NetSim®

Accelerate Network R & D

5G NTN

A Network Simulation & Emulation Software

By



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Contents

1 Introduction **5**
- 1.1 Earth fixed spot beams and cells . . . 8
- 1.2 Bands . . . 10
- 1.3 Band Frequency Information . . . 12
- 1.4 Simulation GUI . . . 15
  - 1.4.1 Startup window options . . . 15
- 1.5 Multi-Satellite NTN . . . 16
- 1.6 Configure Non-Terrestrial Networks . . . 20
- 1.7 Set device properties . . . 20
- 1.8 Configure reports . . . 22
- 1.9 GUI Parameters . . . 23
- 1.10 Mobility model in NTN . . . 33

2 Link budget **34**
- 2.1 Uplink Link Budget . . . 35
- 2.2 Link Budget Calculations: Example 1 LEO 600 . . . 40
- 2.3 Link Budget Calculations: Example 2 LEO 1200 . . . 41

3 Satellite Antenna Pattern **42**
- 3.1 TR 38.811 Antenna model . . . 43
- 3.2 ITU-R S.672 Antenna model . . . 43
- 3.3 Gaussian Antenna Gain Model . . . 44
- 3.4 Phased-Array Antenna Model . . . 45
  - 3.4.1 Phased-array properties . . . 45
  - 3.4.2 Array frame and mobility . . . 46
  - 3.4.3 Enforced constraints . . . 46
- 3.5 Off Boresight Angle Calculation . . . 46
- 3.6 External Antenna Pattern . . . 47
  - 3.6.1 Pattern coordinates and gain . . . 47
  - 3.6.2 Supported input files . . . 47
  - 3.6.3 Configuration properties . . . 48
  - 3.6.4 Direction ownership and link-budget use . . . 49
- 3.7 Off Boresight Angle Calculation . . . 49
- 3.8 Link Budget Calculations: Example 3 LEO 600 and LEO 1200 . . . 51

4 NTN BLER **52**
- 4.1 User-Configurable BLER . . . 53

5 Uplink Scheduling **53**
- 5.1 NetSim Implementation . . . 53
- 5.2 Downlink Scheduler . . . 54

6 Interference Models **54**
- 6.1 CIR based Interference . . . 54
- 6.2 Link Budget Calculations: Example 4 LEO 600 and LEO 1200 . . . 54

7 Radio Measurements Log **55**

8 Frequency Reuse **57**

9 Link Budget with Interference **58**
- 9.1 Calculations for FRF 1 . . . 59
- 9.2 Calculations for FRF 3 . . . 60

10 Beam Radius Calculations **61**
- 10.1 Hexagonal tessellation based on beam radius . . . 62

11 Featured Examples **63**
- 11.1 Impact of LEO Altitude Variation on SNR and Path Loss . . . 63
- 11.2 SNR Variation Across Outdoor Scenarios with Varying Transmit Power . . . 69
- 11.3 SNR and Pathloss variation with varying elevation angles . . . 73

11.4 Verification of NetSim results against the 3GPP TR 38.821 Set 1 calibration 76
11.4.1 Objective 76
11.4.2 3GPP reference scenario 76
11.4.3 Calibration case matrix 76
11.4.4 Simulation setup 77
11.4.5 Parameter configuration 79
11.4.6 Application properties 79
11.4.7 Log configuration 80
11.4.8 Results and Discussion 80
11.4.9 Part 2: Peak Throughput and Spectral Efficiency Evaluation 82
11.5 Aircraft mobility over 5G NTN satellites 86
11.5.1 Summary 86
11.5.2 Problem statement 87
11.5.3 Approach 87
11.5.4 Simulation setup 88
11.5.5 Network topology and mobility 89
11.5.6 Why the serving satellite changes 90
11.5.7 Serving-satellite timeline and service availability 91
11.5.8 50-satellite and 100-satellite comparison 92
11.5.9 Interpretation against aircraft connectivity 95
11.6 UE–Satellite Service Link Study 96
11.6.1 Summary 96
11.6.2 Problem statement 96
11.6.3 Approach 96
11.6.4 Simulation setup 96
11.6.5 Network topology and node placement 98
11.6.6 Why the serving link changes 98
11.6.7 Results 99
11.6.8 Interpretation 100
12 Limitations and assumptions **101**

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.

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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 an ideal 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

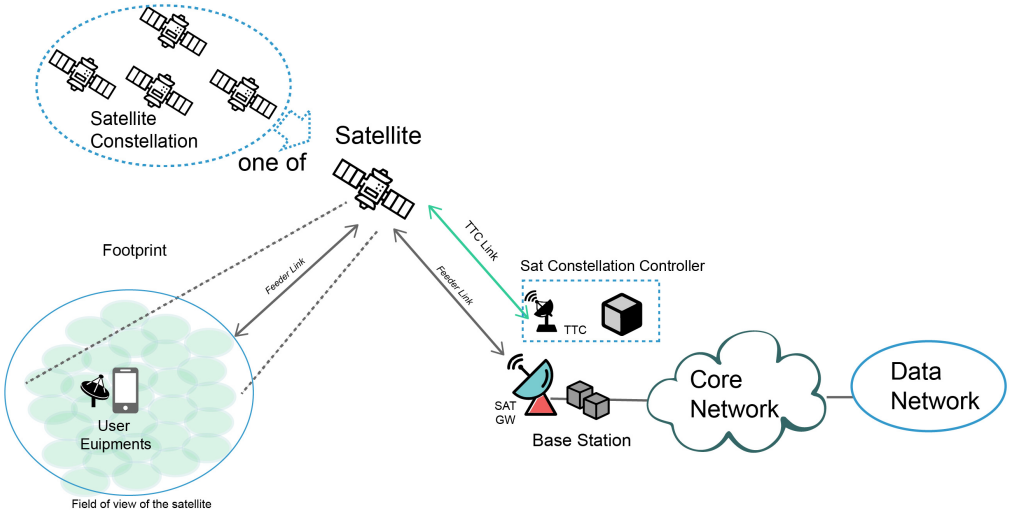


Figure 1-1: *Architecture of 5G Non terrestrial network with LEO/MEO satellites. The satellite communication with the ground station is over an ideal feeder link having 1-spot beam and communication with the UEs is over a service link having multiple spot beams. UEs can be placed within these beams (or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

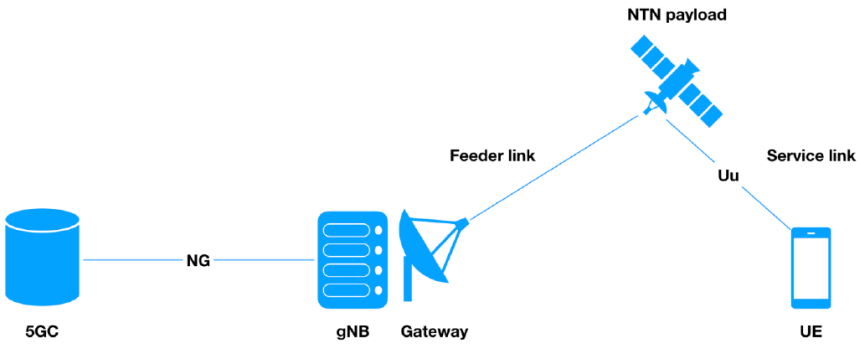


Figure 3: NTN architecture with transparent payload.

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. In NetSim, this feeder link is modeled as an ideal link except for propagation latency. 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.

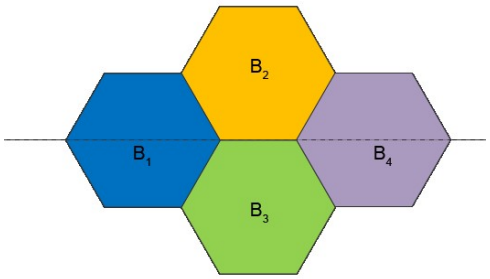


Figure 1-3: *Top view of four tessellated spot beams on the service link. In NetSim, UEs will associate to the beam which provides the highest signal strength. Per 3GPP standards, the mapping of satellite beams to terrestrial cells is one-to-one. Each beam is one physical cell. Thus, we will refer to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

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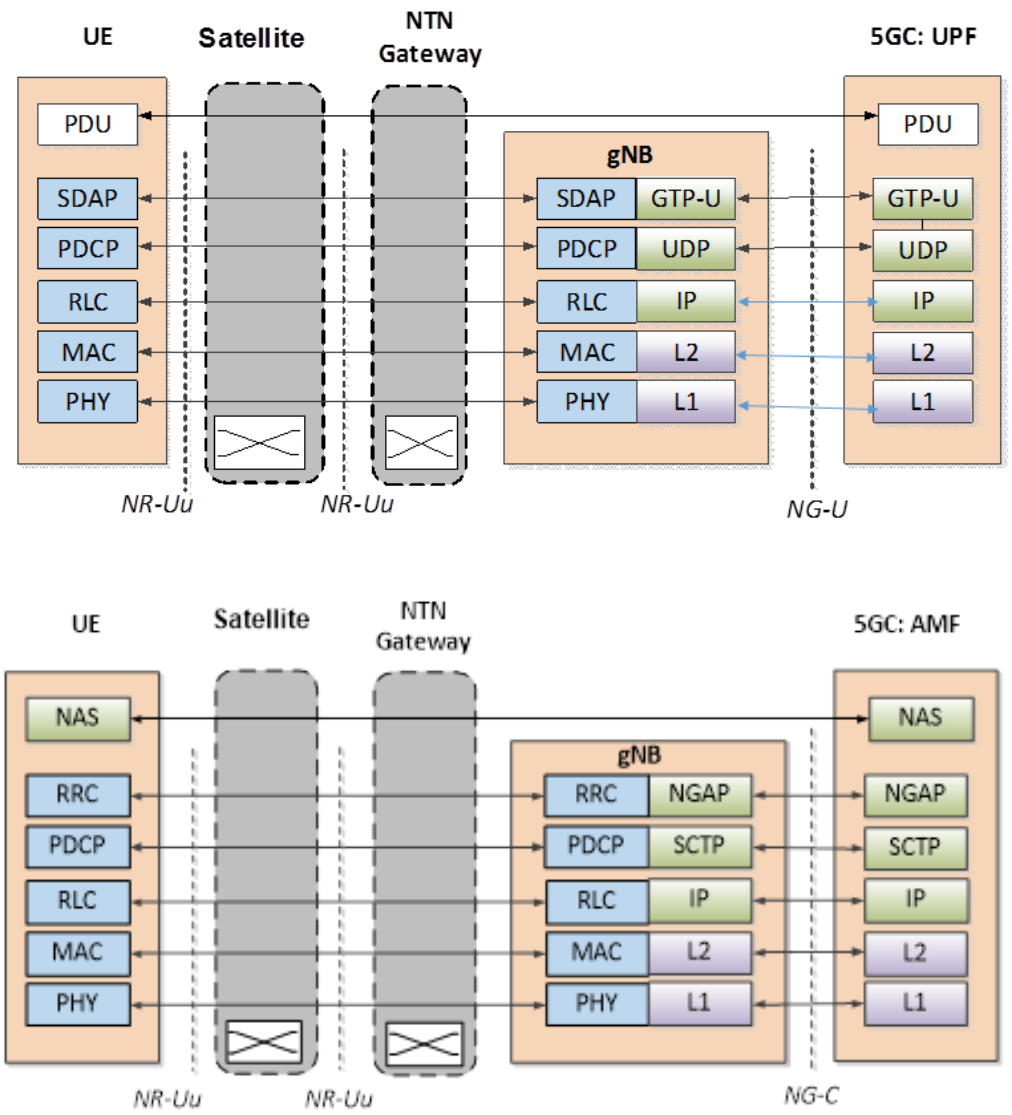


Figure 1-4: *5G NTN User plane and control plane protocol stacks. Source TR 38.821.*

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.

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- 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 supports predefined 1-, 7-, and 19-beam layouts, and beams can be dropped based on user requirements.
  - 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 $\frac{\frac{ISD}{2}}{\frac{D}{2}} = \cos(30)$, 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. In NetSim, the feeder link is treated as an ideal link except for propagation latency. 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 be an ideal link with 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. θ 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 θ is determined using the dot product formula:

$$\theta = \cos^{-1}\left(\frac{\hat{\rho_c}\cdot\hat{\rho_u}}{\|\hat{\rho_c}\|\,\|\hat{\rho_u}\|}\right) \tag{1}$$

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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

The NTN carrier catalogue contains FR1 and FR2 FDD operating bands for S, L, C, Ku, and Ka service-link studies. The selected carrier configuration determines the carrier-band label, the uplink and downlink frequency ranges, the channel bandwidth, PRB count, subcarrier spacing, and guard-band option used by the PHY and propagation models.

- S-band entries include `n252` and `n256`.
- L-band entries include `n253`, `n255`, and `n254`. `n254` is a mixed L/S case: its uplink is in L-band and its downlink is in S-band.
- C-band is included as a provisional catalogue entry for C-band NTN studies.
- Ku-band entries include FR1 `n247` and `n248`, and FR2 `n508` and `n509`.
- Ka-band entries include `n510`, `n511`, and `n512`.

For FDD bands the uplink and downlink center frequencies can be different. NetSim therefore uses the uplink center frequency for uplink loss calculations and the downlink center frequency for downlink loss calculations.

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

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    - 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). S and Ka use the released table values. L reuses the S-band table in this phase. C and Ku use provisional log-frequency interpolation between the S-band and Ka-band anchor values.
  - Additional loss, PL_{AD} in dB. Range [0.0, 10.0]. Default [0.0]. This user-defined constant is applied directly in the NTN link budget.
  - Scintillation loss, PL_{SL} in dB. Range [0.0, 10.0]. Default [0.0]. Typical values are 0.5–3 dB for S-band to Ka-band links with elevation angle $\geq 10°$.
  - Polarization loss, PL_{POL} in dB. Range [0.0, 3.0]. Default [0.0]. Typical values are 0.5–1.0 dB for circular/linear mismatch.
  - Atmospheric loss, PL_{ATM} in dB. Range [0.0, 30.0]. Default [0.0]. This term covers atmospheric absorption by gases and rain and becomes more significant in Ka-band and Ku-band. In this phase, atmospheric and rain loss are user inputs and are not calculated automatically.
  - 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 for legacy S/L rows, and up to 100 MHz for supported Ku FR1 rows such as `n247` and `n248`
  - FR2 – 50, 100, 200, 400 MHz, based on the selected operating band
- 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.

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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
n252	2000 MHz – 2020 MHz	2180 MHz – 2200 MHz	FDD
n253	1668 MHz – 1675 MHz	1518 MHz – 1525 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
n247	13750 MHz – 14000 MHz	10700 MHz – 12750 MHz	FDD
n248	14000 MHz – 14500 MHz	10700 MHz – 12750 MHz	FDD
n509	14000 MHz – 14500 MHz	10700 MHz – 12750 MHz	FDD
n508	13750 MHz – 14000 MHz	10700 MHz – 12750 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

NetSim NTN carrier band catalogue

In an NTN scenario, the user selects a CA configuration such as `n252`, `n253`, `n254`, `n255`, `n247`, `n248`, `n508`, `n509`, `n510`, `n511`, `n512`, or the C-band entry. Each CA configuration belongs to one carrier-band family. After the CA configuration is selected, NetSim shows the channel bandwidths supported for that band and duplex direction.

The catalogue supports the following NTN carrier-band families:

- **S-band**: supports S-band NTN operating bands such as `n252` and `n256`.
- **L-band**: supports L-band NTN entries such as `n253`, `n254`, and `n255`. `n254` uses L-band uplink and S-band downlink frequencies.
- **C-band**: supports the provisional C-band catalogue entry.
- **Ku-band**: supports FR1 NTN bands `n247` and `n248`, and FR2 NTN bands `n508` and `n509`.
- **Ka-band**: supports Ka-band NTN operating bands such as `n510`, `n511`, and `n512`.

The supported bandwidth list depends on the selected operating band and duplex direction. `n253` is available with 5 MHz bandwidth because its uplink and downlink spans are 7 MHz. `n247` and `n248` provide Ku FR1 bandwidths up to 100 MHz, including 35, 50, 70, and 100 MHz. `n508` and `n509` provide Ku FR2 bandwidth rows, and `n508` includes 400 MHz downlink support where the catalogue contains the matching downlink row.

Band-aware propagation behavior

NetSim uses the selected carrier band when calculating NTN service-link loss. For FDD bands, the uplink and downlink center frequencies can be different. This difference is small for some bands, but it is large for C and Ku bands. Therefore, uplink loss is calculated with the uplink center frequency, and downlink loss is calculated with the downlink center frequency.

The same band-aware frequency handling is used for the serving link, co-channel interference, and inter-satellite or frequency-reuse interference. This keeps the path-loss calculation aligned with the selected NTN band for both traffic and interference links.

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Frequency used in the propagation model

For each component carrier, NetSim calculates the center frequency from the carrier row as:

$$f_c = \frac{F_{low} + F_{high}}{2} \tag{2}$$

where F_{low} and F_{high} are the lower and upper frequency limits of the selected uplink or downlink carrier row. The value is converted from MHz to GHz before it is passed to the satellite propagation model.

The frequency f_c is used in:

- free-space path loss,
- antenna gain calculations,
- C-band and Ku-band shadow-fading standard-deviation interpolation,
- C-band and Ku-band clutter-loss interpolation.

User-specified additional loss, scintillation loss, polarization loss, and atmospheric loss are not derived from the carrier frequency. They are applied as scalar losses entered by the user.

Shadow fading and clutter model

For NTN service-link loss, the log-normal shadow-fading standard deviation and clutter loss are selected using the outdoor scenario, LOS/NLOS state, elevation angle, carrier band, and carrier frequency. TR 38.811 provides tabulated values for S-band and Ka-band. L, C, and Ku are handled as follows:

- **S-band**: uses the S-band values from TR 38.811.
- **Ka-band**: uses the Ka-band values from TR 38.811.
- **L-band**: reuses the S-band shadow-fading and clutter values.
- **C-band**: uses log-frequency interpolation between the S-band anchor at 2 GHz and the Ka-band anchor at 20 GHz.
- **Ku-band**: uses log-frequency interpolation between the S-band anchor at 2 GHz and the Ka-band anchor at 20 GHz.

For C-band and Ku-band, the interpolation factor is:

$$\alpha = \frac{\log_{10}(f_c) - \log_{10}(f_S)}{\log_{10}(f_{Ka}) - \log_{10}(f_S)} \tag{3}$$

where:

- f_c is the selected uplink or downlink center frequency in GHz,
- $f_S = 2$ GHz is the S-band anchor frequency,
- $f_{Ka} = 20$ GHz is the Ka-band anchor frequency.

The interpolated value for either shadow-fading standard deviation or clutter loss is:

$$X(f_c) = X_S + \alpha\,(X_{Ka} - X_S) \tag{4}$$

where X_S is the S-band table value and X_{Ka} is the Ka-band table value for the same outdoor scenario, LOS/NLOS state, and reference elevation angle.

The factor α is limited to the range $0 \le \alpha \le 1$. Therefore, a carrier below the S-band anchor uses the S-band value, and a carrier above the Ka-band anchor uses the Ka-band value.

The same interpolation rule is used for:

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- shadow-fading standard deviation, σ_{SF},
- clutter loss, PL_{CL}.

For L-band:

$$\sigma_{SF,L} = \sigma_{SF,S} \tag{5}$$

$$PL_{CL,L} = PL_{CL,S} \tag{6}$$

If a C-band or Ku-band carrier frequency falls outside the 2–20 GHz interpolation range, NetSim uses the nearest anchor value.

Scope of the provisional band values

The C-band and Ku-band shadow-fading and clutter values are engineering approximations based on S-to-Ka log-frequency interpolation. L-band reuses S-band values. These values affect only shadow-fading standard deviation and clutter loss. They do not change the total-loss formula, free-space path loss equation, antenna-gain equation, or user-entered scalar losses.

- For S-band and Ka-band, NetSim uses the corresponding TR 38.811 table values.
- For L-band, NetSim uses S-band shadow-fading and clutter values.
- For C-band and Ku-band, NetSim interpolates between S-band and Ka-band table values.
- Atmospheric and rain loss are not calculated from ITU-R rain models in this phase. Users must enter atmospheric loss when it is required for a Ku or Ka link-budget study.
- EIRP density and receiver G/T remain user inputs.
- Higher carrier frequencies imply higher Doppler shift, but the existing NTN assumption of GNSS-based Doppler pre-compensation is unchanged.

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}	35 MHz N_{RB}	50 MHz N_{RB}	70 MHz N_{RB}	100 MHz N_{RB}
15	25	52	79	106	160	188	270	N/A	N/A
30	11	24	38	51	78	92	133	189	273
60	N/A	11	18	24	38	N/A	N/A	N/A	N/A

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	35 MHz	50 MHz	70 MHz	100 MHz
15	242.5	312.5	382.5	452.5	592.5	572.5	692.5	N/A	N/A
30	505	665	645	805	945	925	1045	965	845
60	N/A	1010	990	1330	1290	N/A	N/A	N/A	N/A

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 NetSim Home screen, click **New Simulation**. The NTN options appear as **Single-Satellite NTN** and **Multi-Satellite NTN**, as shown in Figure 1-5.

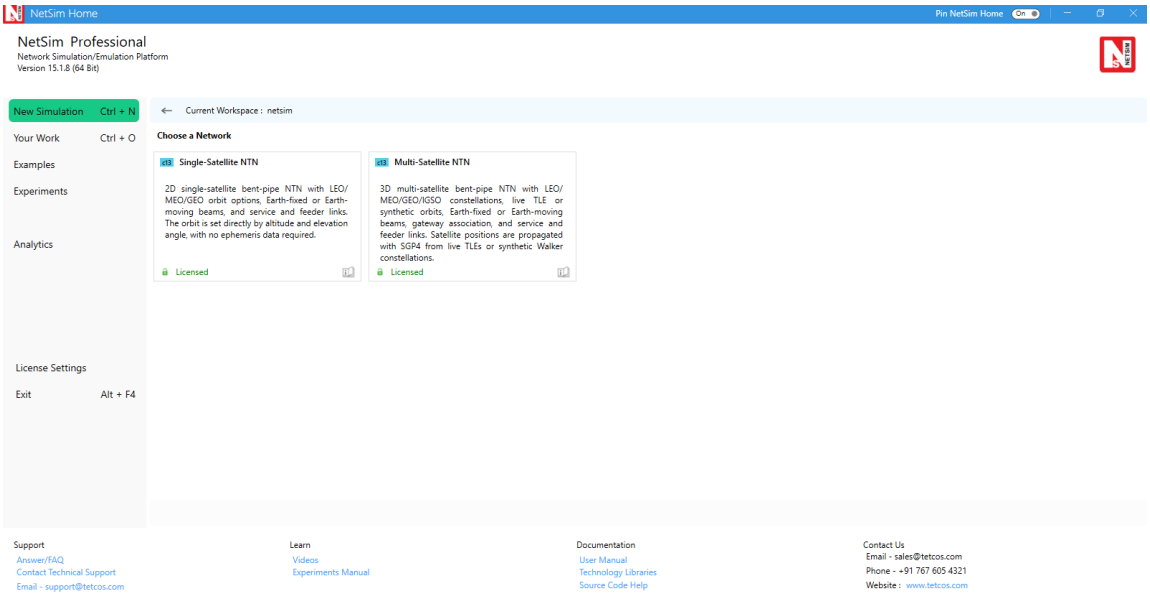


Figure 1-5: *NetSim Home screen showing the Single-Satellite NTN and Multi-Satellite NTN startup options.*

1.4.1 Startup window options

The NTN scenario type decides whether the initial network is created with one serving satellite or with multiple satellites covering the same UE region.

- **Single-Satellite NTN**: creates an NTN scenario with one satellite serving the UE region. Use this option for link-budget studies, beam coverage studies, and basic NTN traffic simulations where all UEs connect through one satellite.
- **Multi-Satellite NTN**: creates an NTN scenario with more than one satellite serving the UE region. Use this option to study coverage overlap, satellite selection, beam association, inter-satellite interference, and changes in the serving satellite during mobility.

After selecting **Single-Satellite NTN**, NetSim opens the setup-mode window shown in Figure 1-6.

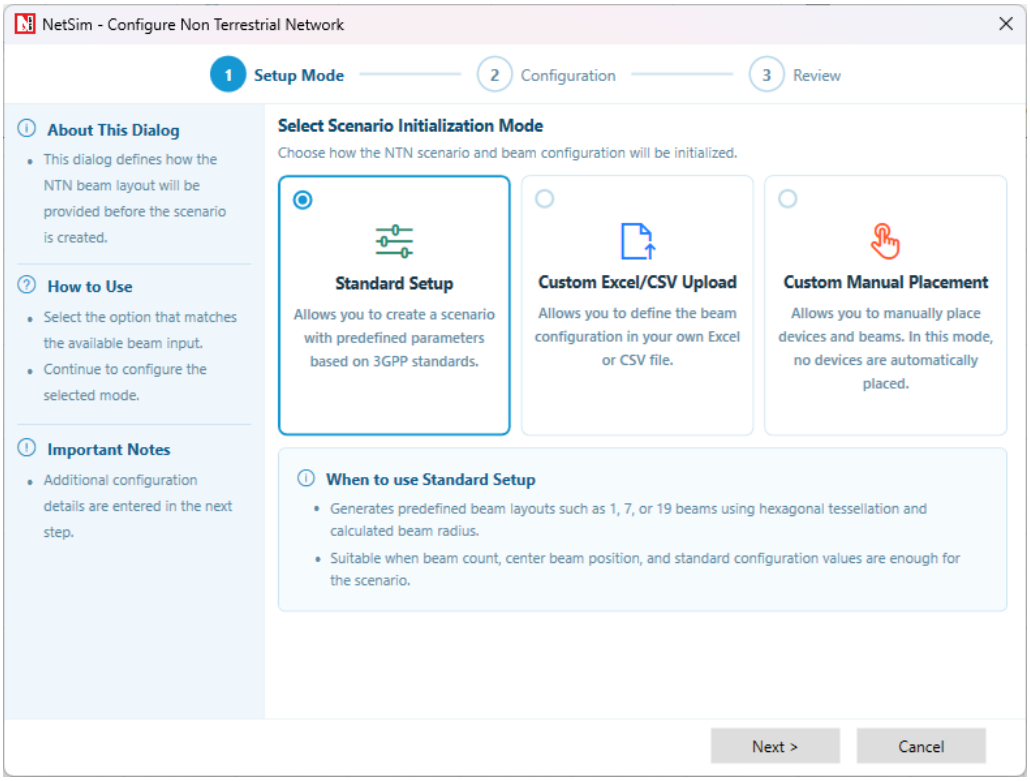


Figure 1-6: *Startup options for configuring a Single-Satellite NTN scenario.*

During initialization, NetSim prepares the NTN topology from the selected setup mode before opening the design workspace. This includes creating the satellite object, gateway and gNB-side nodes, UE devices, service-link beams, feeder-link connectivity, and the default application path through the 5G core. The initialization step also assigns the selected carrier band, bandwidth, subcarrier spacing, beam count, beam type, outdoor scenario, LOS/NLOS behavior, antenna settings, and elevation-mask values required for the first link-budget evaluation.

For a standard setup, these values are populated from the built-in NTN configuration. For Excel/CSV upload, the same fields are read from the user-provided file so that satellite position, UE placement, beam parameters, and radio settings are created consistently. For manual placement, NetSim opens the design area with the NTN libraries and device models enabled, allowing the user to place or modify the devices before running the simulation. After initialization, the simulation begins with the configured beam layout and then computes UE association, path loss, SNR, SINR, and serving-beam selection during runtime.

The three setup modes shown in Figure 1-6 are:

- **Standard Setup**: creates the scenario using predefined NTN values.
- **Custom Excel/CSV Upload**: creates the scenario from a user-prepared Excel or CSV file.
- **Custom Manual Placement**: opens the design area with the default core network, satellite, one UE, and one beam already placed. The user can then place additional devices and beams manually as required.

1.5 Multi-Satellite NTN

In a Single-Satellite NTN scenario, one satellite provides the serving beams for the topology. This setup is useful when the study focuses on one satellite link and radio behavior within that coverage area.

In a Multi-Satellite NTN scenario, several satellites are present in the same topology. UEs may be served by different satellites as their positions and coverage change, so the model can study coverage overlap, serving-satellite changes, and handover behavior.

Multi-Satellite startup wizard

The Multi-Satellite NTN startup window starts with satellite source selection.

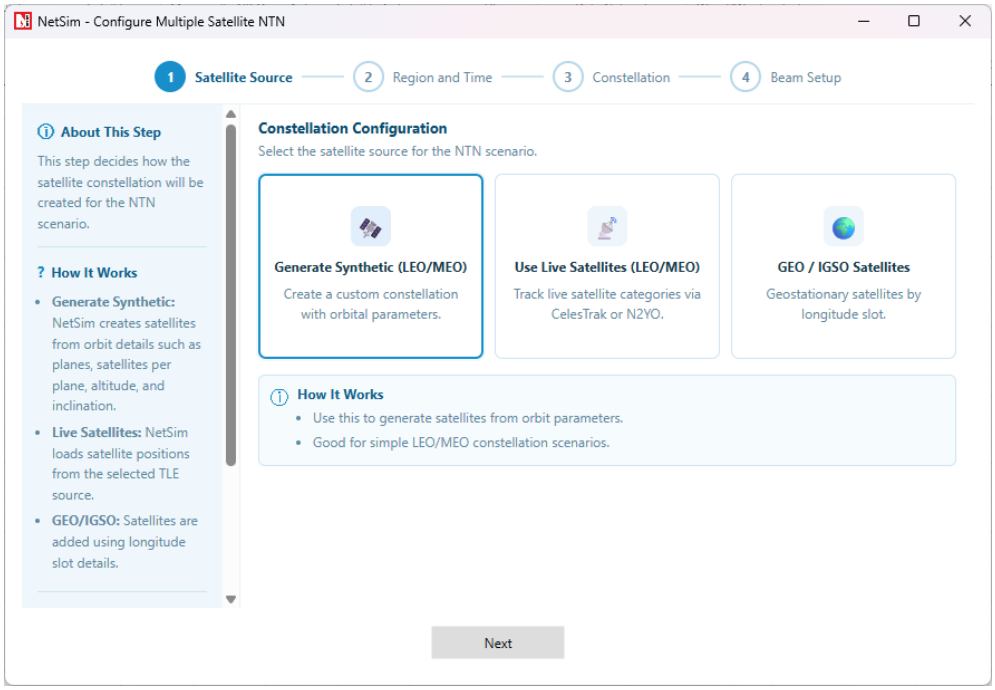


Figure 1-7: *Multi-Satellite NTN wizard: satellite source selection.*

In the initial window, select how the satellites must be created, as shown in Figure 1-7. The three satellite source modes are:

- **Generate Synthetic (LEO/MEO)**: creates a LEO or MEO constellation from orbit parameters entered by the user.
- **Use Live Satellites (LEO/MEO)**: loads satellite positions from a selected live satellite source.
- **GEO / IGSO Satellites**: creates geostationary or inclined geosynchronous satellites using longitude-slot details.

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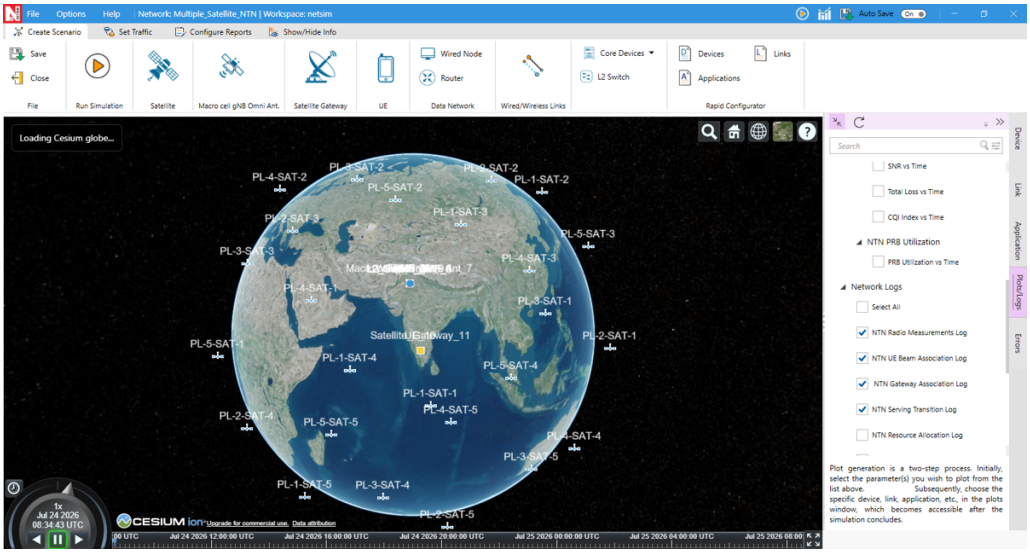


Figure 1-8: *Multi-Satellite NTN 3D topology view showing UEs in the Indian region, core devices around the region, and 25 satellites in orbit.*

Earth-moving beams

Multi-Satellite NTN currently supports `Earth_Moving` beams only. The beam centres move with the satellite footprint.

- `Earth_Moving`: beam centres move with the satellite footprint.

Each satellite has two links:

- **Feeder link**: connects the satellite to the ground network through the gNB side and is modeled as an ideal link except for propagation latency.
- **Service link**: connects the satellite to UEs through NTN radio beams.

Data transmission

The NTN gateway is the ground node used on the feeder side of the satellite link. It connects the terrestrial gNB side to the satellite and carries user-plane traffic between the ground network and the selected satellite. For each satellite, NetSim checks the available gateways and selects the gateway that satisfies the gateway elevation mask and gives the highest elevation angle to that satellite. When satellite mobility changes the satellite position, the gateway-to-satellite association is recalculated.

The gateway association is selected per satellite. A satellite uses one serving gateway at a time for its feeder-link path. If more than one gateway is available, the other gateways act as candidates and are not used in parallel for the same satellite at that time. Multiple satellites may select the same gateway if that gateway gives the best eligible feeder-link view for each of them. Therefore, a single gateway can serve more than one satellite, but one satellite does not split the same user-data path across multiple gateways.

The satellite is modeled as a transparent relay for this path. It forwards packets between the ideal feeder link and service link. The feeder link contributes propagation delay between the gateway and satellite, while feeder-link SNR loss and pathloss degradation are not modeled. Service-link radio measurements, beam selection, SNR, SINR, and interference are evaluated on the UE-facing satellite link.

The important satellite properties in this scenario are `Plane ID`, `Beam Count`, `Beam Type`, `Fast Fading Model`, and `Elevation Mask`. The `Plane ID` groups satellites into orbital planes. Multi-Satellite NTN currently uses `Earth_Moving` beam centres that move with the satellite footprint. The `Elevation Mask` sets the minimum elevation angle required for a UE to use a satellite.

When the simulation starts, NetSim treats every satellite as a separate NTN radio unit for movement, beam coverage, elevation checks, serving-satellite selection, and logs. Each satellite can have its own position, orbital plane, beam list, beam type, and elevation-mask check.

Serving satellite and beam selection

For each UE, NetSim checks all satellites that can cover the UE. A satellite is considered only if the elevation angle from the UE to the satellite is greater than or equal to the satellite's `Elevation Mask`. Satellites below this angle are ignored for that UE at that time.

For every eligible satellite, NetSim checks its beams and calculates the link budget. The calculation includes carrier frequency, slant height, elevation angle, path loss, shadow fading, clutter loss, additional loss, antenna pattern gain, receiver G/T, thermal noise, SNR, and SINR. The UE is then associated with the satellite and beam that gives the highest SNR. If no satellite passes the coverage check, the UE is treated as outside NTN coverage for that evaluation time.

Association and logs

At the beginning of the simulation, NetSim chooses one initial serving satellite for each UE. Although multiple satellites may have service links to the same UE area, only the satellite that gives the selected serving link is used for the UE association at that time. During the simulation, UE mobility and satellite mobility can change the best serving satellite or beam.

The NTN Gateway Association log shows the serving gateway selected for each satellite on the feeder link. The NTN Serving Transition log records changes in the serving satellite or serving beam for each UE. The NTN UE Beam Association log and NTN Radio Measurement log show the selected satellite and beam information on the service link. These logs can be used to inspect gateway selection, satellite selection, beam selection, serving transitions, no-coverage intervals, SNR, SINR, received power, interference power, path loss, shadow fading loss, clutter loss, and the selected MCS over time.

Results and animation

After the simulation run, the Results window shows the application metrics and generated logs, as shown in Figure 1-9.

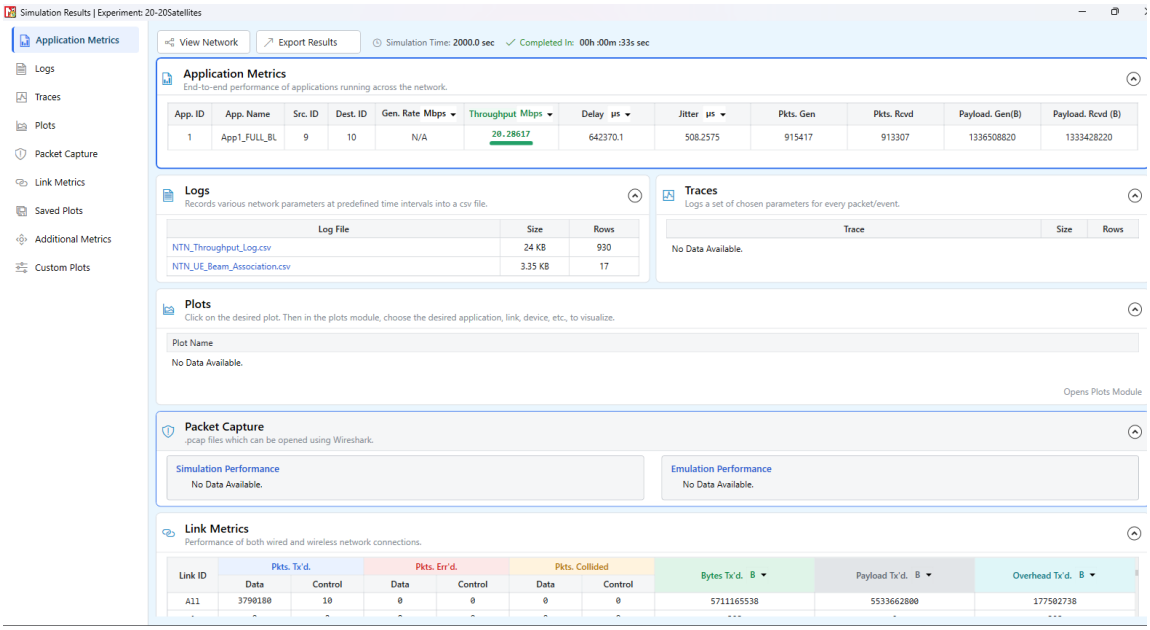


Figure 1-9: *Multi-Satellite NTN results window showing application throughput and NTN logs.*

The animation view in Figure 1-10 shows the UE connected to the serving satellite during the run. The

green link indicates the satellite connection, and the displayed throughput on that link is **23.897 Mbps**.

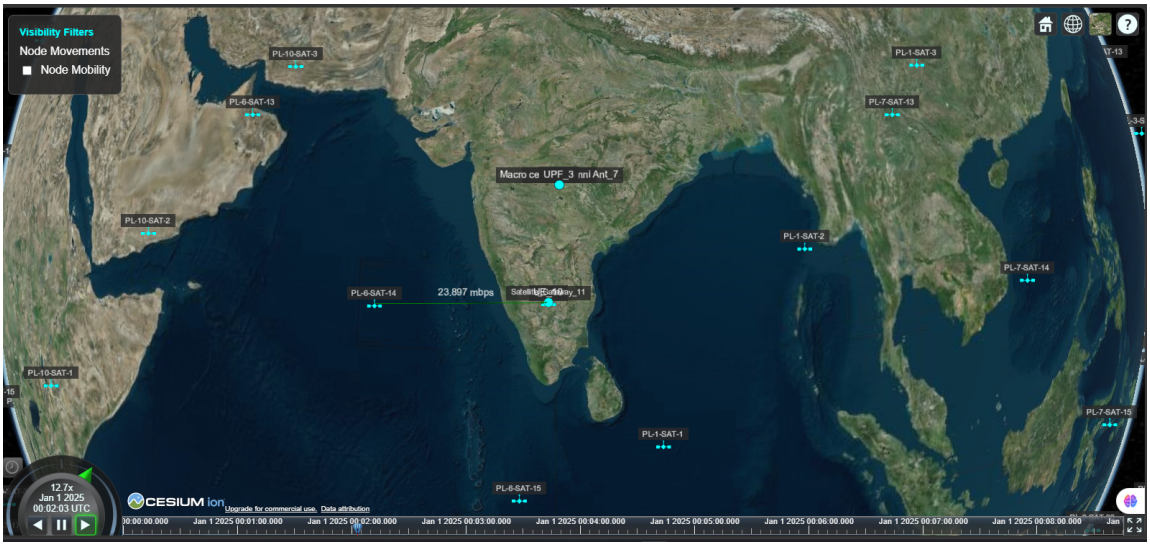


Figure 1-10: *Multi-Satellite NTN animation showing the UE connected to the serving satellite with 23.897 Mbps throughput.*

1.6 Configure Non-Terrestrial Networks

For a Single-Satellite NTN scenario, the configuration window shown in Figure 1-6 is used before the design window is created. After selecting the required setup option and entering the setup values, click **OK**. NetSim then creates the NTN design according to the selected startup option.

1.7 Set device properties



Figure 1-11: *Network setup showing the satellite, gNB, gateway, and UE devices in the NetSim design window.*

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.

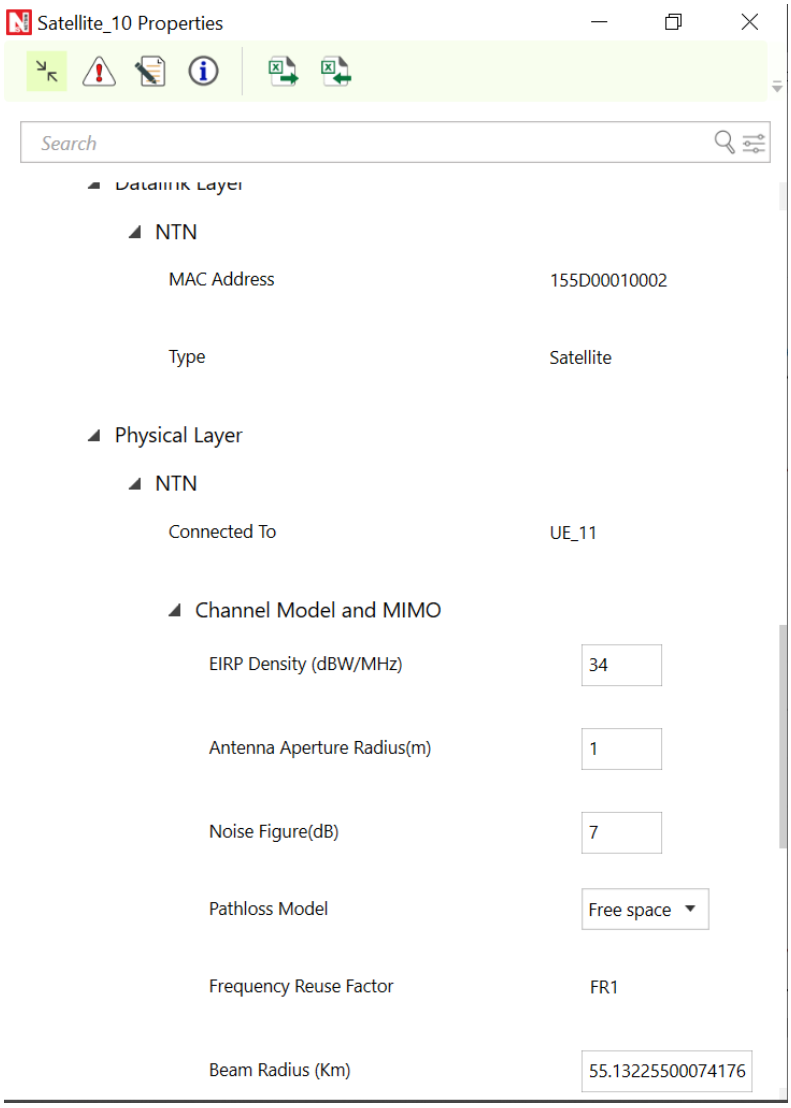


Figure 1-12: *PHY layer properties of Satellite (Feeder link).*

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

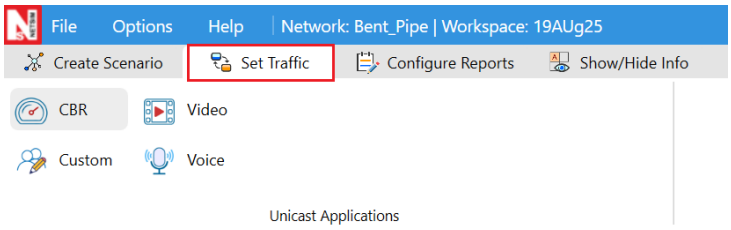


Figure 1-13: *Set traffic tab from top ribbon.*

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



Figure 1-14: *Application settings from right panel.*

1.8 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.

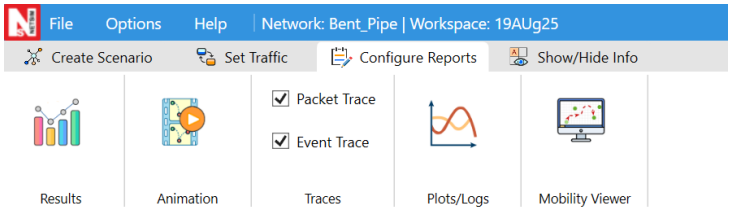


Figure 1-15: *Enabling Packet trace and Event trace from Configure reports tab.*

Enable protocol-specific logs such as NTN Gateway Association Logs, NTN Serving Transition Logs, NTN UE Beam Association Logs, NTN Radio Measurement 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.

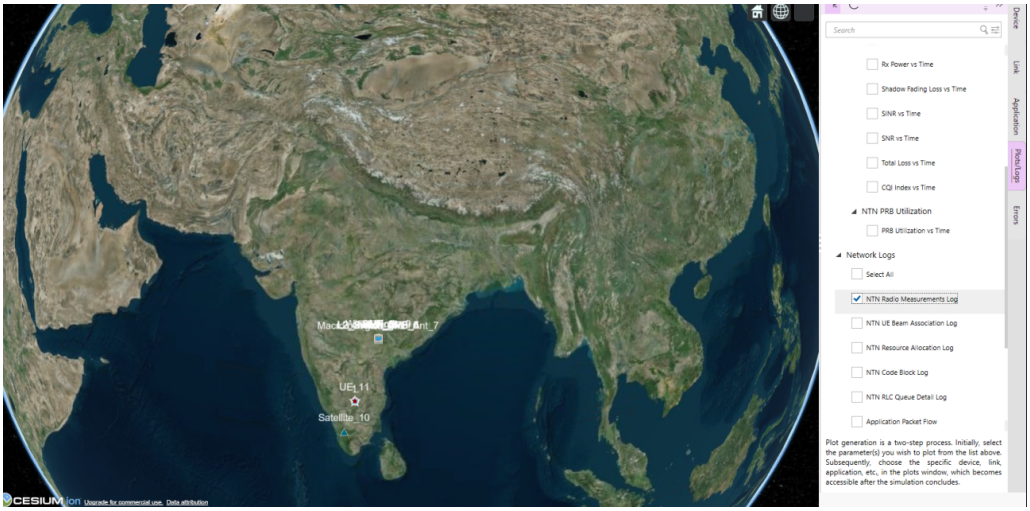


Figure 1-16: *Enable NTN Radio Measurements logs.*

1.9 GUI Parameters

Table 1-6: *GUI configuration parameters.*

Parameter	Type	Range	Description
Interface (Feeder link) – Physical Layer			
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.
NOTE: 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 are separated into two frequency ranges. FR1 includes lower-frequency NTN service-link bands including L, S, provisional C, and Ku FR1 rows. FR2 includes Ka and Ku FR2 rows. 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
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	n252, n253, n254, n255, n256, n247, n248, n508, n509, n510, n511, n512, C	The operating band whose numbering is defined by 3GPP or by the C-band catalogue entry. 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	Based on selected band	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	Based on selected band	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.
Numerology	Local	$\mu = 0, 1, 2, 3$	Sub carrier spacing is derived from numerology per the expression $\Delta f = 2^{\mu} \times 15\,kHz$. 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 available bandwidths depend on the selected CA configuration. FR1 S/L rows use 5–30 MHz where supported; `n253` supports 5 MHz; Ku FR1 `n247`/`n248` support 10–100 MHz; FR2 rows support 50–400 MHz depending on the operating band. 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.

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Parameter	Type	Range	Description
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: $(BWChannel \times 1000\ (kHz) - N_{RB} \times SCS \times 12)/2 - SCS/2$. 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 (μ) as shown below. $Unit = kHz$. 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 μ= 0, a subframe has only one slot, and frame has 10 slots. When μ= 1, a subframe has 2 slots, and a radio frame has 20 slots. When μ= 2, a subframe has 4 slots in it, meaning a radio frame contains 40 slots. When μ= 3, a subframe has 8 slots in it, meaning a radio frame contains 80 slots.
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 μ= 0, a subframe has only one slot. When μ= 1, a subframe has 2 slots. When μ= 2, a subframe has 4 slots. When μ= 3, a subframe has 8 slots.
Slot Duration (μs)	Local	1000, 500, 250, 125μs	Slot duration is a non-editable parameter that depends on numerology selected. μ= 0, Slot Duration = 1000 μs. μ= 1, Slot Duration = 500 μs. μ= 2, Slot Duration = 250 μs. μ= 3, Slot Duration = 125 μs.

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Parameter	Type	Range	Description
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×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 × 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.
Symbol Duration (μs)	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 μs. When $\mu = 1$, symbol duration = 35.71 μs. When $\mu = 2$, symbol duration = 17.86 μs. When $\mu = 3$, symbol duration = 8.93 μs.
Antenna			
TX Antenna Count	Local	1	The number of transmit antennas.
RX Antenna Count	Local	1	The number of receive antennas.
PDSCH CONFIG			

Continued on next page

Parameter	Type	Range	Description
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.
PUSCH CONFIG			
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).
CSI REPORT CONFIG			
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			

Continued on next page

Parameter	Type	Range	Description
Pathloss Model	Local	None	In the current NTN implementation, only None is available. This is because the satellite-to-gNB feeder link is modeled as an ideal, perfect link. It is assumed that the signal reaches the gNB without experiencing any degradation due to pathloss.
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 (α): 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 (α) takes value between 0.5 and 1 with the default value of 0.75.
BLER Model	Global	ZERO_BLER, BLER_ENABLE	Selects the NTN BLER mode. ZERO_BLER fixes the BLER to 0. BLER_ENABLE enables user-configurable BLER, where the BLER Value parameter is used during error modeling.
BLER Value	Global	0–1	Used when BLER Model is set to BLER_ENABLE. This parameter sets the target transport block BLER. NetSim derives the per-code-block error probability from this value based on the number of code blocks in the transport block.
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). $EIRP_{UE} = P_{Tx,UE} + G_{UE,Tx}$.

Continued on next page

Parameter	Type	Range	Description
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			
NTN Gateway Association Log	Global	Enable or Disable	The NTN Gateway Association log file records the serving gateway selected for each satellite on the feeder link. It is used to inspect gateway-to-satellite association changes caused by satellite movement, gateway elevation-mask checks, and feeder-link path selection.
NTN Serving Transition Log	Global	Enable or Disable	The NTN Serving Transition log file records UE serving-link changes, including transitions between serving satellites, serving beams, or no-coverage state. It is used to inspect when mobility or satellite movement changes the UE serving path.
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, Scintillation Loss, Polarization Loss, Atmospheric 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, ScintillationLoss, PolarizationLoss, AtmosphericLoss, 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 subframe.

Continued on next page

Parameter	Type	Range	Description
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, and CBG ID. This log is used to inspect BLER-related processing and code block segmentation in NTN.
Satellite Properties ▷ Service link			
CHANNEL MODEL			
EIRP Density (dBW/MHz)	Global	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)	Global	Editable based on frequency band and satellite altitude	Editable based on the band and the scenario. For the standard scenarios, a precalculated value is provided. The aperture radius determines the beamwidth and, in turn, the beam radius on the Earth's surface.
Noise Figure (dB)	Global	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.
Max Antenna Gain (dB)	Global	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)	Global	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	Global	FR1, FR3	Represents the number of channel groups allocated per beam configuration. FR1 makes all beams use one channel group, while FR3 divides beams across three channel groups to reduce co-channel interference.
Beam Type	Global	Earth_Moving	In Multi-Satellite NTN, `Earth_Moving` reads `Theta` and `Alpha` and recomputes the beam ground point from the satellite pointing direction as the satellite moves.

Continued on next page

Parameter	Type	Range	Description
Beam Radius (km)	Global	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	Global	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	Global	Free Space	NetSim computes signal attenuation per the mean pathloss model. The option available is Free space.
Outdoor Scenario	Global	Rural, Urban, Dense Urban	There are three types of outdoor scenarios possible namely: Rural, Urban, and Dense Urban, as defined in the 3GPPTR38.811 standard section 6.1.2. The propagation characteristics of these scenarios are provided in the NTN Technology library manual.
LOS/NLOS Selection	Global	3GPPTR38.811, USER DEFINED	3GPPTR38.811-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.
LOS Probability	Global	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.

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Parameter	Type	Range	Description
Fading and Beamforming	Global	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	Global	0 to 10 dB	Additional loss is a user-defined constant loss term. The field accepts decimal values and is applied directly in the NTN total-loss calculation.
Scintillation Loss (dB)	Global	0 to 10 dB	User-configurable constant scintillation loss applied in both downlink and uplink. Typical values are 0.5–3 dB for S-band to Ka-band links with elevation angle $\geq 10°$.
Polarization Loss (dB)	Global	0 to 3 dB	User-configurable constant polarization mismatch loss. Typical values are 0.5–1.0 dB for circular/linear mismatch.
Atmospheric Loss (dB)	Global	0 to 30 dB	User-configurable constant atmospheric absorption loss due to gases and rain. This term is small in S-band and can become significant in Ka-band.
Shadowing Model	Global	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.

Continued on next page

Parameter	Type	Range	Description
Standard Deviation Selection (dB)	Global	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.
INTERFERENCE MODEL			
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.

1.10 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.

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 ▷ Position Properties ▷ 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 1-17: *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

$$CNR = EIRP + Rx\frac{G}{T} - k - PL_{FS} - PL_{SM} - PL_{SL} - PL_{POL} - PL_{ATM} - PL_{AD} - B \quad (7)$$

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_{SM} is the shadowing margin in dB

PL_{SL} is the scintillation loss in dB

PL_{POL} is the polarization mismatch loss in dB

PL_{ATM} is the atmospheric 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

$$Rx\frac{G}{T} = G_{rx} - N_f - 10\log_{10}\left(T_0 + (T_a - T_0) \times 10^{-0.1 \times N_f}\right) \quad (8)$$

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]

$$EIRP\ [\text{dBW}] = EIRPDensity\ [\text{dBW/MHz}] + 10\log_{10}(BW\ [\text{MHz}]) \tag{9}$$

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

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

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 θ.

B_{Hz} is the channel bandwidth in Hz.

L_{total} is the total path loss (free-space path loss + shadow fading + clutter loss + additional loss + scintillation loss + polarization loss + atmospheric loss) 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 2.2.*

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)	0, 0, 0	0, 0, 0

Continued on next page

Simulation Parameters	LEO 600km	LEO 1200km
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)	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)	0	0
Scintillation Loss(dB), PL_{SL} (User Input)	0	0
Polarization Loss(dB), PL_{POL} (User Input)	0	0
Atmospheric Loss(dB), PL_{ATM} (User Input)	0	0
Total Pathloss, L (dB) $L = PL_{FS}+PL_{SM}+PL_{AD}+PL_{SL}+PL_{POL}+PL_{ATM}$	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

Continued on next page

Simulation Parameters	LEO 600km	LEO 1200km
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
Carrier to Noise Ratio, CNR (dB) (Per CNR formulas provided in 3GPP TR 38.821 sec 6.1.3.1)	**15.78**	**15.76**

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 2.3.*

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

Continued on next page

Simulation Parameters	LEO 600km	LEO 1200km
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)	0	0
Scintillation Loss(dB), PL_{SL} (User Input)	0	0
Polarization Loss(dB), PL_{POL} (User Input)	0	0
Atmospheric Loss(dB), PL_{ATM} (User Input)	0	0
Total Pathloss, L (dB) $L = PL_{FS}+PL_{SM}+PL_{AD}+PL_{SL}+PL_{POL}+PL_{ATM}$	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
Carrier to Noise Ratio, CNR (dB) (Per CNR formulas provided in 3GPP TR 38.821 sec 6.1.3.1)	**11.58**	**5.49**

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 6.1.*

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

Continued on next page

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 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
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)	0	0
Scintillation Loss(dB), PL_{SL} (User Input)	0	0
Polarization Loss(dB), PL_{POL} (User Input)	0	0
Atmospheric Loss(dB), PL_{ATM} (User Input)	0	0
Total Pathloss, L (dB) $L = PL_{FS}+PL_{SM}+PL_{AD}+PL_{SL}+PL_{POL}+PL_{ATM}$	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

Continued on next page

Simulation Parameters	LEO 600km	LEO 1200km
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
Carrier to Noise Ratio, CNR (dB) (Per CNR formulas provided in 3GPP TR 38.821 sec 6.1.3.1)	**11.58**	**5.49**
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.

$$\alpha = \sin^{-1}\left(\frac{D}{Ru \times L}\right) = 90^\circ \tag{11}$$

Where,

$$Ru = \sqrt{x_{ue}^2 + y_{ue}^2 + z_{ue}^2} \tag{12}$$

$$L = \sqrt{(x_{sat} - x_{ue})^2 + (y_{sat} - y_{ue})^2 + (z_{sat} - z_{ue})^2} \tag{13}$$

$$D = \sqrt{(x_{sat} - x_{ue}) \cdot x_{ue} + (y_{sat} - y_{ue}) \cdot y_{ue} + (z_{sat} - z_{ue}) \cdot z_{ue}} \tag{14}$$

$$\alpha = 90^\circ \tag{15}$$

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

$$d = \sqrt{R_E^2 \sin^2(\alpha) + h_o^2 + 2h_o R_E} - R_E \sin(\alpha) \tag{16}$$

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

$$d = \sqrt{(6.371 \cdot 10^6)^2 \cdot \sin^2(90^\circ) + (6 \cdot 10^5)^2 + 2 \cdot (6 \cdot 10^5)\,(6.371 \cdot 10^6)} - 6.371 \cdot 10^6 \sin(90^\circ) \tag{17}$$

$$d = 600 \text{ km} \tag{18}$$

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 GHz

$$PL_{FS} = 32.45 + 20\log_{10}(f_c) + 20\log_{10}(d) \tag{19}$$

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

The receiver antenna G/T is given by the expression

$$Rx\frac{G}{T} = G_{rx} - N_f - 10\log_{10}\left(T_0 + (T_a - T_0) \times 10^{-0.1 \times N_f}\right) \tag{21}$$

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

$$Rx\frac{G_{rx}}{T} = 0 - 7 - 10\log_{10}(290) = -31.62 \text{ dB/K} \tag{22}$$

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

$$CNR = EIRP + G(\theta) - \text{MaxAntennaGain} + Rx\frac{G}{T} - k - PL_{FS} - PL_{SM} - PL_{AD} - PL_{SL} - PL_{POL} - PL_{ATM} - B \tag{23}$$

Substituting we get

$$CNR = 48.77 + 0 + (-31.62) - (-228.6) - 154.8 - (0.39) - 0 - 0 - 0 - 0 - 74.77 = 15.78 \text{ dB} \tag{24}$$

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

$$\theta = 86.54^\circ \tag{25}$$

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

$$d = \sqrt{R_E^2 \sin^2(\alpha) + h_o^2 + 2h_oR_E} - R_E \sin(\alpha) \tag{26}$$

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

$$d = \sqrt{(6.371 \cdot 10^6)^2 \cdot \sin^2(86.51^\circ) + (12 \cdot 10^5)^2 + 2 \cdot (12 \cdot 10^5)\,(6.371 \cdot 10^6)} - 6.371 \cdot 10^6 \sin(86.51^\circ) \quad (27)$$

$$d = 1202.19 \text{ km} \quad (28)$$

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 GHz

$$PL_{FS} = 32.45 + 20\log_{10}(f_c) + 20\log_{10}(d) \quad (29)$$

$$32.45 + 20\log_{10}(2.185) + 20\log_{10}(1202.19 \times 1000) = 160.84 \text{ dB} \quad (30)$$

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

$$Rx\frac{G}{T} = G_{rx} - N_f - 10\log_{10}\big(T_0 + (T_a - T_0) \times 10^{-0.1 \times N_f}\big) \quad (31)$$

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

$$Rx\frac{G_{rx}}{T} = 0 - 7 - 10\log_{10}(290) = -31.62 \text{ dB/K} \quad (32)$$

We know that bandwidth B [dBHz] $= 10 \times \log_{10}(B$ [Hz]$) = 10 \times \log_{10}\big(30 \times 10^6\big) = 74.77$ 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 86.54°. 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

$$CNR = EIRP + G(\theta) - \text{MaxAntennaGain} + Rx\frac{G}{T} - k - PL_{FS} - PL_{SM} - PL_{AD} - PL_{SL} - PL_{POL} - PL_{ATM} - B \quad (33)$$

Substituting we get

$$CNR = 54.77 - 10.26 + (-31.62) - (-228.6) - 160.84 - (0.39) - 0 - 0 - 0 - 0 - 74.77 = 5.49 \text{ dB} \quad (34)$$

3 Satellite Antenna Pattern

In the section above the link budgets were calculated assuming the maximum transmit antenna gain. NetSim supports the TR 38.811 circular aperture model, the ITU-R S.672 off-axis antenna model and Gaussian antenna model. These models are summarized below.

3.1 TR 38.811 Antenna model

Per section 6.4.1 of TR 38.811, the normalized antenna gain pattern, corresponding to a typical reflector antenna with a circular aperture, is given by

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

where $J_1(x)$ is the Bessel function of the first kind and first order with argument x, a is the radius of the antenna's circular aperture, $k = \frac{2\pi f}{c}$ is the wave number, f is the frequency of operation, c is the speed of light in a vacuum and θ is the angle measured from the boresight of the antenna's main beam. Note that ka equals the number of wavelengths on the circumference of the aperture and is independent of the operating frequency. The above expression provides the gain in linear scale and it needs to be converted to dB scale. The normalized gain pattern for $a = 10\frac{c}{f}$ (aperture radius of 10 wavelengths) is shown below

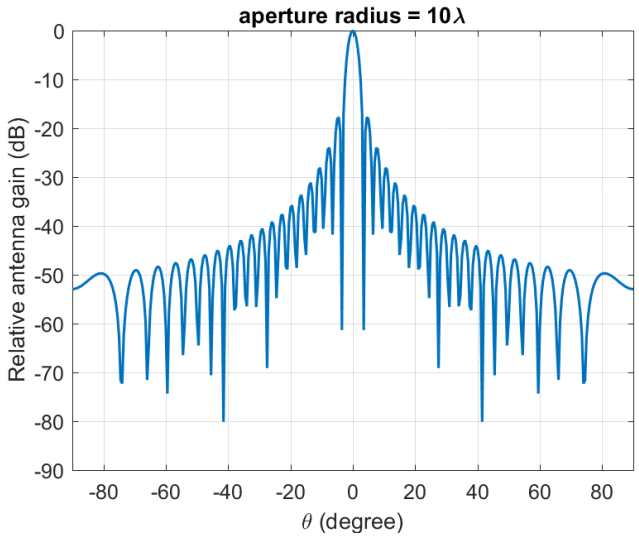


Figure 3-1: *Antenna gain pattern for aperture radius 10 wavelengths, $a = 10\frac{c}{f}$.*

3.2 ITU-R S.672 Antenna model

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

$$G(\psi) = G_m - 3\left(\frac{\psi}{\psi_b}\right)^{\alpha}\ [\text{dBi}] \qquad \text{for } \psi_b \leq \psi \leq a\psi_b \tag{35}$$

$$G(\psi) = G_m + LN + 20\log(z)\ [\text{dBi}] \qquad \text{for } a\psi_b < \psi \leq 0.5b\psi_b \tag{36}$$

$$G(\psi) = G_m + LN\ [\text{dBi}] \qquad \text{for } 0.5b\psi_b < \psi \leq b\psi_b \tag{37}$$

$$G(\psi) = X - 25\log\psi\ [\text{dBi}] \qquad \text{for } b\psi_b < \psi \leq Y \tag{38}$$

$$G(\psi) = LF\ [\text{dBi}] \qquad \text{for } Y < \psi \leq 90^\circ \tag{39}$$

$$G(\psi) = LB\ [\text{dBi}] \qquad \text{for } 90^\circ < \psi \leq 180^\circ \tag{40}$$

Where:

$$X = G_m + LN + 25\log(b\psi_b) \quad \text{and} \quad Y = b\psi_b \cdot 10^{0.04(G_m + LN - LF)} \tag{41}$$

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

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

Parameters used to obtain a, b, and α for the selected near-in-side-lobe level.

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

3.3 Gaussian Antenna Gain Model

The Gaussian antenna gain model approximates how an antenna radiates energy in different directions. It provides a simple mathematical way to estimate how the signal strength decreases as the angle from the antenna's main beam increases.

The model is used to:

- represent antenna radiation patterns
- estimate gain reduction at off-axis angles
- support satellite link budget and interference analysis

The Gaussian antenna gain is given by

$$G(\theta) = -3.01 \left(\frac{\theta}{\theta_{bw}} \right)^2 \tag{42}$$

where:

- $G(\theta)$: gain at angle θ in dB
- θ: off-axis angle in degrees
- θ_{bw}: one-half of the configured 3 dB beamwidth, in degrees. This is the same half-beamwidth convention used for ψ_b in Section 3.2; do not substitute the full GUI beamwidth directly in the ratio.

For the absolute antenna pattern, the Gaussian roll-off is applied from the maximum antenna gain and the pattern is floored at the far side-lobe level $LF = 0$ dBi, as used in ITU-R S.1528. Therefore, beyond the main lobe the gain does not decrease below 0 dBi absolute:

$$G_{\text{abs}}(\theta) = \max \left(G_m - 3.01 \left(\frac{\theta}{\theta_{bw}} \right)^2,\ 0 \right) \quad \text{[dBi]} \tag{43}$$

where G_m is the maximum antenna gain in the main lobe. Equation 43 uses the absolute-gain form implemented by NetSim: the normalized Gaussian roll-off is floored at $-G_m$, so the resulting absolute gain is not allowed to fall below 0 dBi.

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3.4 Phased-Array Antenna Model

The NTN service link supports a uniform rectangular array with N_x elements on the along-track axis and N_y elements on the cross-track axis. The current model is an unsteered broadside array: the beam is earth-moving, its boresight is the satellite nadir direction, and the steering terms are $u_0 = v_0 = 0$. Earth-fixed target tracking and electronic beam steering are outside the present scope.

For an off-boresight angle ψ and an azimuth ϕ in the array frame, the direction cosines are

$$u = \sin\psi\cos\phi - u_0, \qquad v = \sin\psi\sin\phi - v_0. \tag{44}$$

The normalized array factors on the two axes are

$$A_x(u) = \frac{\sin(N_x \pi d_\lambda u)}{N_x \sin(\pi d_\lambda u)}, \qquad A_y(v) = \frac{\sin(N_y \pi d_\lambda v)}{N_y \sin(\pi d_\lambda v)}, \tag{45}$$

where d_λ is the element spacing expressed in wavelengths. At removable singularities the analytical limit is used, so the factor on that axis is one. The normalized array contribution is

$$G_{\mathrm{AF}}(u,v) = 20\log_{10}\left|A_x(u)A_y(v)\right|. \tag{46}$$

The element power response is $\cos^n\psi$, where n is the configured element pattern exponent. NetSim limits the element contribution to -30 dB:

$$G_e(\psi) = \max(10n\log_{10}(\cos\psi), -30), \qquad \cos\psi > 0. \tag{47}$$

The normalized phased-array pattern and the satellite antenna gain are

$$G_{\mathrm{pattern}}(\psi,\phi) = G_{\mathrm{AF}}(u,v) + G_e(\psi), \tag{48}$$

$$G_{\mathrm{sat}}(\psi,\phi) = G_{\max} + G_{\mathrm{pattern}}(\psi,\phi). \tag{49}$$

At boresight, $G_{\mathrm{pattern}} = 0$ dB and the net antenna gain is $G_{\max}$ dBi. Invalid or non-finite inputs, zero element counts, non-positive spacing, negative element exponent, and directions behind the array face use a -100 dB normalized guard value. The normalized pattern does not depend on the configured peak gain.

3.4.1 Phased-array properties

Select **Phased Array** separately under the satellite's **Transmit Antenna** and **Receive Antenna** sections. The GUI writes the following properties to the corresponding `ANTENNA_TX` or `ANTENNA_RX` configuration block.

GUI property	Configuration name	Recommended range; default	Use
Antenna Model	ANTENNA_MODEL	Four listed models; Phased Array	Selects the pattern evaluator for this link direction.
Array Elements X	ARRAY_ELEMENTS_X	1–1024; 23	Element count on the along-track axis, N_x.
Array Elements Y	ARRAY_ELEMENTS_Y	1–1024; 23	Element count on the cross-track axis, N_y.
Element Spacing (wavelengths)	ELEMENT_SPACING_WL	$0 < d_\lambda \leq 1$; 0.5	Common element spacing on both axes.
Element Pattern Exponent	ELEMENT_EXPONENT	$0 \leq n < 100$; 1.3	Exponent of the $\cos^n\psi$ element response.
Max Antenna Gain (dBi)	MAX_ANTENNA_GAIN	$0 < G_{\max} < 100$; 30	Peak gain added to the normalized pattern.

Table 3-1: *Phased-array configuration properties for each NTN satellite antenna profile.*

The transmit and receive profiles are independent. Downlink serving and interference paths use the transmitting satellite's ANTENNA_TX profile. Uplink reception uses the serving satellite's ANTENNA_RX profile. Changing the transmit array therefore changes the satellite downlink pattern without changing the uplink receive pattern, and the reverse applies to receive-array changes. The two profiles may also select different antenna models.

3.4.2 Array frame and mobility

The local array frame uses nadir as its normal. NetSim obtains the along-track axis from the satellite velocity samples in IOPath/Default/satellite.csv, converts the inertial velocity to an ECEF ground-track direction, and forms the cross-track axis orthogonal to nadir and along-track. If a usable velocity sample is unavailable, local North is used as the along-track axis and local East as the cross-track axis. This frame allows rectangular arrays with $N_x \neq N_y$ to produce the expected azimuth-dependent gain as the satellite moves.

The present NTN phased-array scope permits one earth-moving, nadir-pointing beam per satellite. The gain is applied on serving and interfering NTN service-link calculations. The feeder link and the standalone Satellite library do not support phased-array configuration in this release.

3.4.3 Enforced constraints

The ranges in Table 3-1 are recommended configuration limits from the GUI property schema. In the simulation kernel, only zero element counts, non-positive element spacing, and negative element exponent values are guarded by returning the −100 dB normalized pattern value. Other numeric values outside the recommended range are not clipped by the kernel.

The phased-array service-link model also enforces the current beam scope. A phased-array satellite must use exactly one beam and the beam type must be Earth_Moving; otherwise NetSim stops the configuration with an error. A non-zero off-nadir angle is reported as unsupported and the beam is reset to nadir before the beam ground point is recomputed. During a run, scheduled off-nadir beam updates are ignored with an error message. The standalone Satellite module terminates if ANTENNA_MODEL=Phased Array is selected, so this antenna model is available only for the NTN service-link path described here.

3.5 Off Boresight Angle Calculation

3.6 External Antenna Pattern

The external antenna pattern model allows the NTN service link to use a two-dimensional radiation pattern generated by antenna design or measurement software. The pattern is selected independently for the satellite transmit and receive directions. It is evaluated for serving links and interfering links using the same off-boresight geometry and link-budget path as the built-in antenna models. The generic Satellite module does not support this model; it is available only in the LTE/NR NTN satellite configuration.

Select **External Pattern** under the satellite's **Transmit Antenna** or **Receive Antenna** section. The choice is the last item in the antenna-model list and does not change the default, which remains **Phased Array**. If either direction uses an external pattern, the configuration must contain both `ANTENNA_TX` and `ANTENNA_RX` blocks so that transmit and receive ownership is unambiguous.

3.6.1 Pattern coordinates and gain

Each input sample is defined by the polar angle ψ, the azimuth angle ϕ, and a gain or field value. The polar angle is measured from the beam boresight. NetSim defines $\phi = 0$ along the satellite along-track direction projected onto the plane normal to the beam boresight; positive azimuth proceeds toward the corresponding cross-track axis. The frame moves with the satellite and is formed from the satellite position, beam centre, and trajectory velocity. NetSim stops the simulation if this frame cannot be formed because the projected along-track vector is degenerate.

The input table is converted to a peak-relative pattern. If $G_{\text{file}}(\psi, \phi)$ is the gain derived from the file and $G_{\text{file,max}}$ is its largest value, the stored value is

$$G_{\text{rel}}(\psi, \phi) = G_{\text{file}}(\psi, \phi) - G_{\text{file,max}}. \tag{50}$$

The satellite gain used by the link budget is

$$G_{\text{sat}}(\psi, \phi) = G_{\max} + G_{\text{rel}}(\psi, \phi), \tag{51}$$

where $G_{\max}$ is the configured maximum antenna gain or, for a CSV pattern, the peak read from the file when `MAX_ANTENNA_GAIN=FROM_FILE` is selected. NetSim performs bilinear interpolation in dB between the four surrounding grid points. At a pole, where azimuth is physically undefined, the row is reduced to one representative value by averaging power over azimuth. Polar queries outside the supplied ψ extent use the nearest boundary. A pattern whose azimuth samples close the $0°/360°$ seam is interpolated across that seam; otherwise a query outside the supplied azimuth arc uses the nearest boundary.

3.6.2 Supported input files

Both formats are UTF-8 text and must describe a complete rectangular ψ–ϕ grid. Blank lines and comment lines are ignored. Each axis must contain at least two distinct values. A file may contain at most 2,000 polar values, 4,000 azimuth values, and 1,000,000 grid cells. The file size limit is 64 MiB and the line-length limit is 1 MiB.

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Format	Required data	Interpretation and constraints
CSV	Columns `psi_deg`, `phi_deg`, and `gain_dbi`	ψ must lie in $[0, 180]$ degrees. Azimuth may use either $[-180, 180]$ or $[0, 360]$ degrees, but negative values and values above 180° must not be mixed in one file. The gain column contains absolute gain in dBi. The file peak can supply $G_{\max}$ through `FROM_FILE`.
FFD	Header containing `theta phi E_theta E_phi`, followed by four-column data rows	θ must lie in $[0, 180]$ degrees and ϕ in $[0, 360]$ degrees. NetSim converts the real field components to power gain as $10\log_{10}(E_\theta^2 + E_\phi^2)$. The sum must be finite and positive. FFD field magnitudes do not supply an absolute peak gain, so `FROM_FILE` is not permitted.

Table 3-2: *External antenna pattern input formats.*

The order of data rows is not significant. Duplicate coordinates are accepted only when their gain values agree; conflicting duplicates and missing cells are rejected. The loader also rejects non-numeric values, NaN, infinity, invalid angular ranges, unsupported extensions, empty files, and files that exceed the resource limits.

3.6.3 Configuration properties

The pattern file can be configured by format or inferred from a `.csv` or `.ffd` extension. A relative path is resolved from the scenario run folder (`IOPath`); an absolute path can also be read by the runtime. An experiment-local relative path is recommended so that the scenario can be moved as a unit.

GUI property	Configuration name	Accepted value; default	Use
Antenna Model	`ANTENNA_MODEL`	External Pattern; Phased Array	Selects the external evaluator for this direction.
External Pattern Format	`EXTERNAL_PATTERN_FORMAT`	CSV or FFD; CSV	Selects the parser. If omitted, the runtime uses the filename extension.
Configure External Pattern	`EXTERNAL_PATTERN_FILE`	Existing CSV or FFD text file; template file	Identifies the pattern file relative to `IOPath`, or by an absolute path.
Pattern Design Frequency (Hz)	`EXTERNAL_PATTERN_FREQUENCY_HZ`	Finite value greater than zero; 2×10^9	Records the frequency for which the pattern was produced. An FFD header frequency takes precedence when both are present.
Max Antenna Gain (dBi)	`MAX_ANTENNA_GAIN`	Finite value ≥ 0, or `FROM_FILE` for CSV; 30	Adds the absolute peak gain to the normalized pattern.

Table 3-3: *External-pattern configuration properties for each NTN satellite antenna profile.*

The workspace GUI schema applies these properties with local scope in a Bent Pipe setup and global scope in a Multiple Satellite NTN setup. The format, file, and design-frequency controls are displayed only when **External Pattern** is selected. The CSV and FFD file buttons open editable template text files. The GUI serializer must retain the selected values separately in the `ANTENNA_TX` and `ANTENNA_RX` blocks. The runtime accepts `FROM_FILE` for CSV, although a GUI that uses a numeric-only maximum-gain control must add mixed numeric/token handling before it can expose that choice.

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3.6.4 Direction ownership and link-budget use

Downlink serving and interference calculations use the transmitting satellite's `ANTENNA_TX` pattern. Uplink calculations use the serving satellite's `ANTENNA_RX` pattern. The two directions may use different files, formats, design frequencies, and peak gains. The normalized interpolated value is recorded as *Angular Antenna Gain*; adding $G_{\max}$ gives the *Net Satellite Gain* used in the link budget and receiver G/T calculation.

At initialization, NetSim validates the selected file, builds the rectangular table, normalizes it, and retains one cached parsed table for profiles that use the same canonical path and format. Per-direction handles retain their own design-frequency provenance and peak-gain policy. The cache and direction handles are released when LTE/NR finishes. Initialization output identifies the direction, canonical path, format, grid extents, effective peak gain, design-frequency source, and main-lobe information. Warnings identify coarse grids, limited angular coverage, off-boresight peaks, frequency mismatch, and configured/file peak mismatch. A malformed or unreadable pattern is a configuration error and stops the run instead of substituting another antenna model.

The v15.1.16 runtime port reads the selected scenario-local CSV or FFD file during initialization. The content-addressed Pattern Store is a separate integration item and is not linked into this workspace port.

3.7 Off Boresight Angle Calculation

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

φ_t : Latitude of earth station (degrees)

λ_t : Longitude of earth station (degrees)

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

φ_s : Latitude of satellite (degrees)

λ_s : Longitude of satellite (degrees)

H_s : Altitude of satellite above sea level (km)

Step 1: Convert Geodetic Coordinates to ECEF

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

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

$$a = 6378137.0 \text{ m} \tag{52}$$

- Flattening:

$$f = \frac{1}{298.257223563} \tag{53}$$

- First eccentricity squared:

$$e^2 = 2f - f^2 \tag{54}$$

- Numerically:

$$e^2 \approx 0.00669437999014 \tag{55}$$

- Prime vertical radius of curvature

$$N(\phi) = \frac{a}{\sqrt{1 - e^2 \sin^2(\phi)}} \tag{56}$$

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

$$X = (N + h)\cos(\phi)\cos(\lambda) \tag{57}$$

$$Y = (N + h)\cos(\phi)\sin(\lambda) \tag{58}$$

$$Z = N\left((1 - e^2) + h\right)\sin(\phi) \tag{59}$$

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:

$$\Delta r = r_s - r_t = (\Delta X, \Delta Y, \Delta Z) \tag{60}$$

Step 3: Rotate LOS Vector into Local ENU Frame

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

$$\begin{bmatrix} E \\ N \\ U \end{bmatrix} = \begin{bmatrix} -\sin(\lambda_t) & \cos(\lambda_t) & 0 \\ -\sin(\phi_t)\cos(\lambda_t) & -\sin(\phi_t)\sin(\lambda_t) & \cos(\phi_t) \\ \cos(\phi_t)\cos(\lambda_t) & \cos(\phi_t)\sin(\lambda_t) & \sin(\phi_t) \end{bmatrix} \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} \tag{61}$$

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:

$$D_{ts} = \sqrt{E^2 + N^2 + U^2} \tag{62}$$

Step 5: Elevation Angle

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

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$$el = \text{atan2}\left(U, \sqrt{E^2 + N^2}\right) \tag{63}$$

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

Step 6: Azimuth Angle

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

$$az = \text{atan2}(E, N) \tag{64}$$

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

Step 7: Visibility Check

Given a minimum elevation mask angle (maskAngle):

$$\text{visible} = 1 \quad \text{if } el \geq \text{maskAngle} \tag{65}$$

$$\text{visible} = 0 \quad \text{otherwise} \tag{66}$$

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

3.8 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:

$$f = 2.18 \text{ GHz};\ a = 1 \text{ m};\ k = \frac{2\pi f}{c} = \frac{2 \times 3.14 \times 2.18 \times 10^9}{3 \times 10^8} = 45.76 \tag{67}$$

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

$$4\left|\frac{J_1\left(45.76 \times 1 \times \sin(3.33)\right)}{45.76 \times 1 \times \sin(3.33)}\right|^2 = 4\left|\frac{J_1\left(2.656\right)}{2.656}\right|^2 = 0.117 \text{ mW} = -9.31 \text{ dBm} \tag{68}$$

Case 2:

$$\theta = 6.15° \tag{69}$$

$$4\left|\frac{J_1\left(45.76 \times 1 \times \sin(6.15)\right)}{45.76 \times 1 \times \sin(6.15)}\right|^2 = 4\left|\frac{J_1\left(4.900\right)}{4.900}\right|^2 = 0.0165 \text{ mW} = -17.82 \text{ dBm} \tag{70}$$

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.

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Table 3-4: *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)	23.57	47.15
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
Scintillation Loss(dB), PL_{SL}	0	0
Polarization Loss(dB), PL_{POL}	0	0
Atmospheric Loss(dB), PL_{ATM}	0	0
Total Pathloss, L(dB)	157.3	163.81
Rx Antenna Gain	0	0
Noise figure f	7	7
Rx Antenna Temp Ta (K)	290	290
RX equivalent antenna Temp, T $[dBK]$	31.62	31.62
Receiver G/T	−31.62	−31.62
Boltzmann constant k $\left[\frac{dBW}{\frac{K}{Hz}}\right]$	−228.6	−228.6
CNR (Calculation provided below)	4.36	−4.66

Case 1:

$$CNR = EIRP + G(\theta) + Rx\frac{G}{T} - k - PL_{FS} - PL_{SM} - PL_{AD} - PL_{SL} - PL_{POL} - PL_{ATM} - B \quad (71)$$

Substituting we get

$$CNR = 48.77 + (-9.87) + (-31.62) - (-228.6) - 154.14 - 0.57 - 8 - 74.77 = -1.6 \text{ dB} \quad (72)$$

Case 2:

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

Substituting we get

$$CNR = 54.77 + (-12.95) + (-31.62) - (-228.6) - 160.08 - 0.57 - 8 - 74.77 = -4.62 \text{ dB} \quad (74)$$

4 NTN BLER

4.1 User-Configurable BLER

NOTE: The BLER settings are available under the 5G NTN interface in the gNB Physical Layer properties.

When BLER_ENABLE is selected, NetSim reads the configured BLER Value as the target transport block BLER. Inside StoreAMCInfo(), the per-code-block error probability is derived from the target using the back-calculation formula.

If a transport block is segmented into N code blocks, NetSim derives the per-code-block error probability p from the target i-BLER using

$$p = 1 - (1 - i\text{-}BLER_{target})^{1/N} \tag{75}$$

where $i\text{-}BLER_{target}$ is the user-configured transport block BLER and N is the number of code blocks in that transport block. This back-calculation makes the resulting transport block BLER match the configured value.

In the current NTN implementation, HARQ is disabled by default. As a result, retransmissions do not occur, and the BLER calculation in this section applies to new transmissions only.

5 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.

5.1 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 $n = 0, 1, 2, \ldots$
- 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.

5.2 Downlink Scheduler

In NTN, the detailed downlink scheduler described in this manual is the **Round Robin** scheduler. The Round Robin scheduler allocates downlink resources cyclically across the associated UEs, subject to the available PRBs, UE association, beam coverage, and the selected MCS for each UE.

Other downlink scheduler behavior follows the NetSim 5G NR implementation. For details on those schedulers and their configuration, refer to the 5G NR documentation.

6 Interference Models

6.1 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

$$CNIR\,[\text{dB}] = -10\log_{10}\left(10^{-0.1\,CNR\,[\text{dB}]} + 10^{-0.1\,CIR\,[\text{dB}]}\right) \tag{76}$$

6.2 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

$$CNR\,[\text{dB}] = -10\log_{10}\left(10^{-0.1\times(-1.6)} + 10^{-0.1\times5}\right) = -2.46\text{ dB} \tag{77}$$

Case 2:

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

$$CNIR\,[\text{dB}] = -10\log_{10}\left(10^{-0.1\,CNR\,[\text{dB}]} + 10^{-0.1\,CIR\,[\text{dB}]}\right) \tag{78}$$

$$= -10\log_{10}\left(10^{-0.1\times(-4.62)} + 10^{-0.1\times5}\right) = -5.07\text{ dB} \tag{79}$$

Table 6-1: *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

$$\text{Interference [mW]} = \text{Noise [mW]} \times \left(\frac{CNR\,[\text{mW}]}{CNIR\,[\text{mW}]} - 1\right) \tag{80}$$

$$\text{Interference [dB]} = 10 \times \log_{10}(\text{Interference [mW]}) \tag{81}$$

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Case 1:

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

$$\text{Interference [mW]} = 10^{0.1\times(-99.05)} \times \left(\frac{10^{0.1\times 4.36}}{10^{0.1\times 1.66}} - 1\right) \tag{82}$$

$$\text{Interference [mW]} = 1.073 \times 10^{-10} \tag{83}$$

$$\text{Interference [dB]} = 10 \times \log_{10}\left(1.073 \times 10^{-10}\right) = -99.69 \text{ dB} \tag{84}$$

Case 2:

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

$$\text{Interference [mW]} = 10^{0.1\times(-99.05)} \times \left(\frac{10^{0.1\times(-4.66)}}{10^{0.1\times(-5.11)}} - 1\right) \tag{85}$$

$$\text{Interference [mW]} = 1.3439 \times 10^{-11} \tag{86}$$

$$\text{Interference [dB]} = 10 \times \log_{10}\left(1.3439 \times 10^{-11}\right) = -108.71 \text{ dB} \tag{87}$$

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.

7 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 7-1: *Enabling NTN Radio Measurement log.*

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

Table 7-1: *NTN log usage for gateway, serving transition, beam, and radio checks.*

Log file	What it records	When to use it
NTN Gateway Association Log	Serving gateway selected for each satellite on the feeder link	Check which gateway carries the satellite feeder path and when gateway association changes
NTN Serving Transition Log	UE serving-link changes, including serving satellite changes, serving beam changes, and no-coverage transitions	Check when the UE serving path changes because of UE mobility, satellite movement, or coverage loss
NTN UE Beam Association Log	Serving satellite, serving beam, UE position, slant height, elevation angle, link budget values, SNR, SINR, CQI, MCS, and associated-beam flag	Check UE attachment, beam selection, no-coverage cases, and association changes during mobility
NTN Radio Measurements Log	Per-carrier radio measurements such as loss terms, antenna gain, received power, thermal noise, interference power, SNR, SINR, CQI, and MCS	Check per-subframe radio-link values used for NTN PHY analysis

- 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

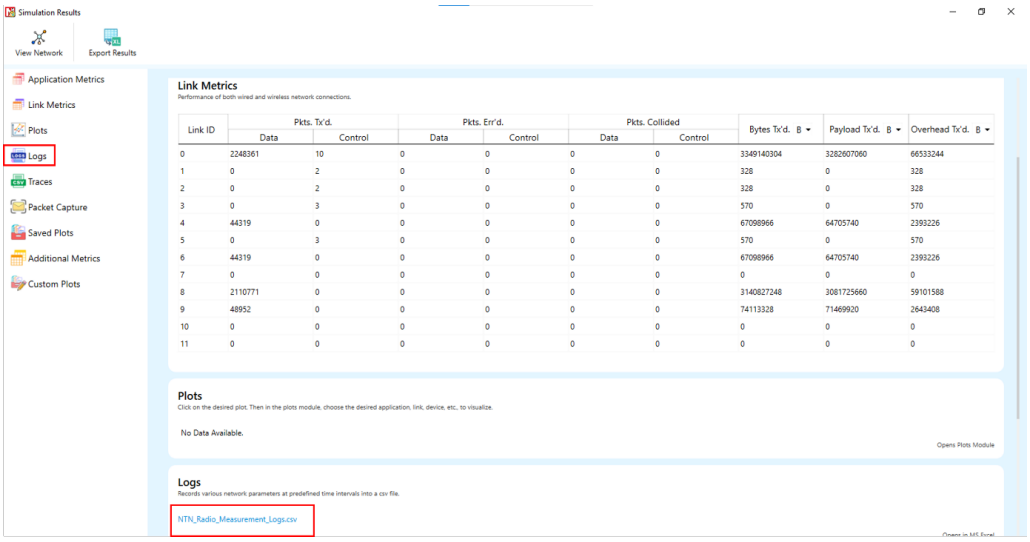


Figure 7-2: *NTN Radio Measurement Log file highlighted in the Results window.*

8 Frequency Reuse

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

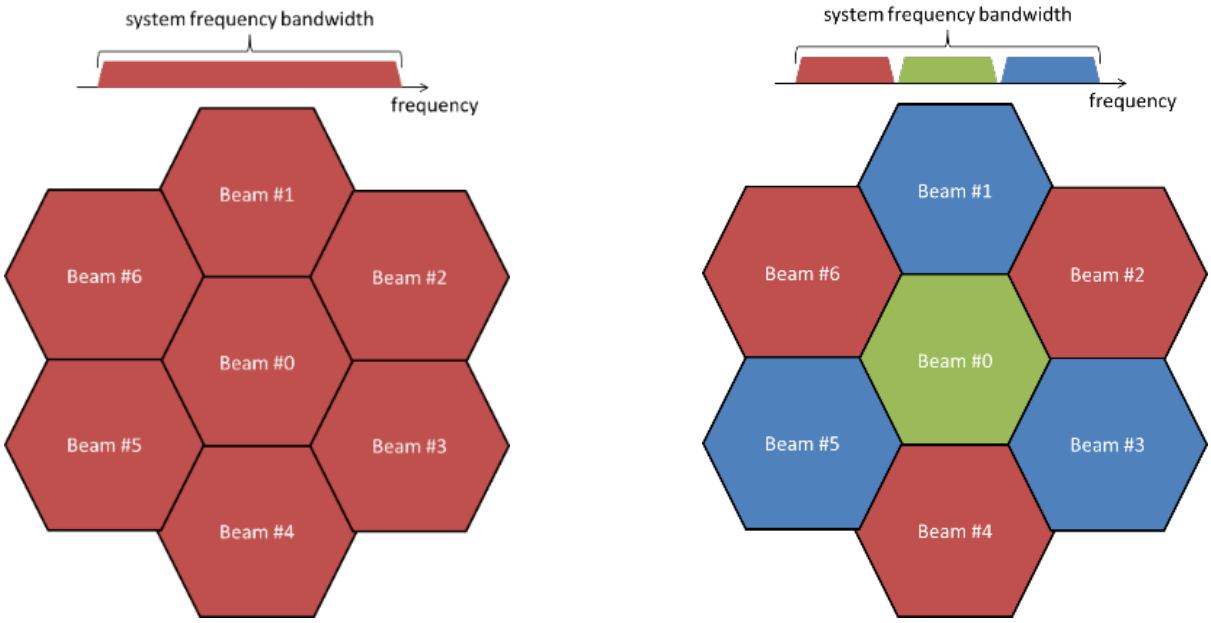


Figure 8-1: *Frequency reuse in a 7-beam layout. Left: FR1 – all beams share the full system bandwidth. Right: FR3 – the bandwidth is divided among three channel groups to reduce inter-beam interference.*

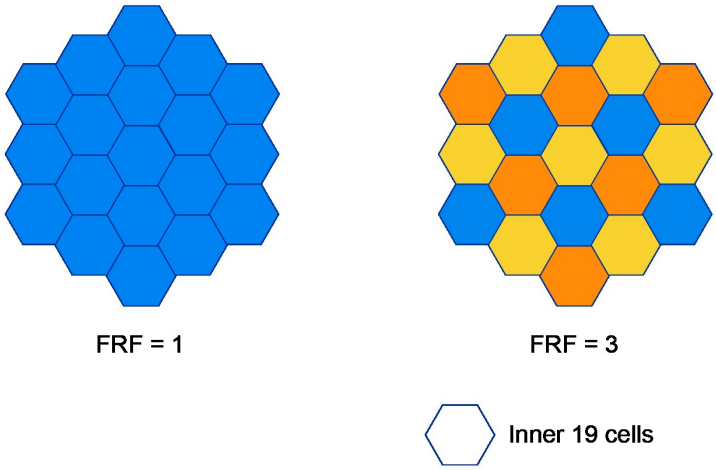


Figure 8-2: *The 7-cell and 19-cell cases for FR1 and FR3.*

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

$$BW_{channel} = \frac{BW_{Total} - (N_{channels} - 1) \times BW_{GuardBand}}{N_{channels}} \quad (88)$$

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.

9 Link Budget with Interference

Table 9-1: *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)	47.15	47.15
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
Scintillation Loss (dB)	0	0
Polarization Loss (dB)	0	0
Atmospheric Loss (dB)	0	0
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

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9.1 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.

$$\theta = 85.26^\circ \tag{89}$$

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

$$d = \sqrt{R_E^2 \sin^2(\alpha) + h_o^2 + 2h_o R_E} - R_E \sin(\alpha) \tag{90}$$

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

$$d = \sqrt{(6.371 \cdot 10^6)^2 \cdot \sin^2(85.26^\circ) + (12 \cdot 10^5)^2 + 2 \cdot (12 \cdot 10^5)\,(6.371 \cdot 10^6)} - 6.371 \cdot 10^6 \sin(85.26^\circ) \tag{91}$$

$$d = 1203.46 \text{ km} \tag{92}$$

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

$$PL_{FS} = 20 \log_{10}\left(\frac{4\pi d}{\lambda}\right) = 20 \log_{10}\left(\frac{4\pi \left(1203.46 \times 10^3\right)\left(2 \times 10^9\right)}{3 \times 10^8}\right) = 160.85 \text{ dB} \tag{93}$$

The receiver antenna G/T is given by the expression

$$Rx\frac{G}{T} = G_{rx} - N_f - 10 \log_{10}\left(T_0 + (T_a - T_0) \times 10^{-0.1 \times N_f}\right) \tag{94}$$

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

$$Rx\frac{G_{rx}}{T} = 0 - 7 - 10 \log_{10}(290) = -31.62 \text{ dB/K} \tag{95}$$

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

And finally, we obtain CNR as

$$CNR = EIRP + G(\theta) + Rx\frac{G}{T} - k - PL_{FS} - PL_{SM} - PL_{AD} - PL_{SL} - PL_{POL} - PL_{ATM} - B \tag{96}$$

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

$$Rx \text{ Power (dBm)} = CNR + \text{Noise} = -4.12 + (-99.06) = -103.18 \text{ dBm} \tag{97}$$

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

$$CINR \text{ (Linear)} = \frac{Rx \text{ Power}}{\text{Noise} + \text{Interference Power}} = \frac{10^{\frac{-103.18}{10}}}{10^{\frac{-99.06}{10}} + 10^{\frac{-106.37}{10}}} \tag{98}$$

$$= \frac{4.82 \times 10^{-11}}{1.24 \times 10^{-10} + 2.31 \times 10^{-11}} = \frac{4.82 \times 10^{-11}}{1.471 \times 10^{-10}} = 0.327 \tag{99}$$

$$CINR\ (\text{dBm}) = 10 \times \log_{10}(0.327) = -4.86\ \text{dB} \tag{100}$$

CINR calculated is -2.77 dB

9.2 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.

$$\theta = 85.26^\circ \tag{101}$$

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

$$d = \sqrt{R_E^2 \sin^2(\alpha) + h_o^2 + 2h_o R_E} - R_E \sin(\alpha) \tag{102}$$

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

$$d = \sqrt{(6.371 \cdot 10^6)^2 \cdot \sin^2(85.26^\circ) + (12 \cdot 10^5)^2 + 2 \cdot (12 \cdot 10^5)(6.371 \cdot 10^6)} - 6.371 \cdot 10^6 \sin(85.26^\circ) \tag{103}$$

$$d = 1203.46\ \text{km} \tag{104}$$

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

$$PL_{FS} = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) = 20\log_{10}\left(\frac{4\pi\left(1203.46 \times 10^3\right)\left(2 \times 10^9\right)}{3 \times 10^8}\right) = 160.85\ \text{dB} \tag{105}$$

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

$$Rx\frac{G}{T} = G_{rx} - N_f - 10\log_{10}\left(T_0 + (T_a - T_0) \times 10^{-0.1 \times N_f}\right) \tag{106}$$

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

$$Rx\frac{G_{rx}}{T} = 0 - 7 - 10\log_{10}(290) = -31.62\ \text{dB/K} \tag{107}$$

$$Rx\frac{G}{T} = G_{rx} - N_f - 10\log_{10}\left(T_0 + (T_a - T_0) \times 10^{-0.1 \times N_f}\right) \tag{108}$$

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

And finally, we obtain CNR as

$$CNR = EIRP + G(\theta) + Rx\frac{G}{T} - k - PL_{FS} - PL_{SM} - PL_{AD} - PL_{SL} - PL_{POL} - PL_{ATM} - B \tag{109}$$

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

$$Rx \text{ Power (dBm)} = CNR + \text{Noise} = -4.66 + (-103.83) = -108.49 \text{ dBm} \tag{110}$$

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

$$CINR \text{ (Linear)} = \frac{Rx \text{ Power}}{\text{Noise} + \text{Interference Power}} = \frac{10^{\frac{-108.49}{10}}}{10^{\frac{-103.83}{10}} + 10^{\frac{-116.51}{10}}} \tag{111}$$

$$= \frac{1.41 \times 10^{-11}}{4.13 \times 10^{-11} + 2.33 \times 10^{-12}} = \frac{1.41}{4.353} = 0.324 \tag{112}$$

$$CINR \text{ (dBm)} = 10 \times \log_{10}(0.324) = -4.89 \text{ dB} \tag{113}$$

CINR calculated is -4.89 dB

10 Beam Radius Calculations

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

$$G(\theta_{HPBW}) = 4 \times \left| \frac{J_1(ka\sin(\theta_{HPBW}))}{ka \cdot \sin(\theta_{HPBW})} \right|^2 = \frac{1}{2} \tag{114}$$

Taking square root

$$\left| \frac{2 \cdot J_1(ka\sin(\theta_{HPBW}))}{ka \cdot \sin(\theta_{HPBW})} \right| = \frac{1}{\sqrt{2}} \tag{115}$$

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

$$ka\sin(\theta_{HPBW}) \approx 1.616 \tag{116}$$

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

$$\frac{2\pi}{\lambda} \cdot \frac{D}{2} \sin(\theta_{HPBW}) \approx 1.616 \tag{117}$$

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

$$\theta_{HPBW} \text{ [degrees]} \approx \frac{60\lambda}{D} \tag{118}$$

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

$$\theta_{HPBW} \text{ [degrees]} = \frac{30 \times c}{a \times f} \tag{119}$$

The beam radius is calculated at half the HPBW angle:

$$R = h \tan\left(\frac{\theta_{HPBW}}{2}\right) \tag{120}$$

Table 10-1: *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
θ_{3dB} (or θ_{HPBW})(Calculation provided below)	4.5	0.9	0.409
Beam Radius (km)	47.15	78.54	127.76

$$\theta_{HPBW} = \frac{30 \times \lambda}{a} = \frac{30 \times c}{a \times f} \tag{121}$$

$$\text{LEO 1200: } \theta_{HPBW} = \frac{30 \times 3 \times 10^8}{1 \times 2 \times 10^9} = 4.5^\circ, \quad R = 1200 \tan\left(\frac{4.5^\circ}{2}\right) = 47.15 \text{ km} \tag{122}$$

$$\text{MEO 10000: } \theta_{HPBW} = \frac{30 \times 3 \times 10^8}{5 \times 2 \times 10^9} = 0.9^\circ, \quad R = 10000 \tan\left(\frac{0.9^\circ}{2}\right) = 78.54 \text{ km} \tag{123}$$

$$\text{GEO 35786: } \theta_{HPBW} = \frac{30 \times 3 \times 10^8}{11 \times 2 \times 10^9} = 0.409^\circ, \quad R = 35786 \tan\left(\frac{0.409^\circ}{2}\right) = 127.76 \text{ km} \tag{124}$$

Table 10-2: *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
θ_{3dB} (or θ_{HPBW})(Calculation provided below)	1.8	0.45	0.18
Beam Radius (km)	18.85	39.27	56.21

$$\text{LEO 1200: } \theta_{HPBW} = \frac{30 \times 3 \times 10^8}{0.25 \times 20 \times 10^9} = 1.8^\circ, \quad R = 1200 \tan\left(\frac{1.8^\circ}{2}\right) = 18.85 \text{ km} \tag{125}$$

$$\text{MEO 10000: } \theta_{HPBW} = \frac{30 \times 3 \times 10^8}{1 \times 20 \times 10^9} = 0.45^\circ, \quad R = 10000 \tan\left(\frac{0.45^\circ}{2}\right) = 39.27 \text{ km} \tag{126}$$

$$\text{GEO 35786: } \theta_{HPBW} = \frac{30 \times 3 \times 10^8}{2.5 \times 20 \times 10^9} = 0.18^\circ, \quad R = 35786 \tan\left(\frac{0.18^\circ}{2}\right) = 56.21 \text{ km} \tag{127}$$

10.1 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.

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- 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 $\sqrt{3} \cdot R$

11 Featured Examples

11.1 Impact of LEO Altitude Variation on SNR and Path Loss

The experiment examines how LEO altitude affects downlink SNR and free-space pathloss using the final example configurations. The scenario is Rural and the satellite is directly overhead at a logged elevation angle of 90°. The experiment is run for S band and K band with altitudes of 300, 600, 1200, 1500, 1800, and 2100 km. Within each band, antenna settings, loss settings, UE position, and radio parameters are held fixed so that the altitude change isolates the slant-range effect.

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.

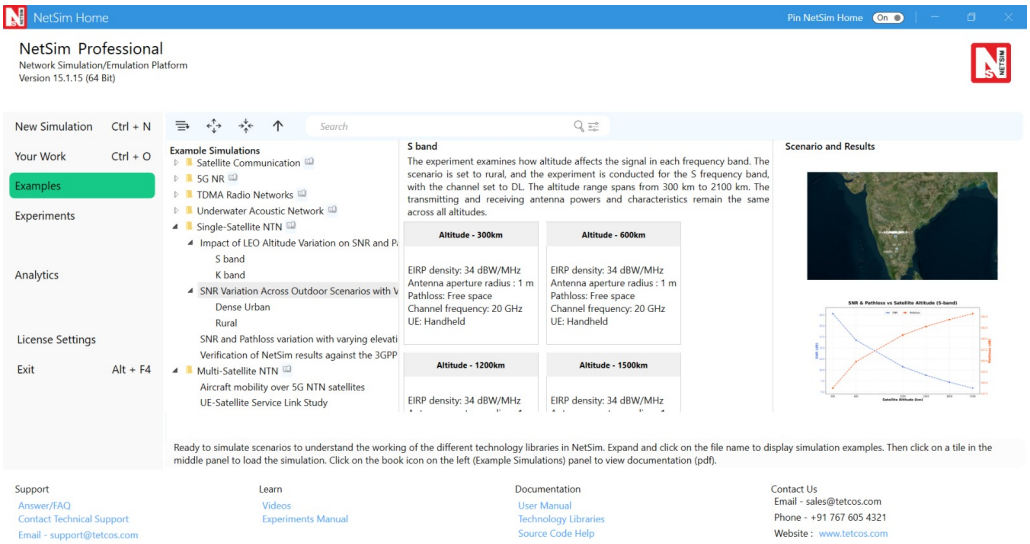


Figure 11-1: *List of scenarios for the example of Impact of LEO Altitude Variation on SNR and Path Loss.*

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



Figure 11-2: *Network setup used for the LEO altitude-variation examples. The same topology is used while the satellite altitude and operating band are varied.*

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 11-1: *Input Parameters for Link Budget Simulation Across Multiple Satellite Altitudes.*

Simulation Properties	Values
Satellite ▷ Interface_2 (Service link) properties	
EIRP Density (dBW/MHz)	34
Antenna Model (Tx/Rx)	TR 38.811 S.6.4.1; maximum gain 30 dBi
Pathloss Model	Free Space
Additional Loss (dB)	0
Scintillation Loss (dB)	0
Polarization Loss (dB)	0
Atmospheric Loss (dB)	0
Shadow Fading Model	Log Normal; user-defined 5 dB
LOS probability	1 (LOS)
Clutterloss Model	None
Outdoor Model	Rural
Altitude (km)	300, 600, 1200, 1500, 1800, 2100
UE Noise Figure (dB)	7
gNB ▷ Interface_4 (Feeder link) properties	
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 11-3: *Enabling the NTN UE Beam Association log.*

Pathloss and SNR calculation for 600 km The satellite and UE are at latitude 12.9716° N and longitude 77.5946° E using WGS84. At a satellite altitude of 600 km, the satellite is directly overhead and the logged elevation angle is 90°. For this overhead geometry:

$$\alpha = \sin^{-1}\left(\frac{D}{L}\right) = 90^\circ \tag{128}$$

Here, ϕ and ℓ are the UE geodetic latitude and longitude, and $\hat{\mathbf{n}}_{ue}$ is the local upward unit vector:

$$\hat{\mathbf{n}}_{ue} = (\cos\phi\cos\ell,\ \cos\phi\sin\ell,\ \sin\phi)^T \tag{129}$$

$$L = \sqrt{(x_{sat} - x_{ue})^2 + (y_{sat} - y_{ue})^2 + (z_{sat} - z_{ue})^2} \tag{130}$$

$$D = \hat{\mathbf{n}}_{ue} \cdot (\mathbf{r}_{sat} - \mathbf{r}_{ue}) \tag{131}$$

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

$$d = \sqrt{R_E^2 \sin^2(\alpha) + h_o^2 + 2h_o R_E} - R_E \sin(\alpha) \tag{132}$$

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

$$d = \sqrt{(6.371 \cdot 10^6)^2 \cdot \sin^2(90^\circ) + (6 \cdot 10^5)^2 + 2 \cdot (6 \cdot 10^5)\,(6.371 \cdot 10^6)} - 6.371 \cdot 10^6 \sin(90^\circ) \tag{133}$$

$$d = 600 \text{ km} \tag{134}$$

The free space pathloss PL_{FS} for a channel with $f_c = 2.185$ GHz, or $\lambda = \frac{c}{f} \approx 0.1373$ m, and $d = 600$ km is

$$PL_{FS} = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) = 20\log_{10}\left(\frac{4\pi\left(600\times10^{3}\right)\left(2.185\times10^{9}\right)}{3\times10^{8}}\right) = 154.8 \text{ dB} \quad (135)$$

$$SNR = P_{Rx,\text{dBm}} - N_{\text{thermal,dBm}} - NF_{\text{dB}} \quad (136)$$

$$SNR = -77.21 - (-100.96) - 7 \quad (137)$$

$$= 16.75 \text{ dB} \quad (138)$$

Results After the simulation, open `NTN_UE_Beam_Association.csv` under Logs in the simulation results window. The final plots use the `Beam Selection` row from each altitude run; the plotted fields are `DL SSB SNR(dB)` and `PathLoss(dB)`. The numerical calculation above uses the logged received power and thermal noise, with the configured UE noise figure.

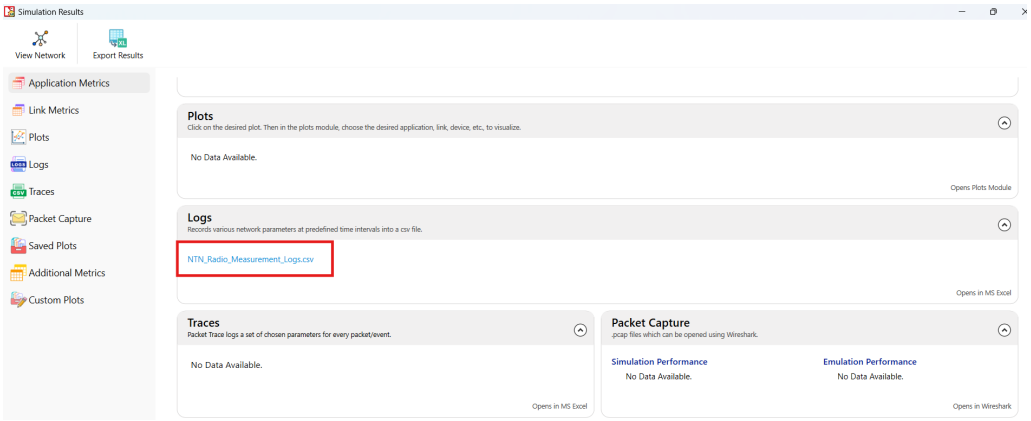


Figure 11-4: *Simulation results window: network logs are opened from the Logs panel (illustrative radio-log view).*

	K	L	M	N	O	P	Q	R	S	T	U	V	
1	EIRP(dBW)	PathLoss(dB)	ShadowFadingLoss(dB)	AdditonalLoss(dB)	ClutterLoss(dB)	TotalLoss(dB)	BeamFormingGain(dB)	Angular Antenna Gain(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	-84.64	16.17	16.17	
3	47.01	154.8	0	0	0	154.8	N/A	0	0	-84.64	16.17	16.17	
4	47.01	154.8	0	0	0	154.8	N/A	0	0	-84.64	16.17	16.17	
5	47.01	154.8	0	0	0	154.8	N/A	0	0	-84.64	16.17	16.17	
6	47.01	154.8	0	0	0	154.8	N/A	0	0	-84.64	16.17	16.17	
7	47.01	154.8	0	0	0	154.8	N/A	0	0	-84.64	16.17	16.17	
8	47.01	154.8	0	0	0	154.8	N/A	0	0	-84.64	16.17	16.17	
9	47.01	154.8	0	0	0	154.8	N/A	0	0	-84.64	16.17	16.17	
10	47.01	154.8	0	0	0	154.8	N/A	0	0	-84.64	16.17	16.17	
11	47.01	154.8	0	0	0	154.8	N/A	0	0	-84.64	16.17	16.17	
12	47.01	154.8	0	0	0	154.8	N/A	0	0	-84.64	16.17	16.17	
13	47.01	154.8	0	0	0	154.8	N/A	0	0	-84.64	16.17	16.17	
14	47.01	154.8	0	0	0	154.8	N/A	0	0	-84.64	16.17	16.17	

Figure 11-5: *S-band SNR and pathloss at 600 km (illustrative radio-log view).*

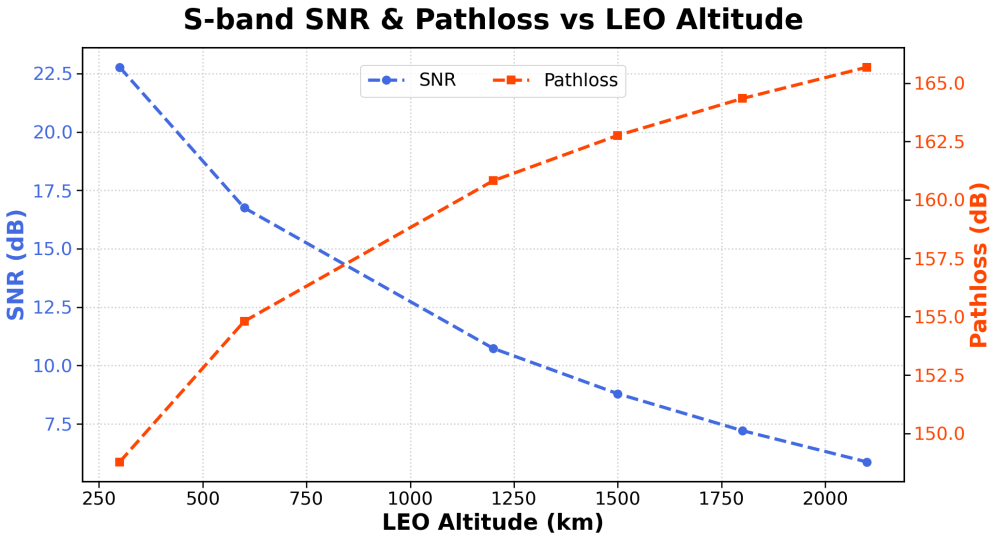


Figure 11-6: *S-band SNR and pathloss versus satellite altitude: rural scenario, 20 MHz bandwidth, and* 90° *elevation.*

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 11-2: *Simulation settings for K-band altitude variation example.*

Simulation Properties	Values
Satellite ▷ Interface_2 (Service link) properties	
EIRP Density (dBW/MHz)	4
Antenna Model (Tx/Rx)	TR 38.811 S.6.4.1; maximum gain 30 dBi
Pathloss Model	Free Space
Additional Loss (dB)	0
Scintillation Loss (dB)	0
Polarization Loss (dB)	0
Atmospheric Loss (dB)	0
Shadow Fading Model	Log Normal; user-defined 5 dB
LOS probability	1 (LOS)
Clutterloss Model	None
Outdoor Model	Rural
Altitude	300, 600, 1200, 1500, 1800, 2100
VSAT ▷ Interface_1 (Service Link) properties	
UE Noise Figure (dB)	1.2
Tx/Rx Antenna Gain (dB)	35
gNB ▷ Interface_4 (Feeder link) properties	
CA Configuration	K Band n510
Channel Frequency (GHz)	18.75
Channel Bandwidth (MHz)	200

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

The satellite and UE are at latitude 12.9716° N and longitude 77.5946° E using WGS84. At a satellite altitude of 600 km, the satellite is directly overhead and the logged elevation angle is 90°. For this overhead geometry:

$$\alpha = \sin^{-1}\left(\frac{D}{L}\right) = 90^\circ \tag{139}$$

Here, ϕ and ℓ are the UE geodetic latitude and longitude, and $\hat{\mathbf{n}}_{ue}$ is the local upward unit vector:

$$\hat{\mathbf{n}}_{ue} = (\cos\phi\cos\ell,\ \cos\phi\sin\ell,\ \sin\phi)^T \tag{140}$$

$$L = \sqrt{(x_{sat} - x_{ue})^2 + (y_{sat} - y_{ue})^2 + (z_{sat} - z_{ue})^2} \tag{141}$$

$$D = \hat{\mathbf{n}}_{ue} \cdot (\mathbf{r}_{sat} - \mathbf{r}_{ue}) \tag{142}$$

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

$$d = \sqrt{R_E^2 \sin^2(\alpha) + h_o^2 + 2h_o R_E} - R_E \sin(\alpha) \tag{143}$$

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

$$d = \sqrt{(6.371 \cdot 10^6)^2 \cdot \sin^2(90^\circ) + (6 \cdot 10^5)^2 + 2 \cdot (6 \cdot 10^5)\,(6.371 \cdot 10^6)} - 6.371 \cdot 10^6 \sin(90^\circ) \tag{144}$$

$$d = 600 \text{ km} \tag{145}$$

The free space pathloss PL_{FS} for a channel with $f_c = 18.75$ GHz, or $\lambda = \frac{c}{f} = 0.016$ m, and $d = 600$ km is

$$PL_{FS} = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) = 20\log_{10}\left(\frac{4\pi\left(600 \times 10^3\right)\left(18.75 \times 10^9\right)}{3 \times 10^8}\right) = 173.47 \text{ dB} \tag{146}$$

$$SNR = P_{Rx,\text{dBm}} - N_{\text{thermal,dBm}} - NF_{\text{dB}} \tag{147}$$

$$SNR_{\log} = 10.86 \text{ dB} \tag{148}$$

Observe the SNR and pathloss in the `Beam Selection` row of `NTN_UE_Beam_Association.csv`. At 600 km, the K-band run reports 10.86 dB SNR and 173.47 dB pathloss in the Beam Selection row. The calculation above uses the logged received power and thermal noise fields from the new run.

EIRP(dBW)	PathLoss(dB)	ShadowFadingLoss(dB)	AdditonalLoss(dB)	ClutterLoss(dB)	TotalLoss(dB)	BeamFormingGain(dB)	Angular Antenna Gain(dB)	UE Rx Antenna Gain(dB)	Rx_Power(dBm)	SNR(dB)	SINR(dB)	Therm
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	
27.01	173.47	0	0	0	173.47	N/A	0	35	-82.51	8.3	8.3	

Figure 11-7: *K-band SNR and pathloss at 600 km (illustrative radio-log view).*

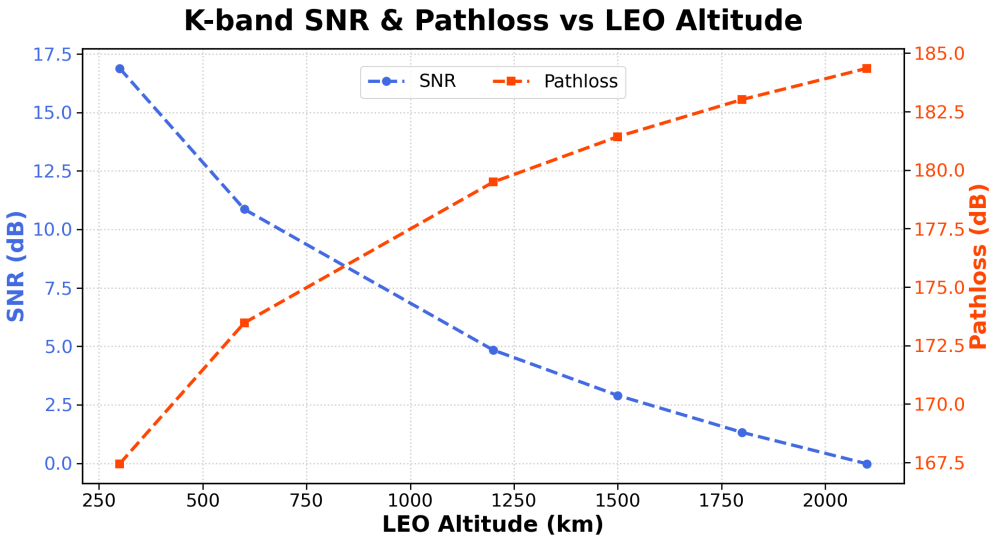


Figure 11-8: *K-band SNR and pathloss versus satellite altitude: rural scenario, 200 MHz bandwidth, and* 90° *elevation.*

Using the final runs, the S-band SNR decreases from 22.77 dB at 300 km to 5.87 dB at 2100 km, while pathloss increases from 148.78 dB to 165.68 dB. The K-band SNR decreases from 16.88 dB to -0.02 dB, while pathloss increases from 167.45 dB to 184.35 dB. In both bands, increasing the overhead slant distance reduces SNR. The K-band SNR remains about 5.89 dB below the S-band case at each altitude because the higher carrier frequency increases free-space pathloss by the same offset for this fixed geometry.

11.2 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.

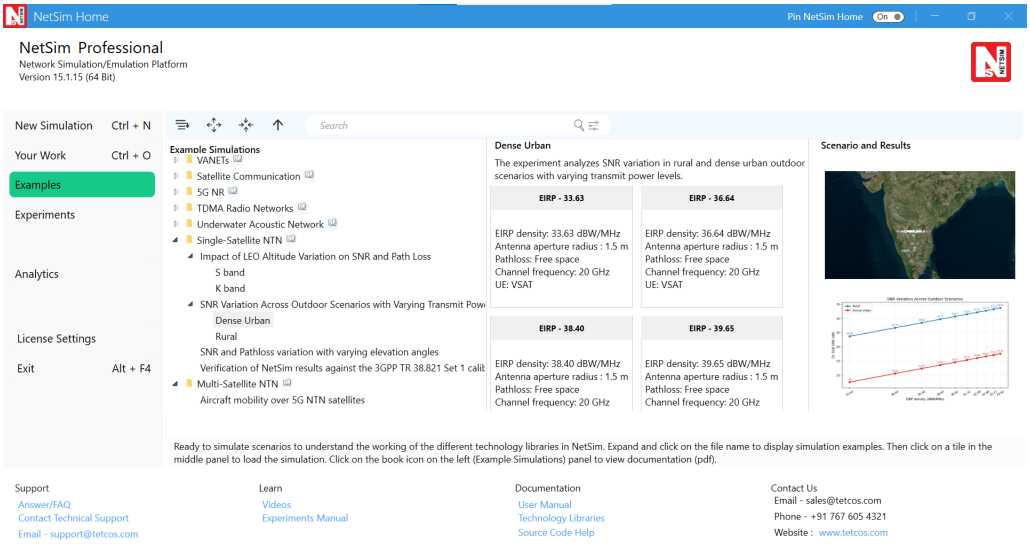


Figure 11-9: *List of scenarios for the example of SNR Variation Across Outdoor Scenarios with Varying Transmit Power.*

The following screenshot shows the log-selection option used for this example.



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

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 11-3: *Simulation settings for SNR variation with transmit power example.*

Simulation Properties	Values
Satellite ▷ Interface_2 (Service link) properties	
Antenna Model (Tx/Rx)	TR 38.811 S.6.4.1; maximum gain 30 dBi
Pathloss Model	Free Space
Shadow model	Log Normal
Additional Loss(dB)	0
Scintillation Loss(dB)	0
Polarization Loss(dB)	0
Atmospheric 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
Derived Tx Power (dBm)	59.65, 62.66, 64.42, 65.67, 66.63, 67.43, 68.10, 68.68, 69.19, 69.65
VSAT ▷ Interface_1 (Service Link) properties	
UE Noise Figure (dB)	1.2
Tx/Rx Antenna Gain (dB)	35
gNB ▷ Interface_4 (Feeder link) properties	
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 11-11: *Enable NTN UE Beam Association log.*

- Run Simulation for 10 seconds.

Results After the simulation, open `NTN_UE_Beam_Association.csv` under Logs in the simulation results window. The refreshed plots use `DL SSB SNR(dB)` from the initial `Beam Selection` row in each of the 20 final scenario runs. As EIRP density increases from 33.63 to 43.63 dBW/MHz, Rural SNR increases from 23.69 to 33.69 dB and Dense Urban SNR increases from 7.59 to 17.59 dB. The Rural case is 16.10 dB higher at each input power. Both cases have 173.47 dB pathloss; the logged clutter losses

are 16.80 dB for Rural and 32.90 dB for Dense Urban, with a logged shadow loss of -0.58 dB in both scenarios.

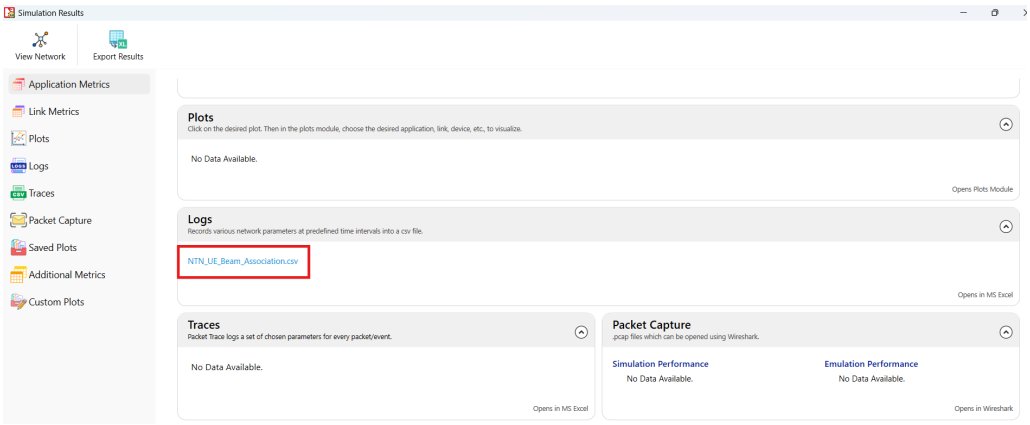


Figure 11-12: *Opening NTN UE Beam Association log from simulation results window.*

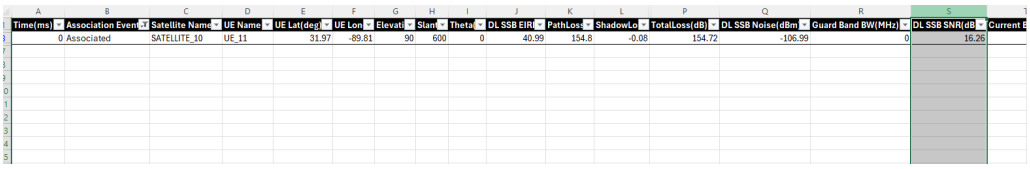


Figure 11-13: *SNR value from NTN UE Beam Association log.*

Clutter loss enabled and NLOS

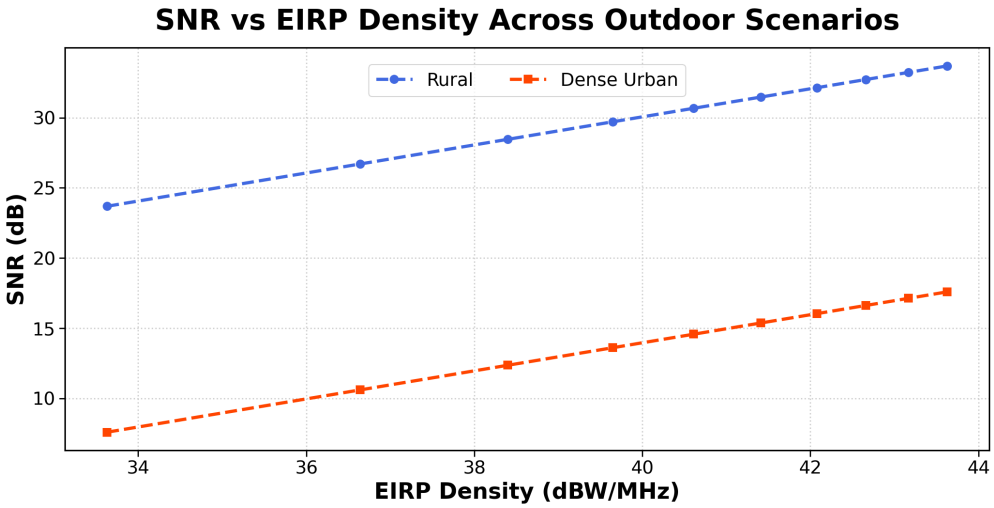


Figure 11-14: *SNR versus EIRP density in Rural and Dense Urban: 400 MHz bandwidth, NLOS, and clutter loss enabled.*

The configuration directly specifies EIRP density. The transmit-power axis below is derived using the configured maximum transmit antenna gain of 30 dBi. Total EIRP over the 400 MHz channel is the EIRP density plus $10\log_{10}(400) = 26.02$ dB. At the lowest EIRP density, total EIRP is therefore 59.65 dBW:

$$EIRP\ [\text{dBW}] = P_{tx}\ [\text{dBm}] - 30 + G_{Tx}\ [\text{dBi}] \tag{149}$$

$$59.65 = P_{tx}\ [\text{dBm}] - 30 + 30 \tag{150}$$

$$P_{tx}\ [\text{dBm}] = 59.65 \tag{151}$$

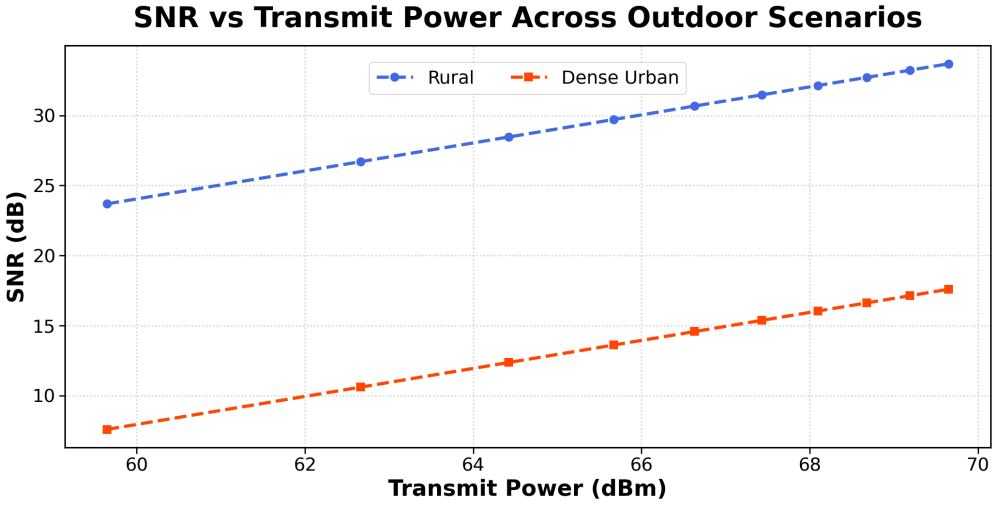


Figure 11-15: *SNR versus derived transmit power in Rural and Dense Urban, using 30 dBi transmit antenna gain.*

11.3 SNR and Pathloss variation with varying elevation angles

In this experiment, a satellite at an altitude of 600 km is used to measure downlink S-band SNR and pathloss for nominal elevation angles from 10° to 90° in steps of 10°. The reference ellipsoid is WGS84 for all devices. The UE position is varied while the satellite altitude and the UE height above ground remain fixed. As the elevation angle increases, the slant distance between the satellite and the UE decreases, reducing pathloss and increasing SNR. The improvement is larger at low elevation angles and becomes smaller as the satellite approaches the overhead position.

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.

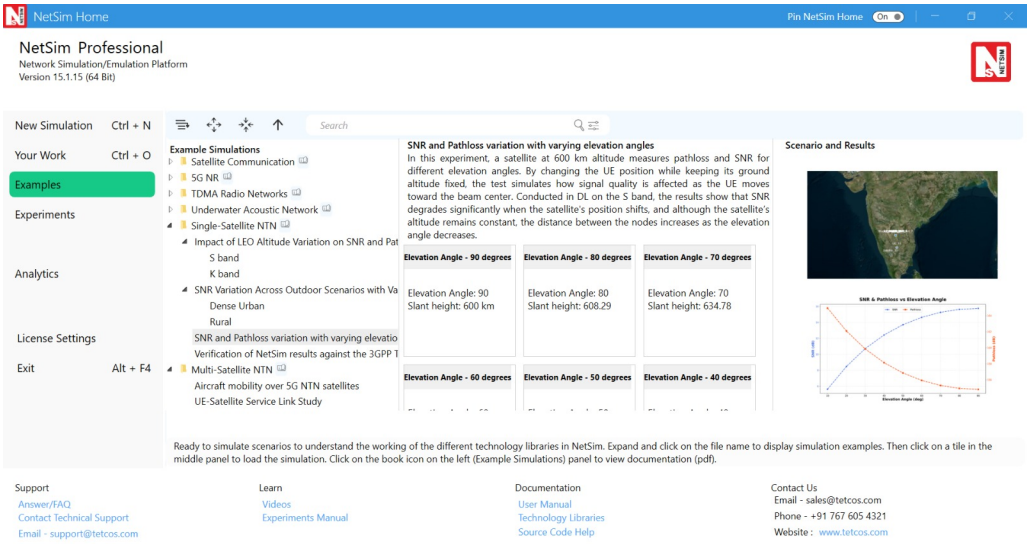


Figure 11-16: *List of scenarios for the example of SNR and Pathloss variation with varying elevation angles.*

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



Figure 11-17: *Network setup used for the LEO altitude-variation examples. The same topology is used while the satellite altitude and operating band are varied.*

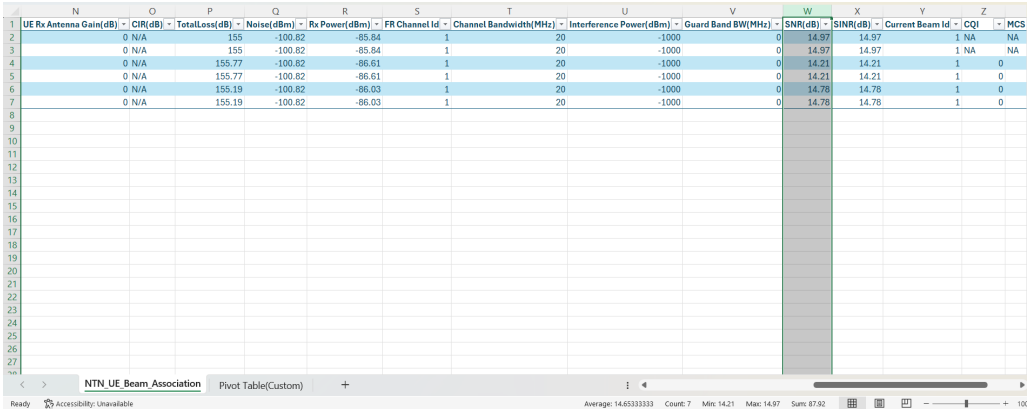
Settings in the example config file

The elevation-angle scenarios use S band n256 with 20 MHz bandwidth, 33 dBW/MHz EIRP density, TR 38.811 S.6.4.1 Tx/Rx satellite antennas with 30 dBi maximum gain, Free-space pathloss, Log Normal shadow fading with user-defined 5 dB standard deviation, LOS probability 1, no clutter loss, and a 5 degree elevation mask. The UE uses 0 dBi antenna gain and 7 dB noise figure.

Table 11-4: *Logged SNR, pathloss, and slant height versus elevation angle.*

Nominal elevation angle	10	20	30	40	50	60	70	80	90
Logged elevation angle (deg)	10.07	20.10	30.12	40.13	50.13	60.11	70.08	80.05	90.00
Slant height (km)	1924.494	1387.206	1071.733	880.140	759.473	682.411	634.582	608.362	600.000
DL SSB SNR (dB)	5.63	8.47	10.71	12.42	13.70	14.63	15.26	15.63	15.75
Pathloss (dB)	164.93	162.08	159.84	158.13	156.85	155.92	155.29	154.92	154.80

Results The elevation angle and slant height depend on the UE position and can be observed in the NTN UE Beam Association log. The refreshed plot uses the `DL SSB SNR(dB)` and `PathLoss(dB)` fields from the `Beam Selection` row in each final elevation-angle scenario. The horizontal axis shows the nominal scenario angles; the logged angles range from 10.07° to 90.00° and differ from the nominal values by at most 0.13°.



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
0	N/A	155	-100.82	-85.84	1	20	-1000	0	14.97	14.97	1	NA	NA
0	N/A	155	-100.82	-85.84	1	20	-1000	0	14.97	14.97	1	NA	NA
0	N/A	155.77	-100.82	-86.61	1	20	-1000	0	14.21	14.21	1	0	
0	N/A	155.77	-100.82	-86.61	1	20	-1000	0	14.21	14.21	1	0	
0	N/A	155.19	-100.82	-86.03	1	20	-1000	0	14.78	14.78	1	0	
0	N/A	155.19	-100.82	-86.03	1	20	-1000	0	14.78	14.78	1	0	

Figure 11-18: *Slant height and Elevation angle in NTN UE Beam Association log.*

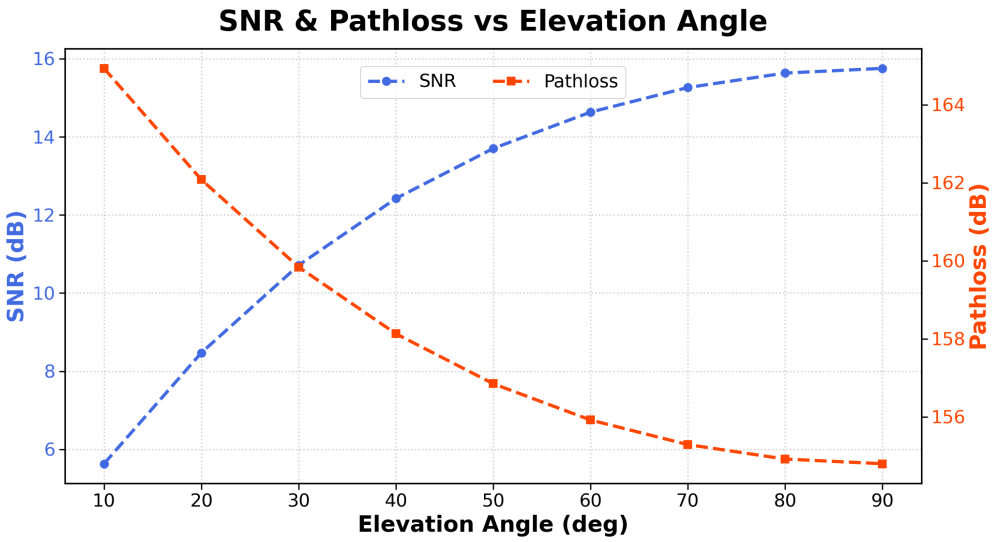


Figure 11-19: *Impact of Elevation Angle on Signal-to-Noise Ratio (SNR) and Pathloss in a Satellite Link.*

As the nominal elevation angle increases from 10° to 90°, SNR increases from 5.63 dB to 15.75 dB, while pathloss decreases from 164.93 dB to 154.80 dB. This corresponds to an SNR improvement of 10.12 dB and a pathloss reduction of 10.13 dB. At 30° and 60°, the SNR values are 10.71 dB and 14.63 dB, and the pathloss values are 159.84 dB and 155.92 dB, respectively. The curves flatten near the overhead position: from 80° to 90°, SNR increases by only 0.12 dB and pathloss decreases by 0.12 dB.

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11.4 Verification of NetSim results against the 3GPP TR 38.821 Set 1 calibration

This experiment verifies the NetSim downlink radio measurements against the Set 1 calibration reference in 3GPP TR 38.821. The study uses the four S-band handheld-terminal cases listed in Table 6.1.1.1-9: SC9, SC10, SC14, and SC15. The cases cover LEO altitudes of 600 km and 1200 km and frequency reuse factors of 1 and 3. The NetSim time-mean CDFs are compared with the company curves reported in R1-1913404 and with the percentile values in 3GPP TR 38.821 Table 6.1.1.2-1.

11.4.1 Objective

The objective is to verify the distributions of downlink coupling loss and Geometry SINR for the 19 metric beams defined by the Set 1 calibration geometry. The comparison uses the 5^{th}, 50^{th}, and 95^{th} percentiles.

11.4.2 3GPP reference scenario

The scenario follows the calibration assumptions in 3GPP TR 38.821 Section 6.1.1.1, especially Tables 6.1.1.1-1, 6.1.1.1-3, 6.1.1.1-4, 6.1.1.1-5, 6.1.1.1-6, and 6.1.1.1-9. The antenna pattern is based on Section 6.4.1 of 3GPP TR 38.811. A transparent LEO payload provides the S-band service link. The central beam is at a 90° reference elevation, the propagation environment is rural with clear-sky line-of-sight, and the UEs are placed outdoors. Beam attachment uses RSRP. The calibration metrics are coupling loss and Geometry SINR, where coupling loss is the signal loss between the satellite antenna port and the UE antenna port. For every valid downlink row in the NTN Radio Measurement Log, the post-processing calculates coupling loss as

$$\text{Coupling Loss (dB)} = \text{TotalLoss(dB)} - [30 + \text{Angular Antenna Gain(dB)}] - \text{UE Tx/Rx Antenna Gain(dB)}. \tag{152}$$

The 30 dB term is the configured maximum satellite transmit antenna gain. The angular antenna gain is the beam gain at the UE position, and the UE term is the logged UE transmit/receive antenna gain. The calculation removes the serving satellite and UE antenna gains from the logged total loss to obtain the antenna-port-to-antenna-port coupling loss. Rx power, interference power, and noise are not used in this calculation; they are used separately for Geometry SINR. Duplicate records for the same UE and timestamp are removed, the coupling-loss samples are averaged per UE, and the CDF is then formed from the 190 UE time-mean values. Geometry SINR is calculated as

$$\text{Geometry SINR} = -10 \log_{10} \left(\frac{I}{C} + \frac{N}{C} \right). \tag{153}$$

Here, C is the received power from the serving beam, I is the sum of the received co-channel interference power from the interfering beams, and N is the receiver noise power over the configured signal bandwidth. The noise term includes the UE receiver noise figure. The quantities C, I, and N are used as linear powers in the ratio; the result is then expressed in dB.

11.4.3 Calibration case matrix

Table 11-5: *3GPP TR 38.821 Set 1 downlink calibration cases.*

Case	3GPP case	Orbit	Reuse option	NetSim FRF	Total beams	Metric UEs
SC9	9	LEO-600	Option 1	FR1	61	190
SC10	10	LEO-600	Option 2	FR3	127	190
SC14	14	LEO-1200	Option 1	FR1	61	190
SC15	15	LEO-1200	Option 2	FR3	127	190

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Each case has 19 metric beams and 10 UEs per metric beam. Therefore, the statistics contain 190 UEs. The additional beams are present to supply the interference seen by the inner 19 beams; they are not included as metric UEs.

11.4.4 Simulation setup

The NetSim scenarios use the following setup:

- One transparent LEO satellite is used for each case. The orbit altitude is 600 km for SC9 and SC10 and 1200 km for SC14 and SC15.
- The inner calibration region contains 19 beam centres in the hexagonal layout defined by 3GPP TR 38.821 Table 6.1.1.1-4. The central beam boresight is at the 90° reference elevation.
- Ten UEs are placed uniformly throughout the Voronoi cell associated with each of the 19 metric beam centres. The placement is area-uniform within each cell and is not a set of equally spaced points on a circle or a set of points forced onto the beam centre.
- The FR1 cases use 61 beams. The FR3 cases use 127 beams. The outer beams are simulated to provide co-channel interference to the inner 19 beams.
- UEs are stationary during the 5 second run. The service link uses S-band, a 30 MHz carrier, and the frequency reuse factor selected for the case.
- The propagation baseline is rural, outdoor, clear-sky line-of-sight. Ionospheric scintillation, clutter, and additional loss are set to zero; atmospheric absorption is enabled as configured in the scenario.
- Downlink interference uses the exact geometric model. Uplink interference and uplink results are not used in this downlink verification.

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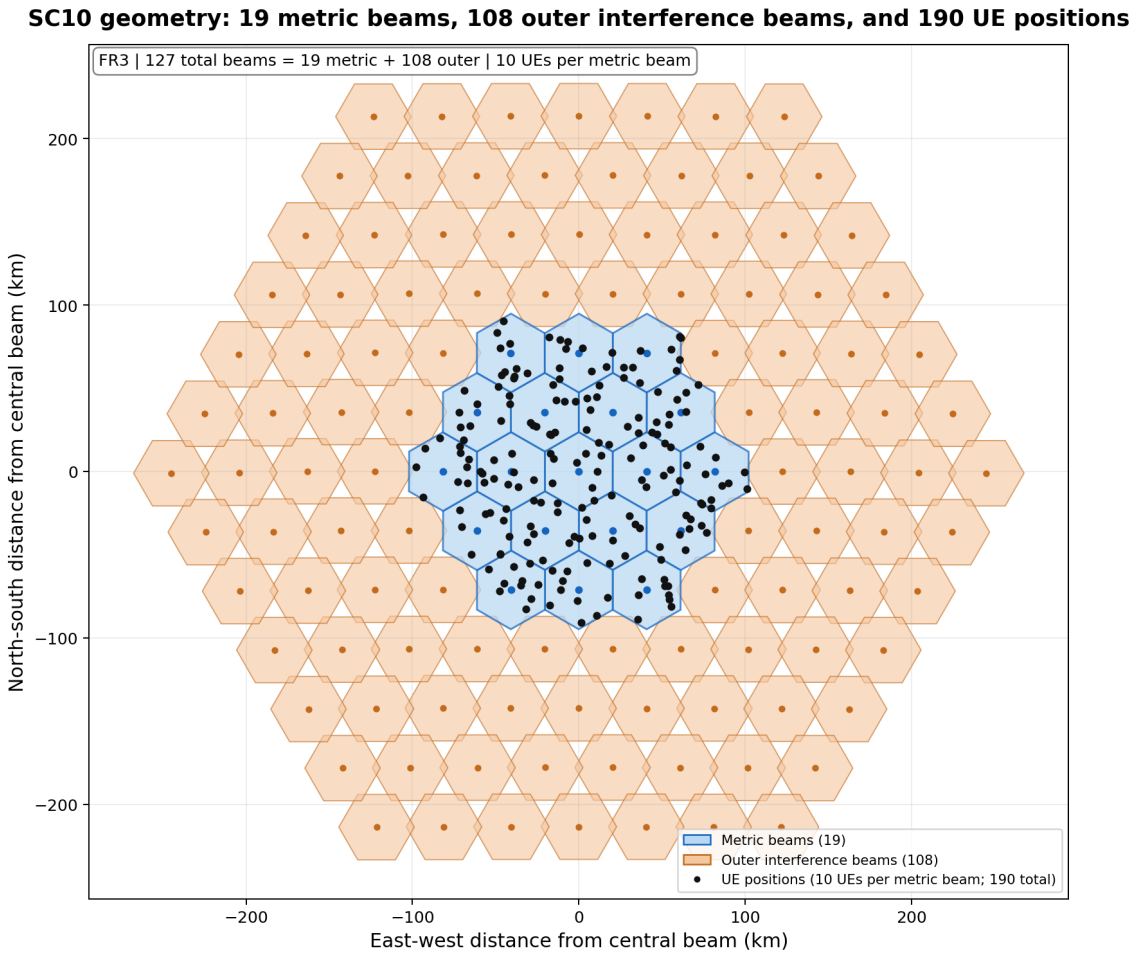


Figure 11-20: *SC10 downlink geometry representation used for the calibration.*



Figure 11-21: *Equivalent SC10 downlink scenario created in NetSim.*

Outer-beam coverage for interference

3GPP TR 38.821 states that the 19-beam layout is the metric region and that surrounding beams must be

simulated independently when they contribute interference. For frequency reuse factor 1, two additional beam tiers are required around the 19-beam layout. For reuse factors greater than 1, four additional tiers are required. The co-channel beams in these tiers contribute interference, while only the UEs in the inner 19 beams are used for the calibration statistics. The NetSim beam counts of 61 for FR1 and 127 for FR3 implement these two extensions in the hexagonal geometry.

11.4.5 Parameter configuration

Table 11-6: *NetSim parameters used for the Set 1 downlink calibration.*

Parameter	NetSim setting and 3GPP reference
Orbit and test cases	LEO-600 for SC9 and SC10; LEO-1200 for SC14 and SC15. The case mapping follows 3GPP TR 38.821 Table 6.1.1.1-9.
Satellite EIRP density	34 dBW/MHz for LEO-600 and 40 dBW/MHz for LEO-1200, per beam, from Table 6.1.1.1-1.
Satellite transmit gain	30 dBi maximum gain, from Table 6.1.1.1-1.
Service-link band	S-band, NetSim carrier n256, 1985–2015 MHz. The calibration assumptions use the approximately 2 GHz S-band service link in Table 6.1.1.1-5.
Downlink carrier	30 MHz with 160 PRBs and 15 kHz subcarrier spacing in the NetSim configuration. The bandwidth and reuse treatment follow Table 6.1.1.1-5.
Frequency reuse	FR1 for SC9 and SC14; FR3 for SC10 and SC15. These correspond to reuse Options 1 and 2 in Table 6.1.1.1-5.
Antenna model	TR 38.811 Section 6.4.1 Bessel-pattern model, with the NetSim antenna properties used by the scenarios: aperture value 1 and maximum gain 30 dBi.
Propagation model	Rural outdoor environment, LOS probability 1, log-normal shadowing selection based on TR 38.811. The baseline uses clear-sky propagation.
Loss settings	Atmospheric loss is enabled with the scenario value 0.07. Clutter, additional, and scintillation losses are zero. The zero scintillation setting follows the calibration assumption in Table 6.1.1.1-5.
Interference	Exact Geometric Model for downlink interference. The outer beam tiers provide the interfering transmissions.
UE radio settings	UE height 1.5 m, transmit power 23 dBm, antenna gain 0 dBi, noise figure 7 dB, and antenna temperature 290 K. The saved NetSim cases use one transmit and one receive antenna branch. Table 6.1.1.1-3 lists the handheld reference as one transmit and two receive branches; the receive-branch setting is therefore reported as a NetSim implementation detail.
UE distribution	10 UEs per metric beam, 190 UEs in total, uniformly distributed in the Voronoi cell of each inner beam centre, as required by Table 6.1.1.1-5.
Mobility and duration	No mobility; 5 second simulation duration.

11.4.6 Application properties

The configuration contains 190 unicast Full Buffer applications, one for each metric UE. The applications use source device ID 9 and destination IDs 11–200, so every metric UE receives the same traffic configuration. The downlink is kept loaded during the radio measurement run; the reported CDFs are calculated from the radio measurement log.

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Table 11-7: *Full Buffer application properties applied to all metric UEs.*

Application property	Value
Number of applications	190
Application type	FULL_BUFFER
Application method	UNICAST
Source and destinations	Source device ID 9; one destination for each UE ID 11–200
Transport protocol	UDP
Packet size	1460 B
Packets in flight	500
Start and end time	1 and 100000

11.4.7 Log configuration

Enable the NTN Radio Measurement Log and the NTN UE Beam Association Log from Configure Reports ▷ Plots ▷ Network Logs before running each case. The radio measurement log supplies coupling loss and Geometry SINR. The beam association log verifies the serving beam for the 190 metric UEs.

11.4.8 Results and Discussion

The processing selects downlink records, groups samples by UE, calculates the time mean for each UE, and then forms the CDF across the 190 metric UEs. This time-mean method prevents one UE with many measurement timestamps from receiving more weight than another UE. The company curves in the overlays are the 11 company results in R1-1913404. The NetSim curve is shown as one legend entry labelled "NetSim".

Table 11-8: *Coupling-loss percentile comparison for the four downlink calibration cases.*

Case	5^{th} percentile (dB)		50^{th} percentile (dB)		95^{th} percentile (dB)	
	3GPP	NetSim	3GPP	NetSim	3GPP	NetSim
SC9	123.7	123.759	125.3	125.540	127.0	127.200
SC10	123.7	123.759	125.3	125.540	127.0	127.200
SC14	129.8	129.715	131.3	131.670	133.0	133.126
SC15	129.8	129.715	131.4	131.670	133.0	133.126

Table 11-9: *Geometry SINR percentile comparison for the four downlink calibration cases.*

Case	5^{th} percentile (dB)		50^{th} percentile (dB)		95^{th} percentile (dB)	
	3GPP	NetSim	3GPP	NetSim	3GPP	NetSim
SC9	-3.1	-2.984	-1.1	-1.107	1.0	0.917
SC10	7.3	7.297	8.2	7.940	8.5	8.318
SC14	-3.1	-3.048	-1.1	-1.516	1.0	0.958
SC15	7.3	7.227	8.2	7.937	8.5	8.366

The reference values in both tables are from 3GPP TR 38.821 Table 6.1.1.2-1. Across the eight metric comparisons, the largest absolute difference between the NetSim time-mean value and the tabulated reference is 0.42 dB. The LEO-1200 cases show the expected increase in coupling loss relative to the LEO-600 cases. The FR3 cases show higher Geometry SINR than the corresponding FR1 cases because fewer same-frequency beams contribute co-channel interference. NetSim therefore reproduces the reference percentile range and the altitude and reuse trends for the four Set 1 downlink cases.

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Figure 11-22: 3GPP NTN downlink calibration, case 9: LEO-600, handheld S-band, frequency reuse 1. NetSim against 11 company results in R1-1913404 (TR 38.821 Table 6.1.1.1-5).

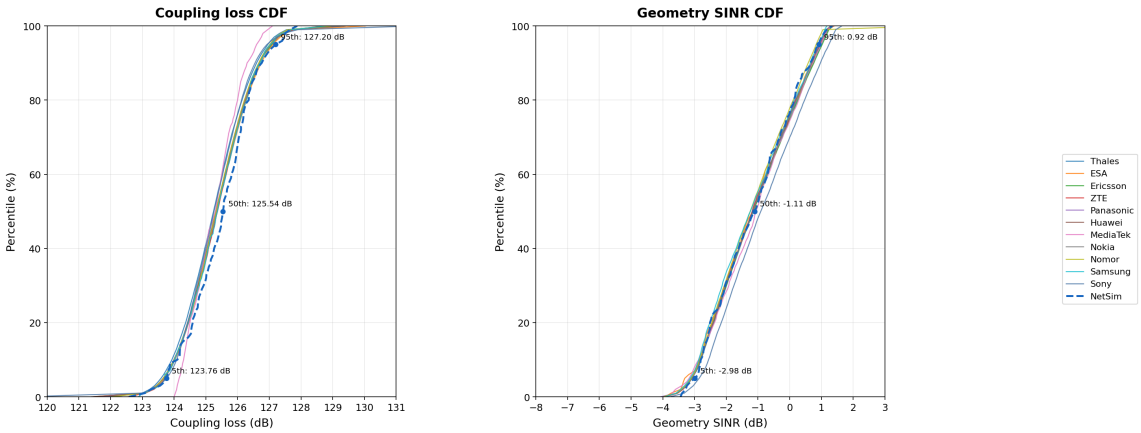


Figure 11-23: 3GPP NTN downlink calibration, case 10: LEO-600, handheld S-band, frequency reuse 3. NetSim against 11 company results in R1-1913404 (TR 38.821 Table 6.1.1.1-5).

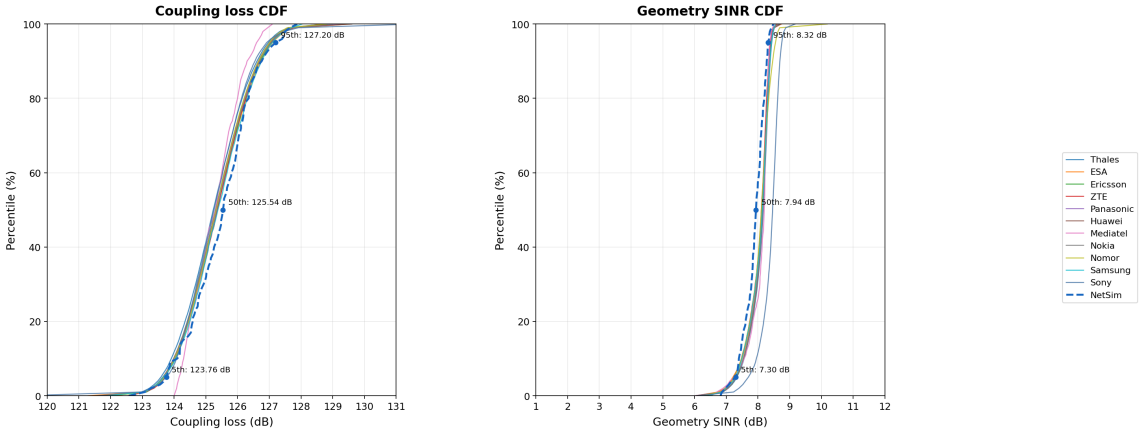


Figure 11-24: 3GPP NTN downlink calibration, case 14: LEO-1200, handheld S-band, frequency reuse 1. NetSim against 11 company results in R1-1913404 (TR 38.821 Table 6.1.1.1-5).

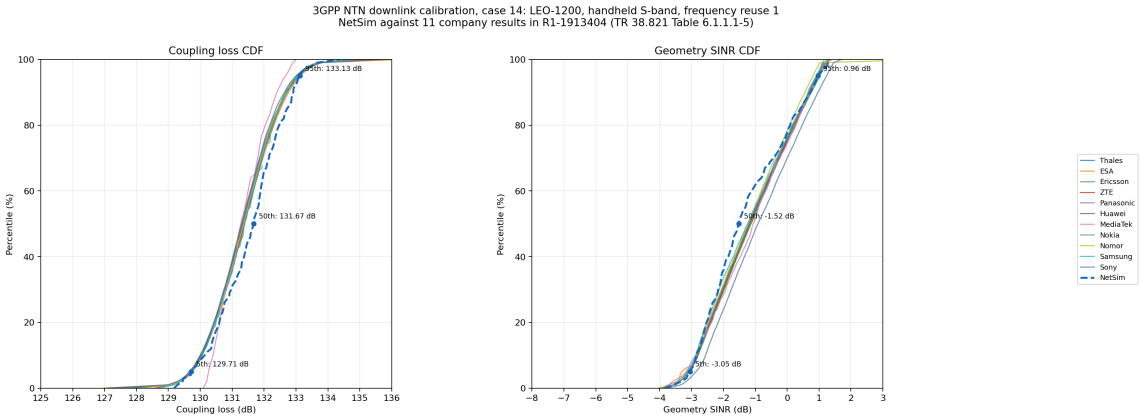
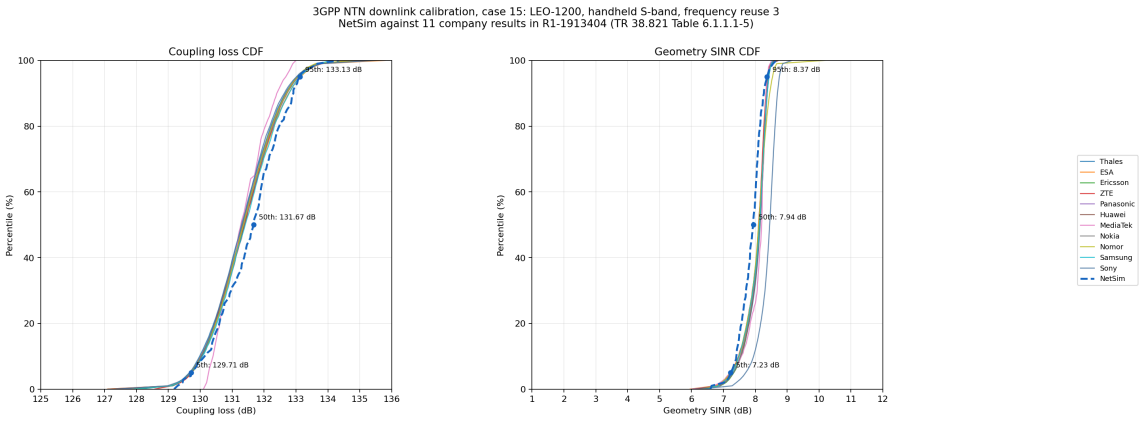


Figure 11-25: 3GPP NTN downlink calibration, case 15: LEO-1200, handheld S-band, frequency reuse 3. NetSim against 11 company results in R1-1913404 (TR 38.821 Table 6.1.1.1-5).



11.4.9 Part 2: Peak Throughput and Spectral Efficiency Evaluation

This part evaluates the application throughput and application spectral efficiency for the same four Set 1 calibration cases. The evaluation uses the 190-UE Full Buffer configurations. The application throughput values are the sum of the 190 downlink applications in each saved scenario.

Objective

The objective is to measure the aggregate application throughput delivered to the 19 metric beams and to calculate the corresponding application spectral efficiency. Each metric beam contains 10 UEs, and the same 30 MHz downlink carrier is used in all four cases. The reported spectral efficiency is normalized by the 19 metric beams and the 30 MHz bandwidth:

$$SE_{\text{app}} = \frac{\text{Aggregate application throughput}}{19 \times 30 \times 10^6}. \tag{154}$$

Simulation setup

- SC9, SC10, SC14, and SC15 use the same 190-UE geometry as the calibration evaluation: 19 metric beams and 10 UEs per metric beam.
- SC9 and SC10 use LEO-600; SC14 and SC15 use LEO-1200.
- SC9 and SC14 use FR1; SC10 and SC15 use FR3. The outer beams supply the interference, while throughput is measured for the inner metric region.
- The service link uses S-band n256, 1985–2015 MHz, 30 MHz bandwidth, 160 PRBs, 15 kHz subcarrier spacing, and numerology $\mu = 0$.
- The PDSCH MCS table is QAM256, the BLER model is Zero BLER, and the downlink scheduler is Round Robin.
- Each UE has one UDP unicast Full Buffer application with a 1460-byte packet size and 500 packets in flight. The application settings are identical for all 190 UEs.
- The saved scenarios use no UE mobility and a 5 second simulation duration.

Table 11-10: *Peak-throughput evaluation cases.*

Case	Orbit	FRF	Total beams	Metric UEs	Applications
SC9	LEO-600	FR1	61	190	190
SC10	LEO-600	FR3	127	190	190
SC14	LEO-1200	FR1	61	190	190
SC15	LEO-1200	FR3	127	190	190

Parameter configuration

Table 11-11: *Common throughput and spectral-efficiency parameters.*

Parameter	Value
Service-link carrier	S-band n256, 1985–2015 MHz
Downlink bandwidth	30 MHz
PRBs and numerology	160 PRBs, 15 kHz subcarrier spacing, $\mu = 0$
PDSCH MCS table	QAM256
BLER model	Zero BLER
Scheduler	Round Robin
Application	UDP unicast Full Buffer, 1460-byte packets, 500 packets in flight
Simulation duration	5 seconds
Spectral-efficiency denominator	19×30 MHz, representing the 19 metric beams
Application metric source	Saved application throughput results for the 190 downlink applications

Theoretical spectral-efficiency reference

For one fully scheduled 30 MHz metric beam, the reference calculation uses

$$SE_p = \frac{\nu Q_m R_{\max} \left(\frac{N_{PRB} \times 12}{T_s} \right) (1 - OH)}{BW}. \tag{155}$$

Using $\nu = 1$, $Q_m = 6$, $R_{\max} = 0.852$, $N_{PRB} = 160$, $T_s = 0.001/14$, $OH = 0.14$, and $BW = 30$ MHz gives an illustrative value of approximately 3.94 bits/s/Hz per fully scheduled beam. This value is a single-beam PDSCH reference and is not used as the application-layer result in Tables 11-12 and 11-13.

The 3.94 bits/s/Hz value is not the target for the four Set 1 calibration runs. TR 38.821 Section 6.1.1.3 evaluates user throughput with 10 UEs per cell and resource-utilization targets around 20% and 50%, whereas the present runs contain 10 UEs per metric beam and calculate application spectral efficiency from the saved application throughput. Sharing reduces each UE's throughput, but it does not by itself reduce aggregate beam spectral efficiency when the beam is continuously scheduled. The difference from 3.94 bits/s/Hz therefore reflects the application-layer measurement, link conditions, scheduling, and multi-beam interference.

To verify the peak reference separately, use one beam and one UE at the beam centre or nadir, with 30 MHz bandwidth, 160 PRBs, $\mu = 0$, one layer, $Q_m = 6$, $R_{\max} = 0.852$, $OH = 0.14$, and continuous PRB allocation. The traffic source must keep the beam scheduled, and the PDSCH result should be averaged after the warm-up period. The target is

$$3.94 \times 30 \text{ MHz} = 118.2 \text{ Mbps} \tag{156}$$

per beam. If all 19 metric beams reached this reference at the same time, the aggregate target would be 2245.8 Mbps. This peak test is separate from the four multi-UE calibration cases and does not replace

their TR 38.821 calibration results.

Application-metric calculation

The application throughput is obtained by summing the throughput reported for the 190 downlink applications in each saved scenario. The application spectral efficiency is calculated from this aggregate application throughput:

$$SE_{\text{app}} = \frac{\text{Aggregate application throughput}}{19 \times 30 \times 10^6}. \tag{157}$$

Results and discussion

Table 11-12: *Application downlink throughput from the saved NetSim results.*

Case	Application throughput (Mbps)
SC9	251.494
SC10	330.430
SC14	242.798
SC15	330.418

Table 11-13: *Application spectral efficiency normalized over the 19 metric beams.*

Case	Application spectral efficiency (bits/s/Hz)
SC9	0.441
SC10	0.580
SC14	0.426
SC15	0.580

Satellite capacity, area traffic capacity, and average spectral efficiency

For each case, satellite capacity is the aggregate application throughput reported in Table 11-12. The coverage area is calculated from the 19 metric beams using

$$A_{\text{total}} = 19 \left(\frac{3\sqrt{3}}{2} R^2 \right), \tag{158}$$

where $R = 23.574$ km for LEO-600 and $R = 47.148$ km for LEO-1200. Area traffic capacity is calculated as satellite capacity divided by A_{total}, and average spectral efficiency is calculated as satellite capacity divided by 19×30 MHz.

Table 11-14: *Capacity and spectral-efficiency metrics for the four downlink calibration cases.*

Case	Satellite capacity (Mbps)	Beam radius (km)	Area traffic capacity (kbps/km^2)	Average spectral efficiency (bits/s/Hz/TRxP)
SC9	251.494	23.574	9.168	0.441
SC10	330.430	23.574	12.045	0.580
SC14	242.798	47.148	2.213	0.426
SC15	330.418	47.148	3.011	0.580

Throughput distribution

The application-throughput CDF uses one application-throughput value for each of the 190 UEs in a case. The per-beam CDF is formed by summing the ten application-throughput values assigned to each of the

19 metric beams. The 5th, 50th, and 95th percentile values are calculated from the resulting 190-UE and 19-beam datasets.

Table 11-15: *Application and per-beam throughput CDF percentiles for the four downlink calibration cases.*

Case	Per-UE application throughput (Mbps)			Per-beam application throughput (Mbps)		
	5th	50th	95th	5th	50th	95th
SC9	0.695	1.092	1.688	11.322	13.292	14.993
SC10	1.659	1.755	1.761	17.125	17.409	17.590
SC14	0.695	1.089	1.688	11.183	12.763	14.222
SC15	1.657	1.755	1.761	17.235	17.392	17.555

Figure 11-26: CDF of application throughput per UE for the four downlink calibration cases.

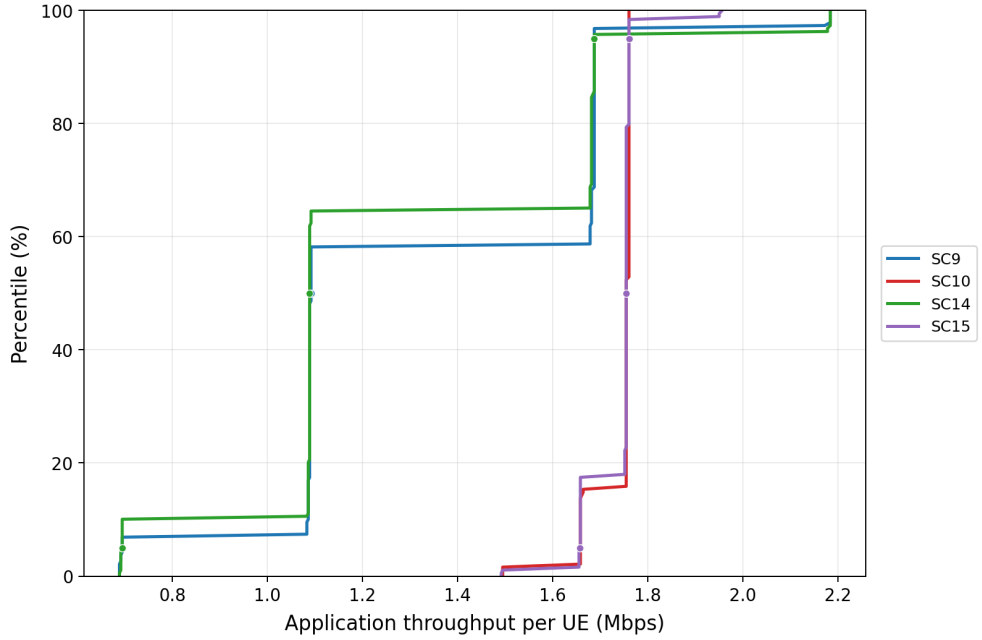
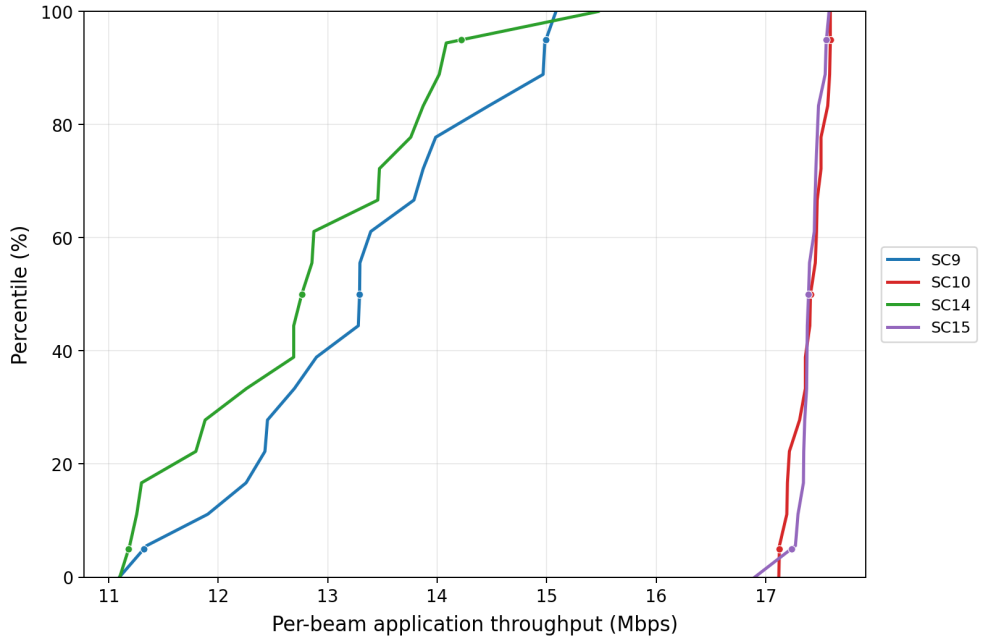


Figure 11-27: CDF of per-beam application throughput for the four downlink calibration cases.



The FR3 cases provide higher aggregate throughput and spectral efficiency than the corresponding FR1 cases because the reuse factor reduces co-channel interference. The LEO-1200 cases have lower throughput than the corresponding LEO-600 cases because of the longer service-link distance and lower received power. SC10 and SC15 show nearly equal values because they use the same FR3 configuration at different satellite altitudes, while SC9 and SC14 show the corresponding FR1 reduction.

The application throughput is an end-to-end value that includes packet delivery through the protocol stack. The application spectral-efficiency values are normalized over the 19 metric beams and should not be compared directly with the 3.94 bits/s/Hz single-beam PDSCH reference. The peak reference requires continuous scheduling of one beam; the calibration cases include multi-UE scheduling, link conditions, and inter-beam interference.

11.5 Aircraft mobility over 5G NTN satellites

11.5.1 Summary

Note: This example is available in NetSim Pro.

This case study models an aircraft moving from Bangalore to Delhi in a 5G NTN network. The aircraft follows the configured mobility path for the complete 2.20 h simulation, which is 2 h 12 min. During the run, the serving satellite changes as the aircraft and satellites move. The 50-satellite and 100-satellite runs use the same Ka-band setting. The comparison reports the serving-satellite timeline, throughput variation with time, downlink SINR variation with time, and application packet delay.

Aircraft connectivity: 50 vs 100 satellites

	50 satellites	100 satellites	
Application throughput	372.47 Mbps	551.59 Mbps	+48.1%
Mean downlink SINR	12.36 dB	12.76 dB	+0.40 dB
Mean packet delay	76.81 ms	21.16 ms	-72.5%
Service availability	67.80%	100.00%	+32.20 pp

Values from the existing NetSim Metrics.xml and UE_10 downlink radio log.

Figure 11-28: *Comparison from the current 50-satellite and 100-satellite workspace runs. Application throughput is 372.47 and 551.59 Mbps, mean downlink SINR is 12.36 and 12.76 dB, and mean packet delay is 76.81 and 21.16 ms, respectively. Service availability is 67.80% and 100.00% over the 2.20 h flight.*

11.5.2 Problem statement

In a non-terrestrial network, aircraft service depends on satellite visibility, elevation angle, beam geometry, and radio-link quality. When the aircraft moves over a long route, the serving satellite can change during the simulation. The objective is to observe this satellite association over time and evaluate the radio and application performance seen by the aircraft.

11.5.3 Approach

The aircraft is configured with a mobility path from Bangalore to Delhi. The application traffic is downlink Full Buffer over UDP, so the aircraft receives continuous downlink traffic during connected periods. Both runs use Ka-band NR NTN with a Gaussian satellite antenna model, Free-space pathloss, and a 10 degree elevation mask. Each satellite uses one Earth_Moving beam. This beam moves along with the satellite, so aircraft service changes as satellite visibility and beam coverage change over time. The analysis compares the 50-satellite and 100-satellite simulation results for throughput, downlink SINR, service availability, and application packet delay.

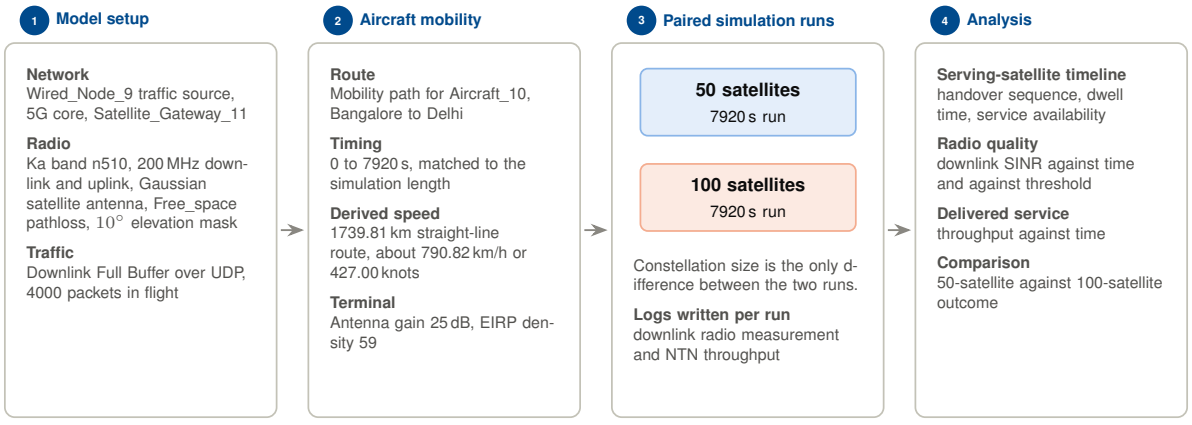


Figure 11-29: *Study workflow. Model setup and aircraft mobility are configured once and held fixed. Constellation size is the only parameter that differs between the two runs, so the difference in the results isolates the effect of satellite density on aircraft service.*

11.5.4 Simulation setup

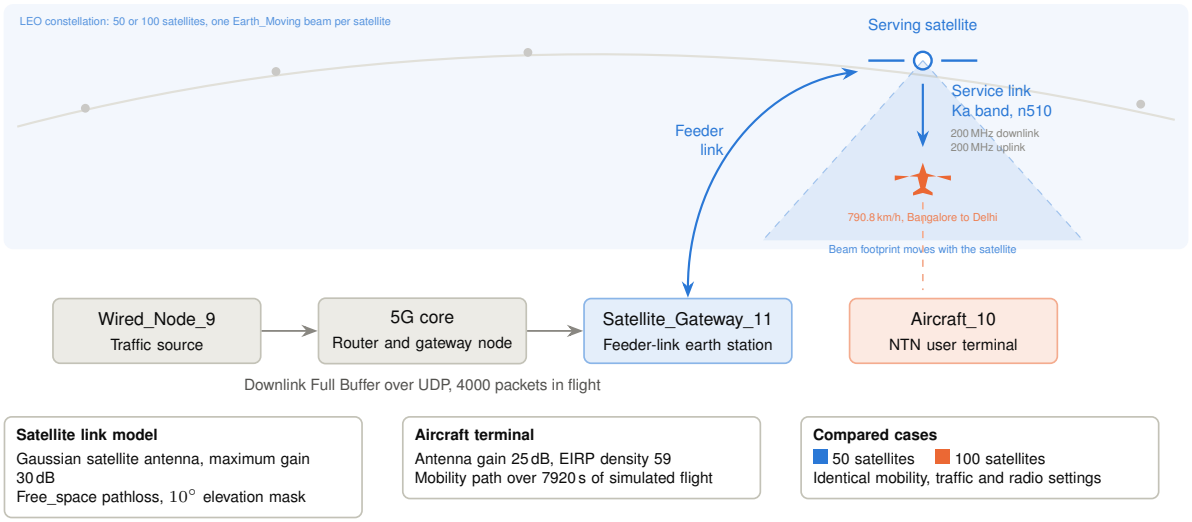


Figure 11-30: *End-to-end model. Downlink Full Buffer traffic originates at Wired_Node_9, passes through the 5G core to Satellite_Gateway_11, crosses the ideal feeder link to the serving satellite, and reaches Aircraft_10 over the Ka-band service link. Each satellite carries one Earth_Moving beam, so the footprint travels with the satellite rather than staying fixed over the ground.*

Table 11-16: *Scenario configuration*

Parameter	Value
Aircraft	Aircraft_10
Mobility model	Mobility path for Aircraft_10
Start point	Bangalore
End point	Delhi
Simulation time	7920 s
Mobility time window	0–7920 s
Mobility route	Direct aircraft route from Bangalore to Delhi
Route speed	About 790.82 km/h, or 427.00 knots
Traffic	Downlink Full Buffer from Wired_Node_9 to Aircraft_10 using UDP, packets in flight 4000
Radio band and bandwidth	Ka band, n510, 200 MHz downlink and 200 MHz uplink
Satellite antenna model	Gaussian antenna model, beam type Earth_Moving
Terminal and link budget	Aircraft antenna gain 25 dB, EIRP density 59, maximum antenna gain 30 dB
Satellite pathloss model	Free_space with elevation mask 10 degrees
Updated cases	50-satellite and 100-satellite constellations with the same aircraft mobility and traffic settings

Network settings

- Enable the result plots before running the simulation. In the design window, select Configure Reports ▷ Plots and enable the downlink SINR vs time plot and throughput vs time plot.
- Enable the NTN Radio Measurements log and the NTN Throughput log, since these logs are used to generate the SINR and throughput time-series plots in this example.

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- Enable Record Animation before running the scenario so that the aircraft movement and serving-satellite changes can be reviewed after the simulation.

11.5.5 Network topology and mobility

Aircraft_10 uses the configured mobility path. The mobility entries provide the simulation time and aircraft position used by NetSim during the run.

The route starts at 0 s from Bangalore and reaches Delhi at 7920 s. Since 7920/3600 = 2.20, the simulation duration is 2.20 h, or 2 h 12 min, and the aircraft moves for the complete run.

The aircraft position is updated at each mobility time instant. The movement is spread over 7920 s, so the aircraft moves from Bangalore to Delhi during the complete simulation. Since no fixed speed is configured, NetSim derives speed from the distance between consecutive mobility points and the time gap between them. The straight-line route length is about 1739.81 km, giving an average speed of about 790.82 km/h, or 427.00 knots.



Figure 11-31: *Scenario view at the start of the simulation, with the aircraft at the Bangalore start point at 0 s. The yellow line marks the configured mobility path toward Delhi over the 0–7920 s simulation. The same view shows the core network nodes, the satellite gateway, and two of the visible satellites.*

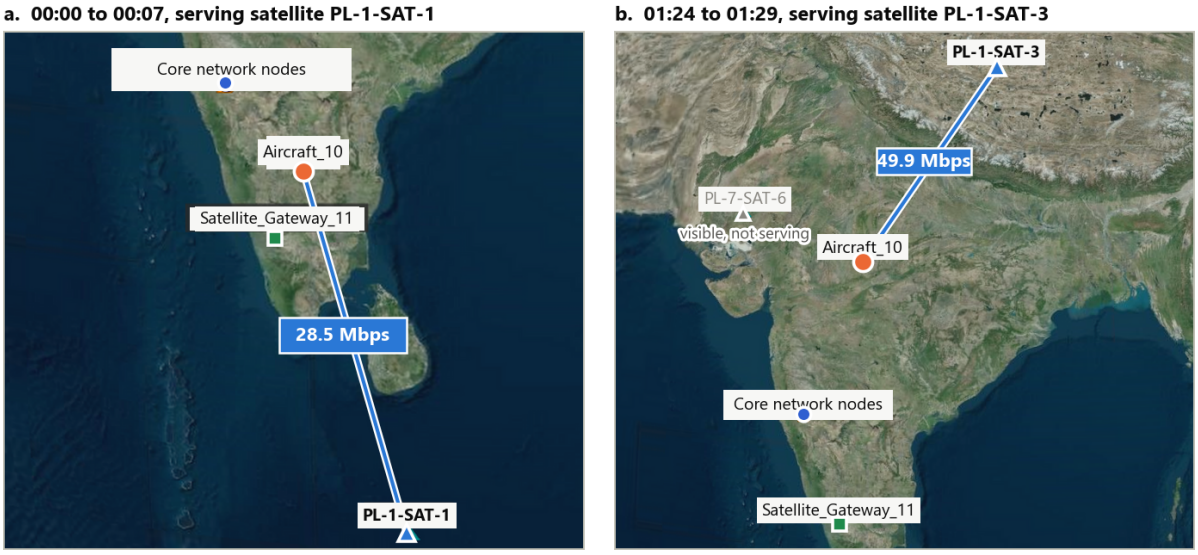
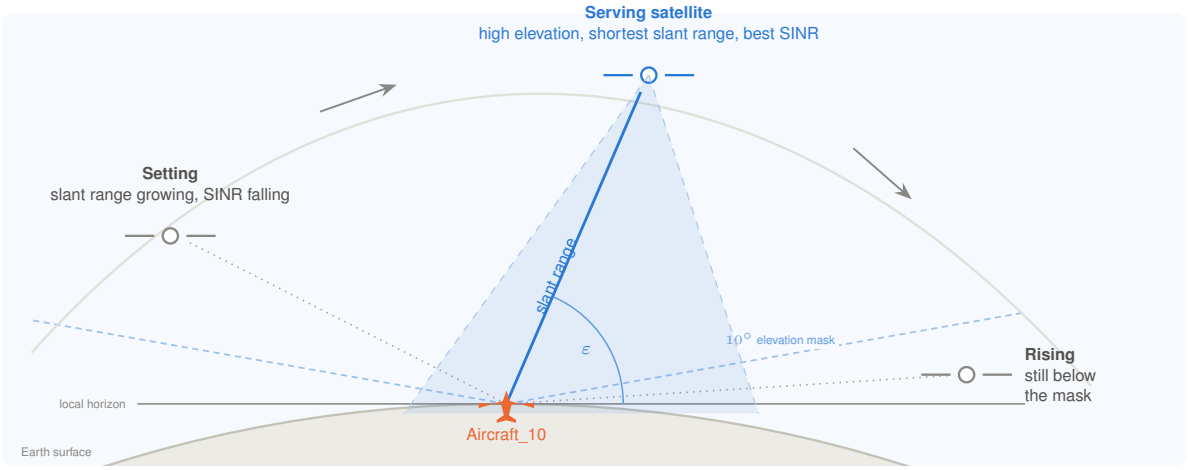


Figure 11-32: *Two mobility snapshots from the 100-satellite run. The blue link and the throughput badge identify the serving satellite at that instant. Early in the flight the aircraft is served by PL-1-SAT-1 at 28.5 Mbps; about an hour and a half later it is served by PL-1-SAT-3 at 49.9 Mbps, with other satellites visible but not serving. Serving-satellite intervals are taken from Table 11-18.*

11.5.6 Why the serving satellite changes

The serving satellite is not fixed for the duration of the flight. Elevation angle, slant range, and beam geometry all vary as the aircraft and the satellites move along their trajectories, and each of these feeds directly into the received SINR.



Why the serving satellite changes, and why service is not continuous. Elevation angle, slant range and beam geometry all change as the aircraft and the satellites move. A satellite is dropped once its elevation falls below the 10° mask or the aircraft leaves its Earth_Moving beam. If no other satellite is yet both above the mask and covering the aircraft, service is interrupted until one is: these are the shaded windows in the result plots.

Figure 11-33: *Link geometry seen from the aircraft. A satellite serves the aircraft only while it is above the 10 degree elevation mask and the aircraft lies inside its Earth_Moving beam. When neither condition holds for any satellite, service is interrupted. These interruptions appear as the shaded windows in the result plots and as the gaps in the serving-satellite timelines.*

11.5.7 Serving-satellite timeline and service availability

Table 11-17 and Table 11-18 report the serving satellite observed for the aircraft over time. The updated 50-satellite run has 16 serving intervals and covers 67.80% of the 2.20 h flight. The updated 100-satellite run has 30 serving intervals and covers the complete flight, giving 100.00% service availability.

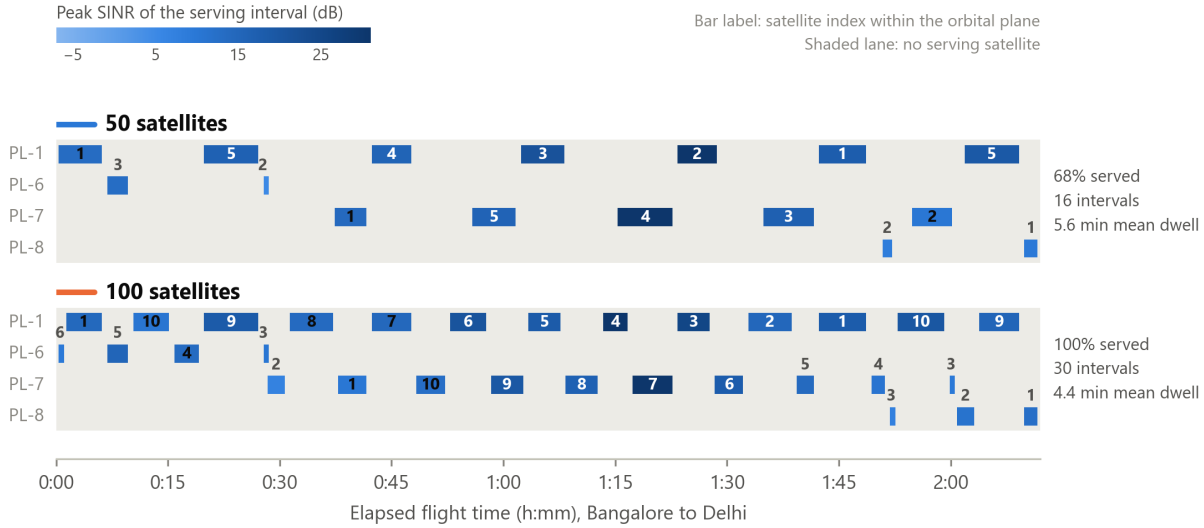


Figure 11-34: *Serving-satellite timeline for both runs. In the updated results, the 50-satellite run has 16 serving intervals, 67.80 per cent service availability, and 5 min 35.63 s mean dwell time. The 100-satellite run has 30 serving intervals, 100.00 per cent service availability, and 4 min 24 s mean dwell time.*

The denser constellation increases service availability by reducing the no-service gaps. The 100-satellite run changes serving satellite more often, but the shorter dwell time is offset by continuous coverage over the full aircraft route.

The serving sequence is derived from the current association logs. The 100-satellite transition at 01:02:42 is taken from the log timestamp. Peak values in the tables are taken from the corresponding radio measurements for the serving interval. Intervals with no table entry in the 50-satellite case correspond to periods where the aircraft is not connected to a serving satellite.

Table 11-17: *Serving satellite timeline for Aircraft_10 in the updated 50-satellite case*

Time (h:min:s)	Serving satellite	Peak SINR (dB)
00:00:00–00:06:30	PL-1-SAT-1	13.53
00:06:30–00:10:00	PL-6-SAT-3	13.26
00:19:30–00:27:30	PL-1-SAT-5	16.61
00:27:30–00:28:00	PL-6-SAT-2	5.28
00:37:00–00:42:00	PL-7-SAT-1	14.34
00:42:00–00:48:00	PL-1-SAT-4	15.97
00:55:30–01:02:00	PL-7-SAT-5	16.12
01:02:00–01:08:30	PL-1-SAT-3	21.62
01:15:00–01:23:00	PL-7-SAT-4	45.18
01:23:00–01:29:00	PL-1-SAT-2	31.07
01:34:30–01:42:00	PL-7-SAT-3	17.09
01:42:00–01:49:00	PL-1-SAT-1	17.86
01:50:30–01:52:30	PL-8-SAT-2	8.45
01:54:30–02:00:30	PL-7-SAT-2	10.35
02:01:30–02:09:30	PL-1-SAT-5	19.15
02:09:30–02:12:00	PL-8-SAT-1	9.59

Table 11-18: *Serving satellite timeline for Aircraft_10 in the updated 100-satellite case*

Time (h:min:s)	Serving satellite	Peak DL SSB SNR (dB)
00:00:00–00:01:00	PL-6-SAT-6	10.93
00:01:00–00:06:00	PL-1-SAT-1	14.40
00:06:00–00:10:00	PL-6-SAT-5	15.65
00:10:00–00:17:00	PL-1-SAT-10	13.73
00:17:00–00:19:30	PL-6-SAT-4	10.15
00:19:30–00:27:30	PL-1-SAT-9	16.08
00:27:30–00:28:00	PL-6-SAT-3	9.21
00:28:00–00:32:00	PL-7-SAT-2	11.17
00:32:00–00:37:30	PL-1-SAT-8	15.40
00:37:30–00:42:30	PL-7-SAT-1	12.19
00:42:30–00:48:00	PL-1-SAT-7	15.86
00:48:00–00:51:30	PL-7-SAT-10	11.50
00:51:30–00:58:00	PL-1-SAT-6	18.77
00:58:00–01:02:42	PL-7-SAT-9	16.19
01:02:42–01:07:30	PL-1-SAT-5	18.33
01:07:30–01:12:30	PL-7-SAT-8	18.39
01:12:30–01:17:00	PL-1-SAT-4	46.77
01:17:00–01:23:00	PL-7-SAT-7	50.72
01:23:00–01:27:30	PL-1-SAT-3	31.73
01:27:30–01:32:30	PL-7-SAT-6	18.14
01:32:30–01:39:00	PL-1-SAT-2	17.96
01:39:00–01:39:30	No association recorded	-
01:39:30–01:42:00	PL-7-SAT-5	11.90
01:42:00–01:49:00	PL-1-SAT-1	18.17
01:49:00–01:51:30	PL-7-SAT-4	12.13
01:51:30–01:52:30	PL-8-SAT-3	10.11
01:52:30–01:59:30	PL-1-SAT-10	18.46
01:59:30–02:00:30	PL-7-SAT-3	8.21
02:00:30–02:02:00	PL-8-SAT-2	5.42
02:02:00–02:09:30	PL-1-SAT-9	18.44
02:09:30–02:12:00	PL-8-SAT-1	13.14

Note: Aircraft_10 is named `UE_10` in the association log. Values are peak DL SSB SNR; the original PDF column reports peak SINR.

11.5.8 50-satellite and 100-satellite comparison

The following comparison uses the updated 50-satellite and 100-satellite aircraft mobility runs with Ka-band n510, 200 MHz bandwidth, Gaussian antenna model, aircraft antenna gain 25 dB, EIRP density 59, maximum antenna gain 30 dB, and packets in flight 4000. Throughput, downlink SINR for `UE_10`, and application packet delay are generated from the corresponding NetSim throughput, radio measurement, and packet logs.

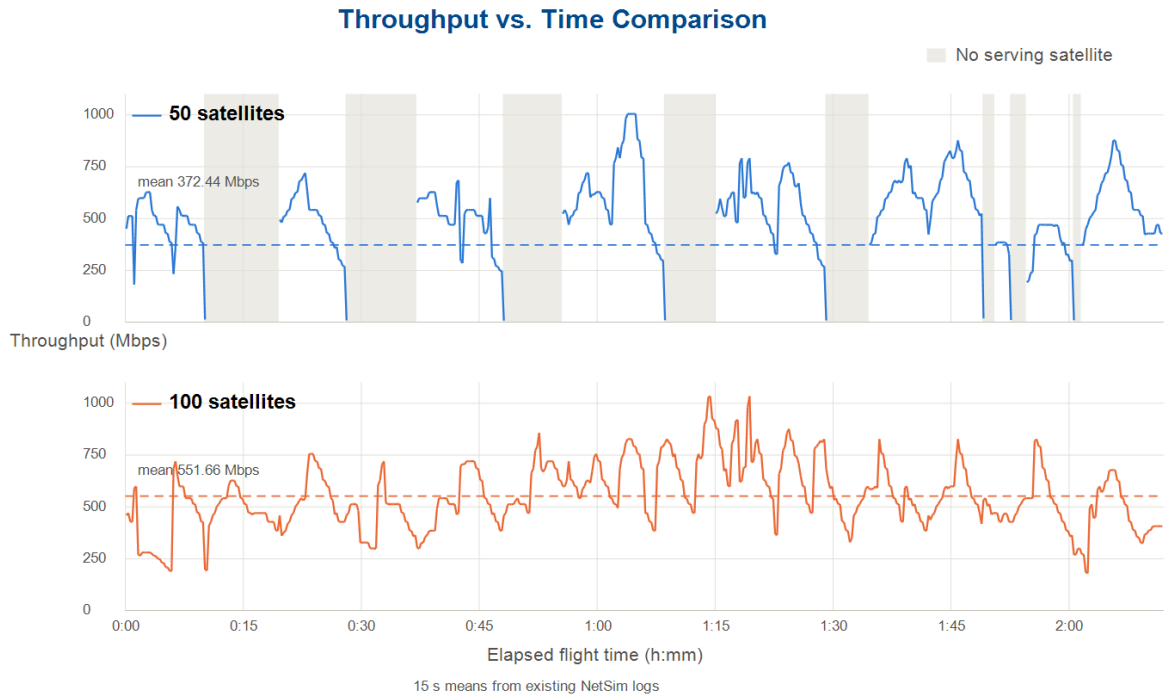


Figure 11-35: *Throughput comparison from the current NetSim logs. Each plotted point is a 15 s mean. The 50-satellite case is above the 100-satellite case; gray bands mark its no-service intervals. The full-flight plotted means are 372.44 and 551.66 Mbps, respectively. The horizontal axis spans the 2.20 h flight with major ticks every 15 minutes.*

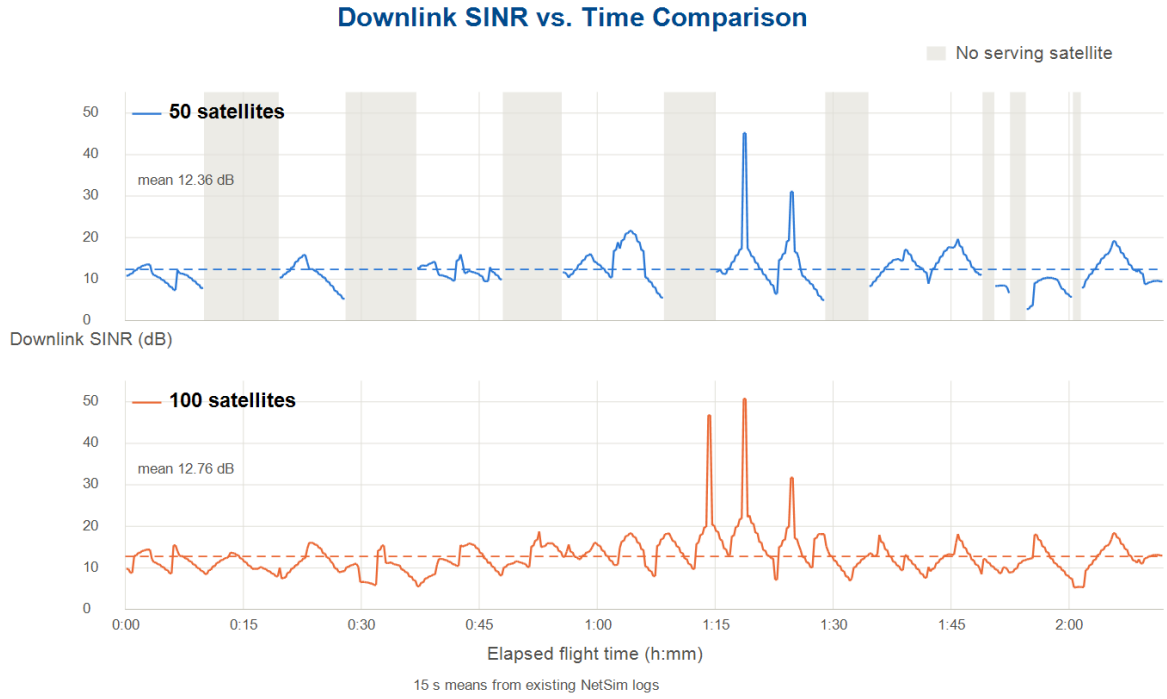


Figure 11-36: *Downlink SINR comparison for `UE_10` from the current radio logs. Each point is a 15 s mean of downlink measurements. The 50-satellite run has 12.36 dB raw connected-sample mean SINR; the 100-satellite run has 12.76 dB. Major time ticks are 15 minutes apart.*

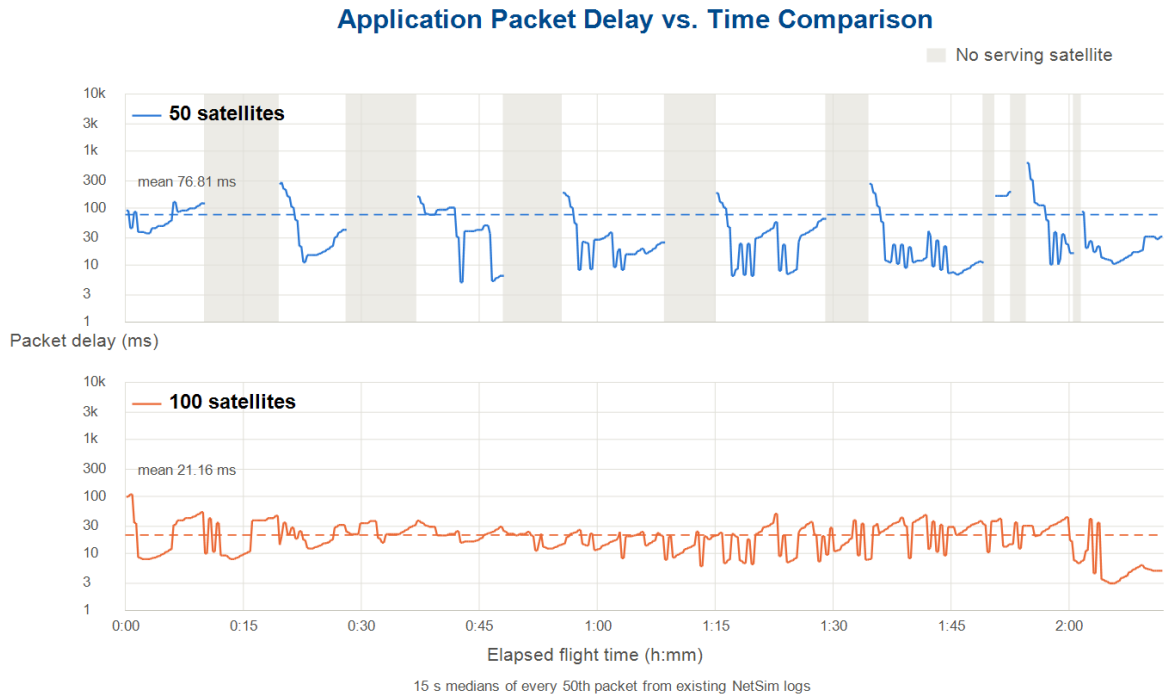


Figure 11-37: *Application packet delay comparison from the current packet logs. Each point is the median of every 50th packet in a 15 s interval, on a logarithmic millisecond scale. The mean over all packets is 76.81 ms for 50 satellites and 21.16 ms for 100 satellites; the plotted medians are separate from these means.*

Plot-source note: The time-series curves use 15 s bins of the existing NetSim logs. Throughput points are means of 0.5 s end-to-end samples; missing 50-satellite samples count as zero in full-flight bins. SINR points are means of `UE_10` downlink radio measurements. Packet-delay points are medians of every 50th packet; the dashed delay lines show the unsampled mean from `Metrics.xml`. The horizontal labels use h:mm, so `0:15` is 15 minutes. The satellite trajectory CSVs still have 30 s position timestamps; 15 s is the plot aggregation interval, not a new simulation run.

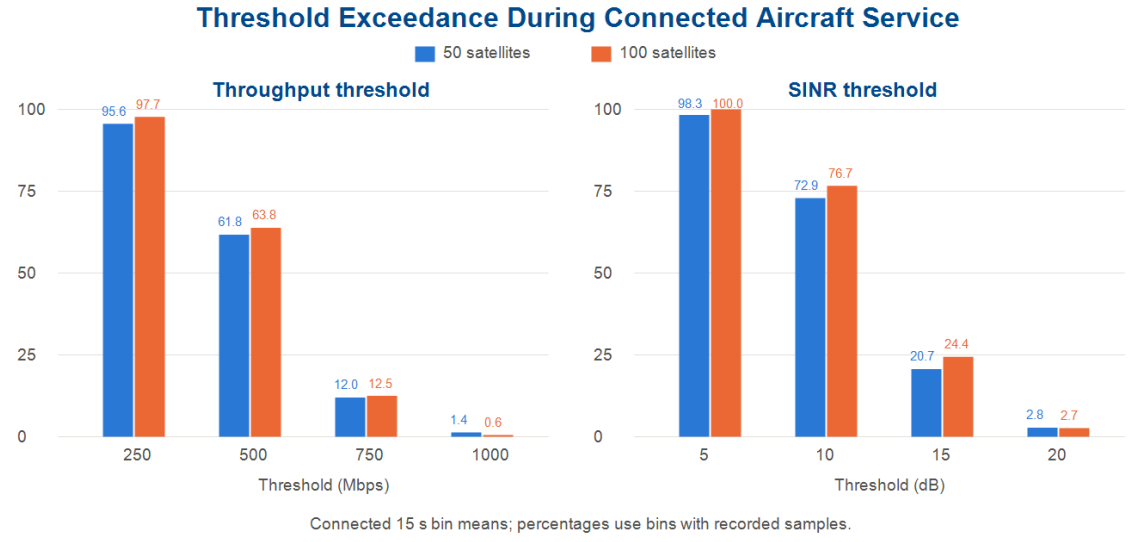


Figure 11-38: *Share of connected 15 s bins above selected throughput and SINR thresholds. At 750 Mbps, the shares are 12.02% for 50 satellites and 12.50% for 100 satellites. At 10 dB SINR, the shares are 72.91% and 76.70%, respectively. Percentages use bins with recorded samples.*

Table 11-19: *Throughput summary from the current NTN throughput logs*

Case	Minimum	Average	Maximum
50 satellites	0.00 Mbps	372.47 Mbps	1004.97 Mbps
100 satellites	105.12 Mbps	551.66 Mbps	1033.47 Mbps

Table 11-20: *Downlink SINR summary from the current NTN radio measurement logs*

Case	Minimum	Average	Maximum
50 satellites	2.80 dB	12.36 dB	45.18 dB
100 satellites	5.32 dB	12.76 dB	50.72 dB

Table 11-21: *Application packet delay summary from the current packet logs*

Case	Minimum	Average	Maximum
50 satellites	2.75 ms	76.81 ms	570.12 s
100 satellites	2.60 ms	21.16 ms	109.96 ms

Table 11-22: *Application throughput and service availability from the current aircraft runs*

Case	App. throughput	Serving intervals	Mean dwell	Service availability
50 satellites	372.47 Mbps	16	5 min 35.63 s	67.80%
100 satellites	551.59 Mbps	30	4 min 24 s	100.00%

The 100-satellite run gives higher application throughput over the full flight than the 50-satellite run: 551.59 Mbps against 372.47 Mbps. It also provides continuous service availability, while the 50-satellite run is connected for 67.80% of the flight. The 100-satellite run records both a higher average SINR over connected samples and a higher maximum SINR and avoids the service gaps that cause large packet-delay spikes.

11.5.9 Interpretation against aircraft connectivity

Both runs use Ka-band n510, 200 MHz bandwidth, one aircraft, Full Buffer UDP traffic, one Earth_Moving beam per satellite, Gaussian antenna gain, and 25 dB aircraft antenna gain. Under this setup, the average throughput over the complete flight is 372.47 Mbps for 50 satellites and 551.66 Mbps for 100 satellites.

The gain from doubling the constellation comes mainly from service availability and packet delivery continuity. The 50-satellite run has 16 serving intervals and covers 67.80 per cent of the flight, while the 100-satellite run has 30 serving intervals and covers the complete flight. The 100-satellite run records a higher average connected-link SINR, 12.76 dB against 12.36 dB, and a higher maximum SINR. It also avoids the no-service gaps that create large queueing-delay spikes. As a result, the 100-satellite run raises average throughput and reduces mean application packet delay from 76.81 ms to 21.16 ms. These results are in the same order as some aviation broadband references, but they should not be read as a one-to-one match to a commercial service. Starlink Aviation lists 100–250 Mbps with peaks up to 450 Mbps, Inmarsat Global Xpress lists downlink speeds up to 50 Mbps, and Viasat Ka aviation states speeds typically greater than 30 Mbps. The NetSim value depends on constellation size, Earth_Moving beam coverage, Gaussian beamwidth, aircraft antenna gain, pathloss, SINR, and packet delivery over the mobility duration.

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The latency values in this study are application packet delay values from the NetSim logs, not propagation delay alone. They include queueing and the interruptions that occur while satellite visibility and the serving beam change.

Overall, the aircraft changes serving satellite as elevation angle, slant range, beam geometry, pathloss, and SINR vary with time. With these settings, the 100-satellite case gives higher application throughput because the denser constellation keeps the aircraft connected for more of the flight.

11.6 UE–Satellite Service Link Study

11.6.1 Summary

Note: This example is available in NetSim Pro.

This case study models a fixed UE in Tokyo served by a LEO constellation of 300 satellites. The satellites follow a file-based trajectory for the complete 90-minute simulation. During the run, the satellites visible from the UE change as the constellation moves over Japan. The downlink is fully saturated: the traffic source always has data to send, so the UE receives the maximum load that the service link can carry. The study reports downlink SNR against time, downlink SINR against time, and throughput against time.

11.6.2 Problem statement

In a LEO constellation, a ground terminal sees several satellites at the same time, and this set changes every few minutes as the satellites move. Elevation angle, slant range, and beam position vary during each pass, so the quality of the service link varies with time even when the terminal is fixed.

The objective is to observe how the signal quality at the UE and the downlink throughput vary with time as the constellation flies overhead. The study records two signal quality measures at the UE: SNR, which compares the serving signal with noise, and SINR, which compares the serving signal with noise plus interference. Comparing the two traces shows how much the other visible satellites affect the service link.

11.6.3 Approach

The UE, the 5G core, and the satellite gateway are placed at Tokyo and remain fixed. The 300 satellites follow positions read from a trajectory file. The application traffic is downlink Full Buffer over UDP, so the UE receives continuous downlink traffic while a serving satellite is available. The run uses S-band NR NTN with a Gaussian satellite antenna model, Free-space pathloss, and a 10 degree elevation mask. Each satellite uses one `Earth_Moving` beam, so the beam footprint moves with the satellite.

The analysis follows three steps:

1. Configure the Tokyo scenario, the constellation trajectory, and the radio and traffic settings listed in the setup tables.
2. Run the simulation for 90 minutes with the NTN Radio Measurements log and the NTN Throughput log enabled.
3. Plot downlink SNR, downlink SINR, and throughput against time from the logs, and read the peak, minimum, and average values.

11.6.4 Simulation setup

The two tables below list the constellation, radio, antenna, channel, and traffic settings used in the run.

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Table 11-23: *Constellation and trajectory parameters*

Parameter	Value
Constellation type	Walker Delta
Satellites	300
Orbital planes	10
Satellites per plane	30
Nominal altitude	550 km
Altitude range in trajectory file	550.102 km to 568.478 km
Mean altitude in trajectory file	556.700 km
Inclination	53 degrees
Trajectory start time	2024-01-01 12:00:00 UTC
Trajectory end time	2024-01-01 13:30:00 UTC
Trajectory step	30 s
Trajectory rows per satellite	181
Simulation time	5400 s, or 90 minutes

Table 11-24: *Radio, antenna, channel, and traffic parameters*

Parameter	Value
Operating band	S band, n256, FR1
Uplink frequency range	1980–2010 MHz
Downlink frequency range	2170–2200 MHz
Channel bandwidth	5 MHz uplink and 5 MHz downlink
Duplex mode	FDD
Subcarrier spacing	15 kHz
PRB count	25
Pathloss model	Free_space with elevation mask 10 degrees
Satellite antenna model	Gaussian, beam type `Earth_Moving`, one beam per satellite, $\theta = 5$ degrees
Satellite link budget	EIRP density 45 dBW/MHz, maximum antenna gain 30 dB
UE antenna gain	0 dB
Shadow fading	Log-normal, user-defined standard deviation 5 dB
Channel fading	No fading
LOS/NLOS selection	User-defined, LOS probability 1
Traffic	Downlink Full Buffer over UDP from the wired node to the UE (saturated downlink)

Network settings

- Enable the result plots before running the simulation. In the design window, select Configure Reports ▷ Plots and enable the downlink SINR vs time plot and the throughput vs time plot.
- Enable the NTN Radio Measurements log and the NTN Throughput log. These logs are used to generate the SNR, SINR, and throughput plots in this example.

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- Enable Record Animation before running the scenario so that the satellite movement over Tokyo can be reviewed after the simulation.

11.6.5 Network topology and node placement

The end-to-end path has four parts. First, the wired node generates the downlink traffic. Second, the packets cross the wired network and the 5G core. Third, the satellite gateway carries the packets over the feeder link to the serving satellite. Fourth, the serving satellite delivers the packets to the UE over the S-band service link. Satellites are named by plane and satellite number, such as `PL-1-SAT-1`.

The UE, the 5G core, and the satellite gateway are placed at Tokyo. The UE is fixed, so the variation in the plots comes from the movement of the satellites and their beams over Japan.



Figure 11-39: *Scenario view with the UE, satellite gateway, and 5G core at Tokyo. The satellites visible around the service area at this instant are labelled by plane and satellite number.*

11.6.6 Why the serving link changes

The beam moves with the satellite ground track, so the UE at Tokyo sees a time-varying set of candidate satellites. A satellite can serve the UE only while it is above the 10 degree elevation mask and the UE lies inside its `Earth_Moving` beam.

The serving link changes for three reasons. First, orbital motion changes the elevation angle of each satellite as seen from the UE. Second, the slant range shrinks and grows during each pass, which changes the received power. Third, the beam footprint shifts with the satellite, so the UE moves from the beam centre toward the beam edge even though the UE itself is fixed. Each of these feeds into the received SNR.

The other visible satellites transmit into the same region, so their received power appears as interference at the UE. SNR does not include this term. SINR includes it. The two traces are therefore plotted together in the results.

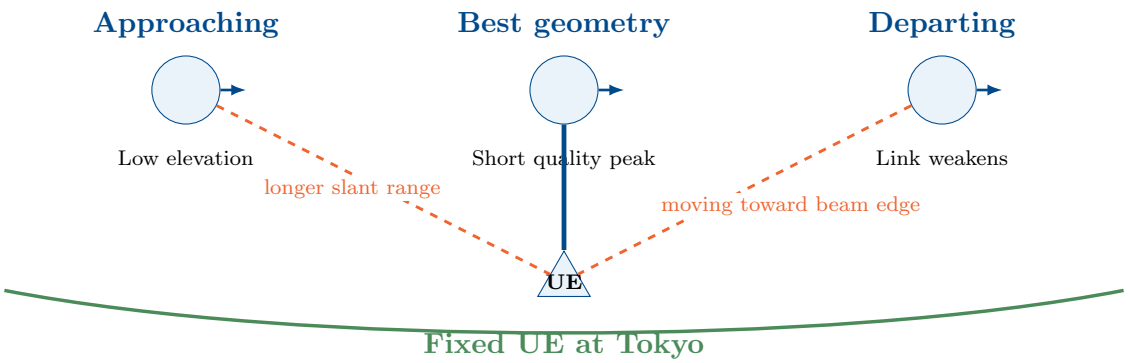


Figure 11-40: *One LEO pass over the fixed UE at Tokyo. Link quality improves as the satellite approaches its best geometry and weakens as the satellite moves away or the UE drifts toward the beam edge.*

11.6.7 Results

Downlink SNR and SINR against time The plot below shows downlink SNR and SINR over the full 90-minute rerun, using the same reference-style time axis with 15-minute spacing. Both traces are read from the DownLink rows for the UE in `NTN_Radio_Measurement_Logs.csv`. For each second, the plot keeps the strongest downlink SNR sample and the SINR of the same sample. This gives one SNR value and one SINR value per second on a common time axis.

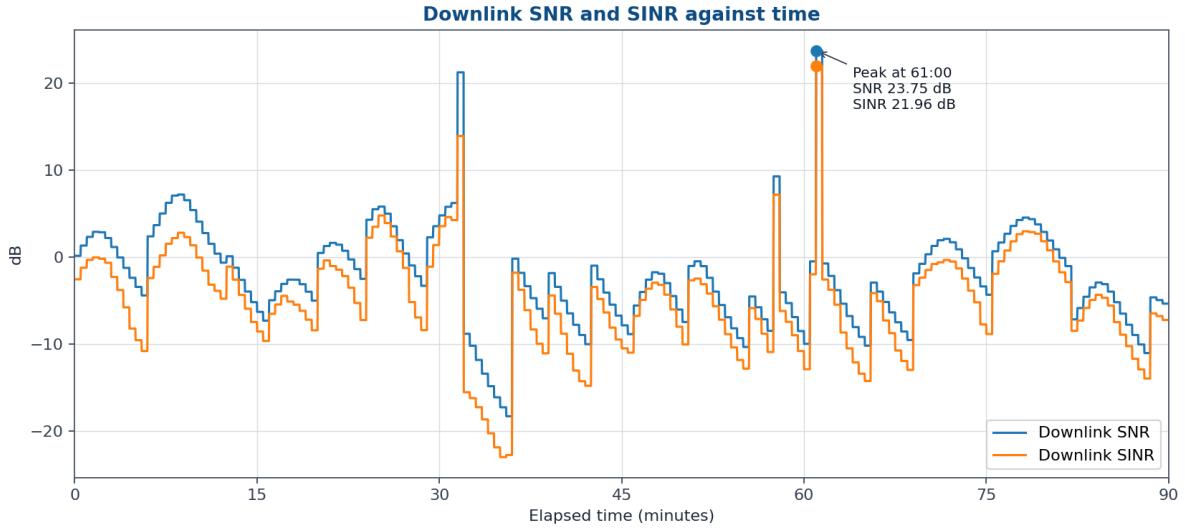


Figure 11-41: *Downlink SNR and SINR against time, plotted from `NTN_Radio_Measurement_Logs.csv`. The blue trace is SNR and the orange trace is SINR. The peak instant at 61:00 is marked for both traces: SNR is 23.75 dB and SINR is 21.96 dB.*

Three features stand out. First, both traces follow a repeating pattern of rise and fall as satellites pass over the UE. Second, the traces stay between about −15 dB and 0 dB for most of the run, with short peaks near 31:30, 57:30, and 61:00. Third, the orange SINR trace lies below the blue SNR trace wherever both are visible. At the marked 61:00 peak instant the gap is 1.79 dB. The largest gap in the run is 7.32 dB at 31:30.

Throughput against time The plot below shows the throughput of the downlink flow over the same 90-minute rerun, read from the NTN Throughput log.

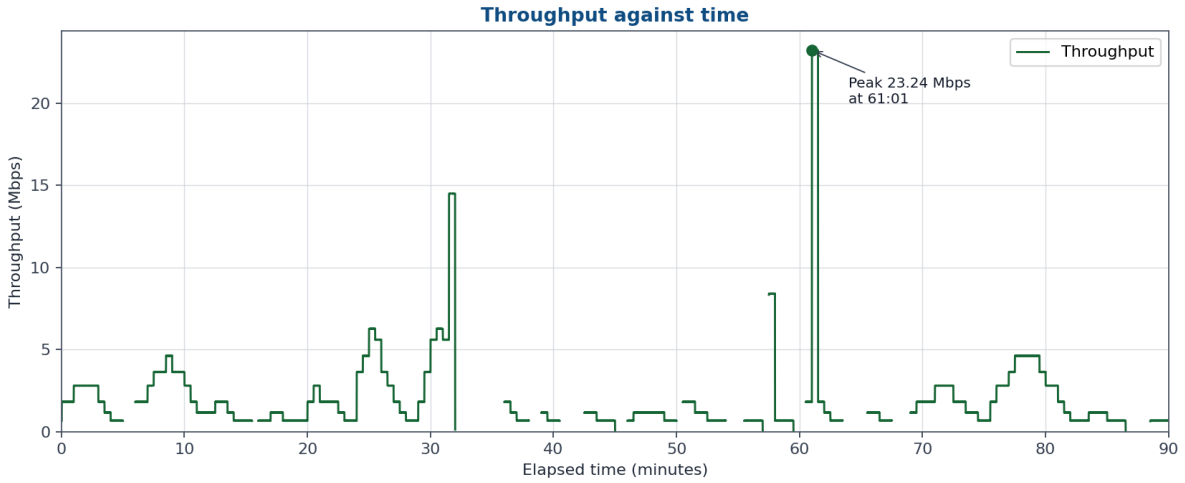


Figure 11-42: *Throughput against time for the saturated downlink flow, plotted from the NTN Throughput log. The axes start from zero, with elapsed time shown in 10-minute steps; breaks in the trace indicate intervals with no throughput samples. The marker shows the throughput peak of 23.24 Mbps at 61:01, close to the SNR and SINR peak instant marked in the radio plot.*

Throughput stays near 1 Mbps for most of the run and rises sharply at the same instants as the SNR and SINR peaks. The marked largest peak reaches 23.24 Mbps at 61:01.

Table 11-25: *Downlink SNR and SINR summary*

Metric	Minimum	Maximum	Time of maximum
Downlink SNR	−18.33 dB	23.75 dB	61:00
Downlink SINR	−23.03 dB	21.96 dB	61:00
SNR minus SINR	–	7.32 dB	31:30

Table 11-26: *Throughput summary*

Metric	Minimum	Average	Maximum
Throughput	0.023 Mbps	2.040 Mbps	23.24 Mbps

Summary of results

11.6.8 Interpretation

The rise and fall of SNR follows the satellite passes described in the section on why the serving link changes. SNR rises when a satellite has a high elevation angle, a short slant range, and a beam centre close to the UE. SNR falls when that satellite moves away and the UE drifts toward the beam edge. With one beam per satellite and a fixed UE, the favourable geometry lasts for a short time in each pass, so the peaks are narrow.

SINR is lower than SNR because SINR includes interference from the other visible satellites. The gap between the two traces is the link margin lost to that interference. The gap is small at the marked peak, where the serving signal is strong, and reaches 7.32 dB where a weaker serving signal and stronger interference occur together.

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Throughput follows the radio link. With a 5 MHz channel and 25 PRBs, the link carries about 1 Mbps when SNR is below 0 dB and reaches 23.24 Mbps only when a satellite passes close to the UE at high elevation. Since the downlink is saturated, throughput is set by the link quality and not by the offered load.

Overall, the signal quality at a fixed UE varies with time as the LEO constellation flies overhead, and the throughput of a saturated downlink follows that variation. Measuring SNR and SINR together separates the effect of satellite geometry from the effect of interference from the other visible satellites.

12 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.
- C-band and Ku-band shadow-fading standard deviation and clutter loss values are provisional. They are computed by log-frequency interpolation between S-band and Ka-band anchor values from TR 38.811.
- L-band shadow-fading standard deviation and clutter loss reuse the S-band values in this phase.
- Atmospheric loss and rain loss are not calculated automatically for the new bands. Users must enter the atmospheric-loss scalar for Ku and Ka link-budget studies.

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- EIRP density and receiver G/T reference defaults for the added bands remain user inputs in this phase.
- Higher carrier frequencies imply higher Doppler shifts, but no new Doppler model is added in this phase. Existing NTN GNSS-based pre-compensation assumptions continue to apply.
- 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.

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