding rate ( $R$ ) = 0.852

Bandwidth = 30 MHz.

$$\text{Observed Spectral Efficiency (SE)} = \frac{\text{Achieved Throughput (bps)}}{\text{Bandwidth (Hz)}} = \frac{105.65 \times 10^6}{30 \times 10^6} = 3.52 \text{ bits/sec/Hz}$$

**Table 10-12:** *Simulation results.*

<b>Simulation Results</b>	
Throughput (Mbps)	105.65
MCS	21
Spectral efficiency (bits/s/Hz)	3.52

Thus, the theoretical peak spectral efficiency as per the ITU-2020-NTN Annex 1 formula is 3.94 bits/sec/Hz, while the observed spectral efficiency from the simulation is 3.52 bits/sec/Hz. This small gap reflects practical network conditions such as protocol overhead, scheduling inefficiencies, and real-time radio impairments.

## 11 Limitations and assumptions

- Antenna polarization is not taken into account
- NetSim does not model the DU, CU split in the gNB
- No support for co-existence between NTN and TN
- No support for RACH procedure. It is assumed to be ideal
- Broadcast and multicast transmissions are not supported
- UE/VSAT, satellite and gNBs are assumed to be perfectly synchronized in frequency and time
- No support for earth moving tracking area
- Every UE has the appropriate Doppler compensation mechanisms.
- Every UE calculates the propagation delay variation between UE and satellite and perfectly estimates the full timing advance.
- Telemetry, Tracking, Command and Monitoring unit (TTC) link is out of the scope of the Study Item and of the 3GPP realm
- Feeder link switchover is not modelled since NetSim currently only models a single terrestrial gNB.
- The satellite is always positioned directly above the main beam, which is at the center of the simulation area.
- Earth is assumed to be flat.
- Beam radius is much smaller than the radius of the earth.
- Both UEs and Satellite use X, Y, Z co-ordinates with X, Y plane on earth and with Z represents the height above earth.
- Ideal Doppler compensation. UEs are assumed to have GNSS capability to pre-compensate Doppler and delay using satellite ephemeris and location.
- HARQ is disabled
- Handover between beams is assumed to be instantaneous without any control packet exchange
- Perfect symbol-level timing advance
- Perfect channel state information at transmitter and receiver
- NTN scenarios run in RLC-UM mode without factoring in the following timers: t-Reordering timer, t-Reassemble timer, T300, T301 and T311 timers.
- The NTN standards include a new SIB, i.e. SIB 19. This is currently not supported and the SIB/MIB implementation is per terrestrial 5G.

- The satellite shifts the signal frequency, amplifies the signal, and transmits it. The satellite receives signals on one of its receive (Rx) interfaces. The antenna gain is added to the received signal. The configured power sensitivity is used to accept the signal. The signal is then amplified (this amplification is not applied to the noise) and the signal frequency is up shifted or down shifted. Then this signal is forwarded to the transmit (Tx) interface associated with the Rx interface on which the signal was received.