6G for Connected Sky
"6G-SKY"

Work Package 4

NTN for Terrestrial Users

Task 4.2

NTN System Level Performance Analysis

Deliverable D4.3

Final Report on NTN System Level Simulations

6G-SKY Project
Aug 1, 2024

Abstract

This D4.3 provides the description of components of the system level simulator (SLS) and simulation results focusing on non-terrestrial networks (NTN) for terrestrial users. This report describes the SLS architecture, the limitations and the new functionalities that have been developed during the project to accurately model the selected scenarios. The scenarios are selected to cover the 3D architecture of combined airspace and non-terrestrial networks (ASN). This report is based on the outcomes of the initial report D4.2 dedicated to the NTN SLS.

6G-SKY, Work Package 4: NTN for terrestrial users

Task 4.2: NTN system level performance analysis

Final report on NTN system level simulations

Editor: Steven Kisseleff, Fraunhofer IIS
Reviewers: Leo Frank, Fraunhofer IIS; Andreas Kercek, Lakeside Labs
Contributors: The contributors are listed in “List of Authors”.

6G-SKY
Final report on NTN system level simulations
Editor: Samhita Roy, Steven Kisseleff, Fraunhofer IIS
Project coordinator: Dominic Schupke, Airbus
Work Package Coordinator: Rainer Wansch, Fraunhofer IIS
Technical Project Coordinator: Cicek Cavdar, KTH
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Executive Summary

This deliverable aims to provide the reader with the initial design considerations of the System Level Simulator (SLS) for the combined Airspace and Non-Terrestrial Networks (NTN, combined ASN networks) with a focus on next generation base-stations (gNB) mounted on Low Earth Orbit (LEO) satellites or on High Altitude Platforms (HAPs).

This project report first discusses the overall structure of the SLS and briefly describes the functionality of each component, including the assumptions that are currently made in the simulator. The report then defines the scenarios that are considered for evaluations during the course of this project. The scenarios are defined in a way such that it covers the topic of flying gNBs at different altitudes, mobile users either on ground or flying and the co-existence of both terrestrial and non-terrestrial gNBs.

The different parameter configurations that are important for the initialization of these scenarios that will be evaluated using the SLS is then defined, which might get further updated based on the developments in other work packages. The parameter configurations are classified under different categories such as satellite payload properties, user terminal properties, channel model properties, scheduler and traffic model properties. The report also provides a list of key performance indicators such as SNR and Throughput will be used to analyze the scenarios that are evaluated for a specific set of parameter configurations.

The description of the handover process between two non-terrestrial gNBs and other features that will be developed over the course of this project is summarized in this report. The role of artificial intelligence (AI) in a 6G system is also covered in this report where one of the potential application of deep reinforcement learning (DRL) in NTN is for trajectory design of UAVs when executing certain tasks, such as data collection for IoT nodes or coverage recovery due to malfunctioned base stations. However, the work package of which this report is part of does not include activities of training any kind of AI model using the simulator.

List of Authors

Name	Affiliation
Steven Kisseleff	Fraunhofer IIS
Kavyashree Koulagi Yayatheertha	Fraunhofer IIS
Luca Feltrin	Ericsson AB
Smriti Gopinath	Ericsson AB
Moustafa Roshdi	Fraunhofer IIS

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Glossary

List of acronyms with alphabetical order.

Acronym	Description
3GPP	3rd Generation Partnership Project
AI	Artificial Intelligence
BLER	Block Error Rate
DL	Downlink
DNN	Deep Neural Network
DP	Dynamic Programming
DQN	Deep Q Networks
DRL	Deep RL
ECEF	Earth Centered Earth Fixed
gNB	Next generation NodeB
HAP	High Altitude Platform
HO	Hand Over
IoT	Internet of Things
KPI	Key Performance Indicator
LEO	Low Earth Orbit
LoS	Line of Sight
NTN	Non Terrestrial Network
PDCP	Packet Data Convergence Protocol
PDUs	Protocol Data Units
PHY	Physical Layer
QoS	Quality of Service
QoS	Quality of Service
RB	Resource Blocks
RL	Reinforcement Learning
RRM	Radio resource management
SCA	Successive Convex Approximation
SINR	Signal to Interference and Noise Ratio
SLS	System Level Simulator
TB	Transport Blocks
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UL	Uplink
UPF	User Plane Functionality

1 Introduction

This report is an outcome of the Task 4.2. The goal of the Task 4.2 is to extend the system-level simulator (SLS) capable of integrating non terrestrial network (NTN) components and providing a comprehensive understanding of a converged end-to-end 6G system. The simulator will support different services requirements for parallel use cases in the network, each with individual quality of services (QoS) for the data traffic. The task will develop the detailed metrics for the performance assessment like system throughput, reliability and latencies for the different QoS classes.
Section 2 provides an overview and brief description of the different components of the SLS. Section 3 of this report summarizes the scenarios that will be executed by the simulator to study performance enhancements due to inclusion of NTN into terrestrial networks. The report also captures all the specifications in Section 0 which will form the basis for the simulations referring to scenarios specified in Section 3. Section 5 lists all the performance indicators that are to be evaluated for the selected scenarios with some existing examples. Section 6 provides description of the handover process that is considered while evaluating a scenario which comprises of two or more base stations serving the same region of interest. Section 7 presents the obtained simulation results. Section 0 describes the prospect of different AI algorithm applications that can be utilized to optimize a converged end-to-end 6G system. Section 9 touches upon the concept of sustainability in space communications. The report ends with Section 10 which describes the way forward and how this report will be used as basis for the future reports.

2 Simulator Overview

The system level simulator (SLS) is based on OMNEST. OMNEST is an event-driven simulation framework with a large number of networking features, protocols and functionalities implemented in C++ [1].
The important components of the SLS are:

- the network protocol stack of the nodes: NrNicUe and NrNicGnb
- the deployment and mobility configurations: UE Deployment and Satellite coverage models
- the antenna configurator: Antenna array models
- the channel configurator: Channel model
- the Physical layer abstraction
- the information centre: Binder
- the result recorder: KPI

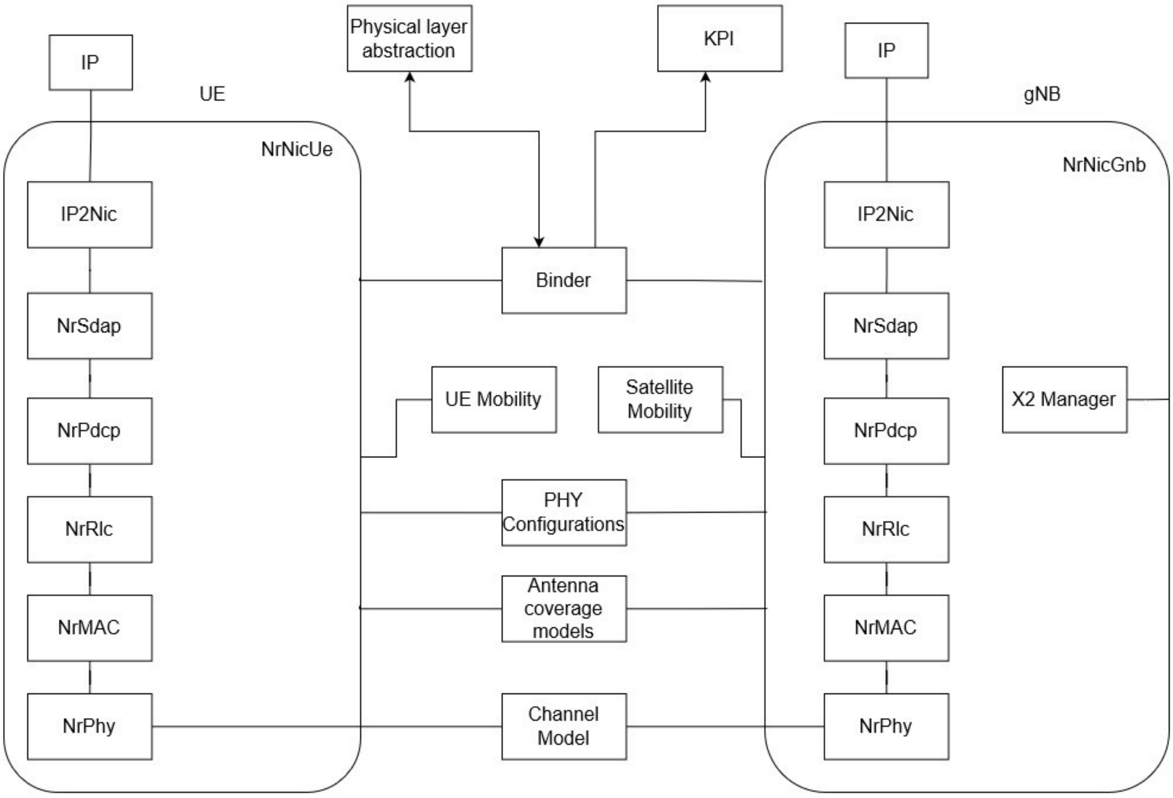


Figure 1 Overview of the SLS components.

2.1 Description of the important modules of the NTN system level simulator

NrNicUe and NrNicGnb:
The protocol stack on both the gNB and the UE consists of four protocols. From the top down, first is the Packet Data Convergence Protocol (PDCP), which receives IP datagrams, performs cyphering and numbering, and sends them to the Radio Link Control (RLC) layer. RLC Service Data Units are stored in the RLC buffer, and they are fetched by the underlying Media Access Control (MAC) layer when the latter needs to compose a transmission. The MAC assembles the RLC Protocol Data Units (PDUs) into Transport Blocks, adds a MAC header, and sends everything through the physical (PHY) layer for transmission.

Channel model:
The channel model module is responsible for configuring the transmission medium. The framework comes integrated with certain terrestrial channel models which was then extended to include both multipath and line-of-sight (LoS) propagation models as applicable to S-band or Ku/Ka-band use cases, respectively [5].

Antenna array model:
The implementation of the gNB and UE antennas in the existing framework have been adapted to match the NTN specifications in [4]. This module is responsible for defining the beam patterns that are supported by a regenerative satellite gNB. Currently the simulator supports only omni-directional antenna pattern but it can be extended to support other beam patterns such as the Bessel type.

UE Deployment and Satellite coverage models:
Different UE types as described in [7] can be instantiated with NTN-specific properties illustrated in [4]. One other important enhancement is the inclusion of satellite trajectory with the ability to import orbital parameters in NORAD TLE format [2]. The Earth-centered-Earth-fixed (ECEF) [3] coordinate geometry is used to accommodate simulation of larger geographical regions in comparison to the terrestrial networks. Furthermore, in order to study realistic mobility scenarios and assess outage probability, the radio environment can be specified with more details using open street maps.

Physical Layer Abstraction:
The 'Compute SINR' block in Figure 2 evaluates the signal-to-noise-interference-ratio (SINR) for every single resource block (RB) that is occupied by the transmitted transport block (TB). The SINR evaluated is then mapped to error probability functions based on 'Block Error Rate (BLER) curves' available within the framework. The PHY layer abstraction (PLA) model has been enhanced to improve the mapping function between SINR and BLER to return error probabilities with higher accuracy for different channel conditions. The lookup table for the BLER curves have also been extended to support different TB sizes for all mod-cods defined in 3GPP.

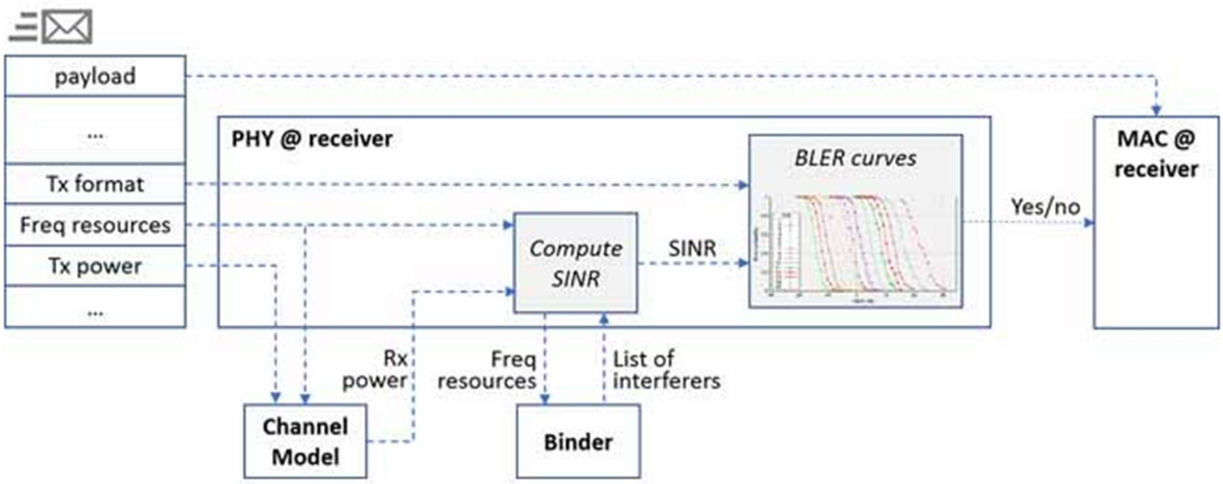


Figure 2: Physical layer abstraction model ***Error! Reference source not found.***.

Binder:
The binder maintains data structures containing network-wide information and can be accessed via method calls by every node (both UEs and gNBs). Examples of information stored in the binder are: membership of UEs to multicast groups; which gNB used which frequency resources, etc. This enables in maintaining a centralized repository of relevant information which simplifies the handling of distributed tasks. Second, it allows users to abstract control-plane functions and elements (e.g., servers or signaling protocols), substituting them with queries to the binder for the relevant information.

KPI:
This module is responsible for recording all results in a vector or scalar format. The results captured will represent the spatio-temporal variations in the deployed scenarios. The KPIs recorded will be then be used for training the AI models.

Figure 3: An example of NTN scenario set-up.

2.2 Assumptions in the Simulator

In the simulator, only the user plane is considered for evaluations and the control plane is completely abstracted. The focus of the simulations is entirely on the user link side. The possible connections that the simulator can support is indicated in Figure 4. It is also assumed that the entire protocol stack of a gNB is implemented on board of the satellite payload. For evaluating co-existence scenarios, it is assumed that terrestrial to NTN or NTN to NTN communication occurs using the X2 interface. Currently in the simulator, there is no geographical representation of cell or beam Id, the cell or beam Id is just used as an indicator to determine which users will a particular gNB provide service to given that the service link quality is above the threshold. Currently in the simulator the beam pattern associated with NTN gNB is fixed resulting in Earth moving cells.

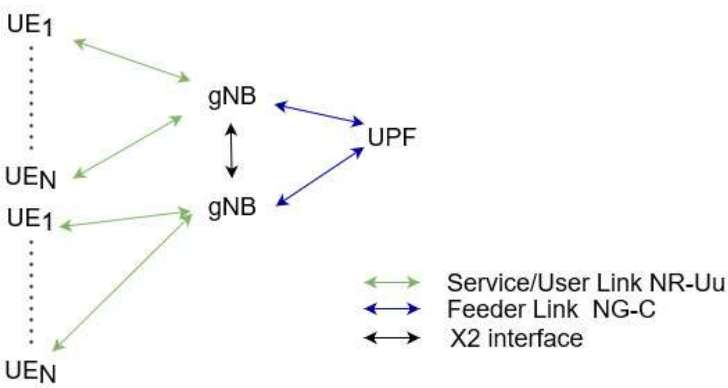


Figure 4: Communication links between nodes.

3 Scenario Description

The scenario description in the context of this report refers to modeling a combined ASN network which is initialized using a set of parameter configurations and is evaluated using the SLS. The two broad classifications of scenarios that are selected for this report are the coverage enhancement and co-existence scenarios.
During the course of the project these scenarios will be analyzed using the SLS. The system performances will be quantified using different performance indicators. The purpose of these evaluations are to study the impact of 3D mobility and benefit of the 3D network architecture. For example, in the case of coverage enhancement scenario, one of the evaluations will be to demonstrate the variation in signal to noise ratio (SNR) as the relative position of the user wrt. the flying gNB changes from being at the center to the edge of the field of view. The purpose of the evaluations will also be to investigate the correlation between different performance indicators. In the case of co-existence scenarios, which are an extension to coverage enhancement scenarios. The purpose of these evaluations are to demonstrate improvement in system performance because of handover between gNBs (which could a terrestrial or non-terrestrial based).

3.1 Coverage Enhancement

For a coverage enhancement scenario, randomly distributed stationary or moving users are considered and the gNB protocol stack is mounted on HAPs/LEO satellite or on a terrestrial base station. An example of which can be seen in Figure 5, where we observe that the terrestrial base station cannot serve a user that is in the middle of the lake. Hence to improve the coverage we add another base station which is mounted on either a LEO satellite or on HAPs The goal of this evaluation is to observe a gain in the system performance indicated through KPIs such as system throughput. At first, the initial results from the simulator are observed with the aim of verifying the core functionalities of the SLS. For example, observing the trend in the results (SNR, EIRP, G/T, attenuation, elevation angle etc.,) for increasing distance between the user and the gNB. Once through with basic functionality tests, the scenarios could be further enhanced by introducing QoS traffic profiles for the data streams.

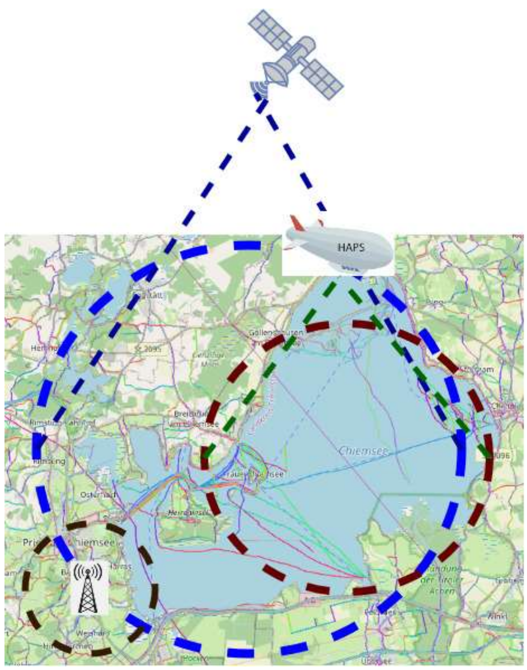


Figure 5: Visual representation of the coverage enhancement scenario.

Currently the simulator assumes equal priority for each user traffic. During the course of this project the simulator will be enhanced to support QoS based traffic profiling also for NTN networks.

3.2 Co-existence

In a combined ASN For a co-existence scenario, multiple gNBs are part of the same network where a handover process is triggered by the deployed users which are moving outside of the coverage area of one gNB into another as shown in Figure 6. The term co-existence highlights that both terrestrial and non-terrestrial gNBs will be avaible to serve the deployed users. The available gNBs will be sharing the same time-frequency resources and based on the scheduler's assignement of resources the user link will be subjected to interference from others. The goal is to have a The gNBs that are considered for this scenario can be configured to fly in the space following a specific path or remain stationary on ground. The coverage area of a flying gNB is determined by the antenna characteristics that are assumed on board. Currently, the simulator assumes a simple directive antenna without any beam steering capability. During the course of this project, the simulator will be enhanced to support a beam steering capability and evaluate the handover scenarios for earth fixed beams.

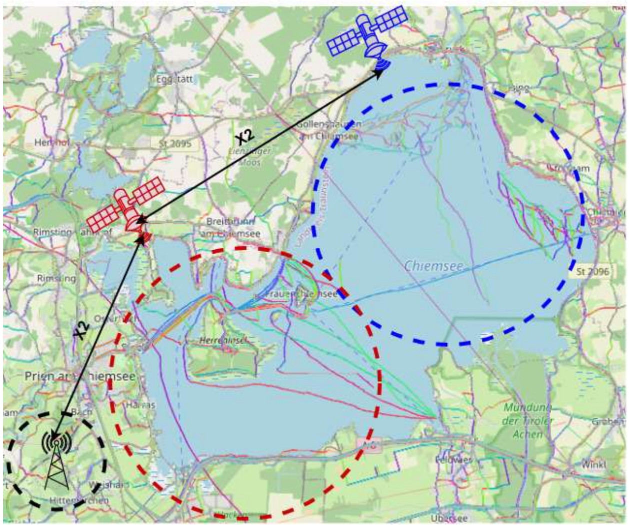


Figure 6 Visual representation of the co-existence scenario

4 Scenario Specifications

The simulator needs to be initialized using a set of parameters to run and evaluate a specific network scenario. Section 0 summarizes the necessary system specification which includes frequency band, antenna configurations, channel models, scheduler types and traffic models.

4.1 Frequency specifications

The different frequency bands that will be considered and the corresponding maximum bandwidth in terms of no. of resource blocks (RB) that can be assigned based on the numerology factor is summarized in Table 1. Currently, there are agenda items in World Radio Congress (WRC) 2023, which includes identification of the frequency bands 3 (FR3) 7.125 to 24.25 GHz for International Mobile Telecommunications (IMT). In Work Package 2, studies are being conducted to define antenna specifications for the FR3 frequencies. Since these discussions are still in preliminary stage, the final FR3 frequency specifications that will be used for the simulator will be updated in D 4.3.

Frequency Band	Frequency to be used	Max. Available Bandwidth (RBs)		Min. Available Bandwidth (RBs)	
S Band (FR1)	UL: 2GHz DL: 2.2 GHz	SCS (kHz)			
		15	30	15	30
		270	273	25	11
Ka Band (FR2)	UL: 30 GHz DL: 20 GHz	SCS (kHz)			
		60	120	60	120
		264	264	66	32

Table 1 Summary of frequency bands and corresponding bandwidth restrictions as per [7].

4.2 Satellite/HAPs specifications

The different altitudes of the flying gNBs that will be considered for the simulations are summarized in Table 2. For HAPs, firstly balloon like trajectory will be assumed which can be further enhanced to follow circular paths upon initial verification.

Orbit Type	Altitude (Km)
HAPS	20
LEO	600

Table 2 Altitude specifications for flying gNBs

For gNB, different transmitter and receiver attributes for different frequency bands are summarized in Table 3 and Table 4.

Orbit Type	Frequency Band	Characteristics	Transmission Direction Uplink	Transmission Direction Downlink
LEO600	S	Frequency	2 GHz	2.2 GHz
		Antenna type	Bessel/Directive	
		Antenna max. Gain (dB)	30	
		Antenna 3 dB beam contour in °	4.4127°	
		EIRP Density (dBW/MHz)	34	
		G/T (dB/K)	1.1	
LEO600	Ka	Frequency	30 GHz	20 GHz
		Antenna type	Bessel/Directive	
		Antenna max. Gain (dB)	38.5	
		Antenna 3 dB beam contour in °	1.7647	
		EIRP Density (dBW/MHz)	4	
		G/T (dB/K)	13	

Table 3 Summary of tx/rx configurations corresponding to different frequency bands and gNB altitude for LEO satellites is from [].

Orbit Type	Frequency Band	Characteristics	Transmission Direction Uplink	Transmission Direction Downlink
HAPS20	S	Frequency	2 GHz	2 GHz
		Antenna type	Bessel/Directive	
		Antenna max. Gain (dB)	11 / 20 / 29 (tbd)	
		Antenna 3 dB beam contour in °	50° / 17° / 6.2° (tbd)	
		EIRP Density (dBW/MHz)	34 or 15/24/29(tbd)	
		G/T (dB/K)	1.1 (-14.9 / -5.9)	
HAPS20	FR3	Frequency	7 GHz	7 GHz
		Antenna type	Bessel/Directive	
		Antenna max. Gain (dB)	11 / 20 / 29 (tbd)	
		Antenna 3 dB beam contour in ° or D/λ	50° / 17° / 6.2° (tbd)	
		EIRP Density (dBW/MHz)	34 or 15/24/29? (tbd)	
		G/T (dB/K)	1.1 (-14.9 / -5.9) (tbd)	

Table 4: Summary of tx/rx configurations corresponding to different frequency bands for HAPs

The characteristics “Antenna Gain” and “Antenna 3 dB beam contour” are necessary to define the antenna projection of flying gNB on Earth’s surface. The characteristics “Antenna 3 dB beam contour”

refers to the half power beam width, which is defined as the angular width of the radiation pattern, including beam peak maximum, between points 3 dB down from maximum beam level (beam peak). It should be noted that the EIRP (Effective Isotropic Radiated Power) values for LEO set-up in S-Band that are used in Table 3 are approximately 20 dB above the co-ordination threshold defined in the ITU RR [9]. This is because the specifications have been defined under the condition that all systems that are operating in this band have co-ordinated with each other on conditions (in particular power levels)that they will be using to provide their services without causing interference to each other's services. Here co-ordination refers to a process between two or more entities that want to offer services using specific frequency bands. For Europe, this is Echostar and Inmarsat, where Echostar has the range 1995 MHz - 2110 MHz (UL) and 2185-2200 MHz (DL) and Inmarsat has the range 1980 MHz - 1995 MHz (UL) and 2170 MHz - 2185 MHz (DL). These spectrum assignments are valid until 2027. Considering a 6G network with deployment start at 2030, it may be possible to use these frequencies.
Concerning the Ka-Band specifications, there are concrete power flux density (pfd) limits defined in [9] for the frequencies and these would allow even much higher powers than considered in Table 3. However, in practice there are so many filings for this spectrum that achieving co-ordination among the different systems is difficult. Especially for NGSO constellations, it is extremely unlikely that a system can operate with powers reaching the pfd limits. Hence, it is reasonable to adopt much lower powers for the SLS.

4.3 User equipment specification

Table 5 provides a summary of UE antenna configuration, which are mainly referenced from [4].

Characteristics	UE Type 1	UE Type 2
Frequency	2 GHz	30 GHz UL and 20 GHz DL
Antenna type	Omni Directional	Directive antenna
Antenna gain	0 dBi	DL: 43.2 dBi, UL: 39.7 dBi
Transmit power	23 dBm	33 dBm
Noise figure	7 dB	1.2 dB

Table 5 Summary of UE antenna configuration referenced from [4].

The UE antenna specification for FR3 is yet to be finalized.

4.4 Channel models

The channel models that are included in the simulator correspond to

- Propagation model
  - Free space path loss
  - Clutter loss
  - Shadow fading
- Atmospheric gaseous and water vapor attenuation model
- Rain-cloud attenuation model
- Ionosphere scintillation model

The channel models in the simulator are developed following the specifications provided in [5] and [6].

4.5 Traffic models

A traffic model is characterized by the size of the packet, packet interval rate and the total data rate. An example of different traffic types that can be considered in the simulator are listed in Table 5.

Application	VoIP	Video
Packet size (B)	70	15000
Packet interval (ms)	20	25
Total data rate (Mbps)	0.028	4.8

Table 6 Summary of traffic configuration-

The 5G QoS model described in [10] will be added to the simulation framework to be able to use standardized 5G QoS flows with characteristic values like allowed packet error ratio, packet delay budget and QoS flow priority from Table 5.7.4-1 of [10] as a scheduling priority. The QoS flows will be implemented in a simplified way because the simulator does not cover the control plane. Every data packet is categorized by its type, and each packet type is added to a QoS flow.

4.6 Scheduling strategies

The different scheduling techniques that will be used to assign resource blocks to the users are:

- Proportional Fair (PF): It is based upon maintaining a balance between the total throughput of the network while at the same time allowing all users at least a minimal level of service. This is done by assigning each data flow a scheduling priority that is inversely proportional to the anticipated SNR of the transmission link.
- Deficit Round Robin (DRR): It is a weighted round-robin method that uses a deficit counter. A maximum packet size number is subtracted from the packet length, and packets that exceed that number are held back until th e next visit of the scheduler.
- Max Carrier to Interference (Max C/I): Max C/I algorithm is a kind of scheduling that emphasizes on maximizing system throughput at the cost of user fairness.
- QoS Scheduler: This scheduler prioritizes packet flows based on the QoS flow identifier.

5 KPIs to be demonstrated using the SLS

The different KPIs that the simulator is able to compute for different scenarios are:

- RSSI/SINR heat map,
- Time series representation of SINR variation for each user,
- Time series representation of network and user throughput,
- Time series representation of resource block share for each user,
- Time series representation of packet drop rate,
- Time series representation of achieved delay at the application layer.

Additional KPIs added during the development of the simulator:

- Outage probability for the given QoS
- Interference generated within system and to other systems

6 Description of handover solution/s considered in a TN/NTN and NTN-NTN network

Mobility procedures in a terrestrial cellular network are triggered when a UE moves from one place in a cellular coverage to another. For a UE in IDLE/INACTIVE mode, the procedures are cell selection and reselection, and for a UE in CONNECTED mode, the procedure is termed handover from a serving cell to a target cell.

For NTN, mobility procedures are triggered also by the motion of the satellite. When a satellite moves out of UE visibility and a new satellite comes in its place a **service-link switch** takes place as illustrated in Figure 7. Independent of whether the UE is moving or not, a handover procedure could be triggered for UE in CONNECTED mode or a cell-reselection procedure for UE in IDLE mode to connect to a cell of the new serving satellite.

Depending on whether the payload is transparent (gNB on ground) or regenerative (gNB on board), the service-link switch can be categorized as intra-gNB or inter-gNB, respectively. Intra-gNB does not require explicit RRC signaling to be triggered as long as both serving satellite and target satellite are connected to the same gNB on the ground. Inter-gNB is essentially a handover between two satellites which requires explicit RRC signaling to be triggered.

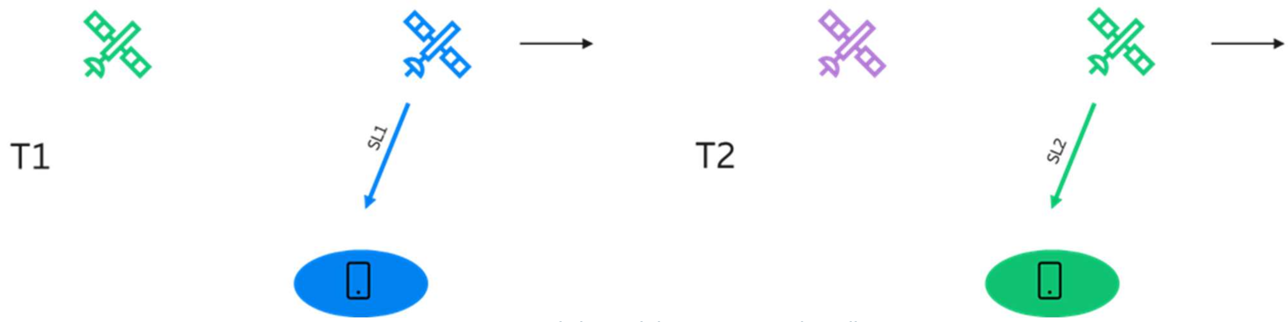


Figure 7 Service link switch between UE and satellite.

When a satellite moves out of NTN gateway visibility a **feeder-link switch** must be performed to a new NTN gateway.
For a transparent payload with a gNB connected to the gateway, a feeder link switch over may result in transferring the connection to a new gNB for all the UEs served by the satellite. For soft feeder link switch as seen in [4], an NTN payload is able to connect to more than one NTN Gateway during a given period, i.e., a temporary overlap can be ensured during the transition between the feeder links. The transition to the new gNB could be a blind HO (network decision without measurement) or a time based conditional handover assisted with measurements.
For a regenerative payload with a full gNB onboard satellite, a feeder link switch can be transparent to the UE as long as the ground AMF does not change. As seen in Figure 9, for a soft switch-over where two feeder links are established at a transition point, the serving cell does not temporarily overlap with a new cell and then disappear.
In case of a hard feeder link switch, only a single link can be maintained, and there will be a period of service discontinuity during the transition threshold.

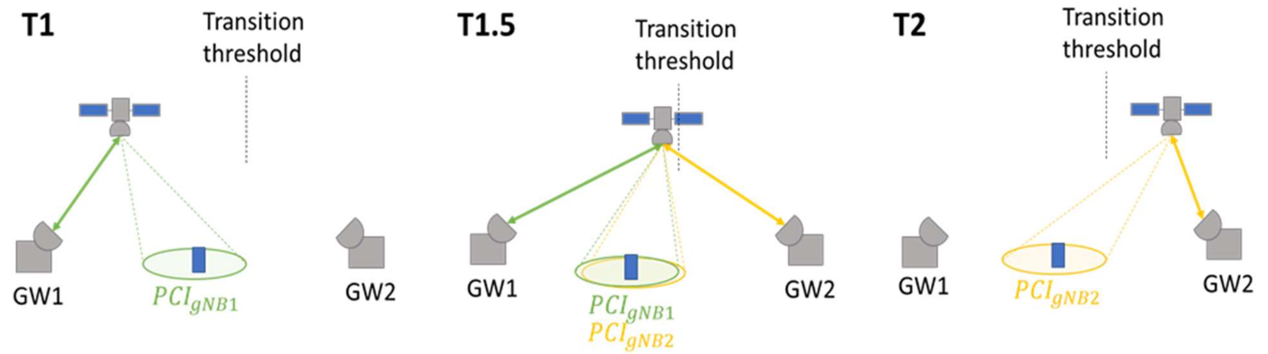


Figure 8 Soft Feeder link switch for transparent payload.

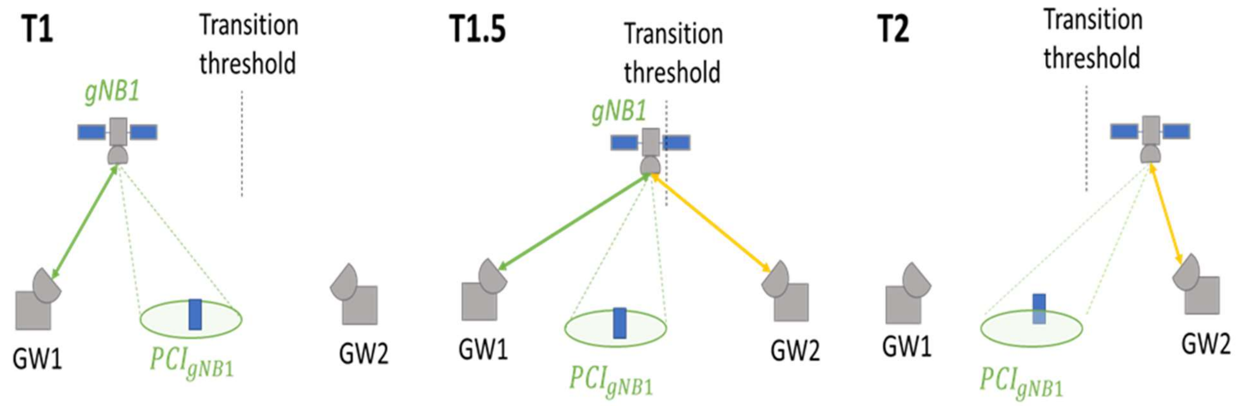


Figure 9 Soft Feeder link switch for regenerative payload.

Handover in Connected mode

The purpose of handover procedures in a network is to allow the user to move seamlessly from one cell to another with as low service interruption as possible. The baseline NR handover uses UE-assisted network controlled handover, in which the UE experiences a certain interruption time after disconnecting from the serving cell until the new connection with the target cell is established. The UE performs periodic measurements on cells on specific downlink channels and sends measurement reports to the network when certain conditions are satisfied. When a measurement report is received by the network, the network decides whether the UE must be handed over to a new cell and starts the HO preparation phase. During this phase, the serving cell requests the target cell to prepare the resources to allocate the UE. Once the target cell acknowledges the HO request for the UE to be handed over, the HO execution starts and the UE releases its connection with the serving cell. Then, the UE proceeds to access the target cell via the random access channel (RACH). The full handover procedure is described in Figure 10Figure 11.

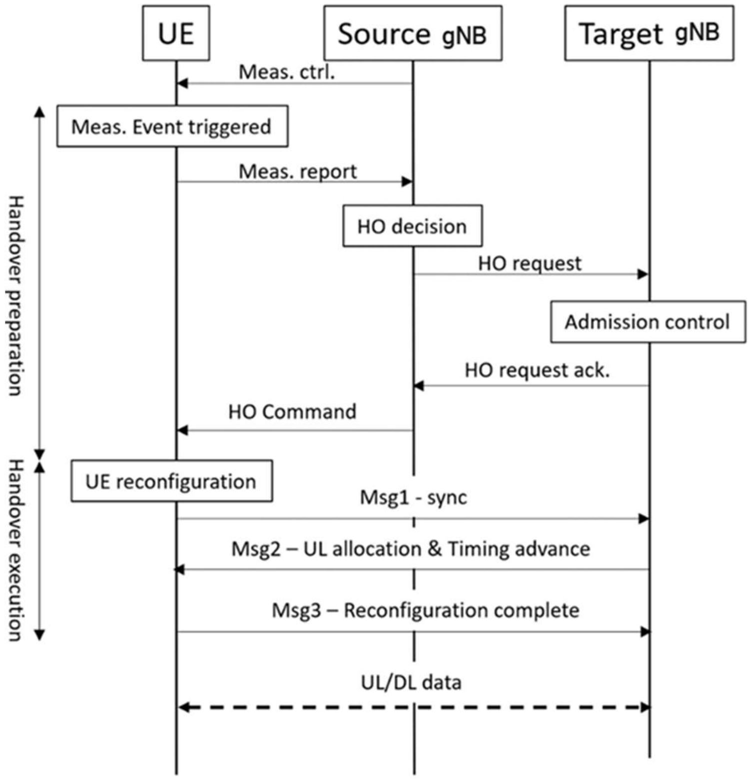


Figure 10 Conventional UE assisted network Handover.

In NTN, NGSO satellites move rapidly with respect to a given UE location. The time such a UE stays within a cell beam of a satellite is typically for only a few minutes, and the time a satellite is in the view of a UE from horizon to horizon is around 20 minutes. The fast movement of satellites mean that the HO procedure from one spot beam to the next or from one satellite to the next has to be executed in a timely fast manner otherwise the UE may not make use of the target satellite resources efficiently and in the worst case may suffer service interruption due to radio link failure. Conditional Handover (CHO) introduced in Rel 16 is a proactive process that allows the UE to decide to perform handover when certain conditions are met. The UE starts evaluating the execution condition(s) upon receiving the CHO configuration and stops evaluating the execution condition(s) once a handover is executed. The full procedure is shown in Figure 11.

The baseline NR HO mainly focuses on reducing the HO interruption time. The CHO procedure [8], which conducts an early HO preparation when the serving cell link is still reliable, ensures that the transmission of the measurement report and the reception of the CHO configuration occur in good radio conditions.
NTN supports the following additional triggering conditions upon which the UE may execute CHO to a candidate cell:

- The radio resource management (RRM) measurement-based event A4;
- A time-based trigger condition, *condEventT1* - a time window in which the UE may execute CHO to the candidate target cell;
- A UE location-based trigger condition, *condEventD1* - distance between UE and a reference location1 becomes larger than a configured threshold, and distance between UE and a reference location2 in a candidate target cell becomes shorter than a configured threshold. In Rel 17, it is assumed that the UE has some positioning capabilities to perform such measurements.

A time-based or a location-based trigger condition is always configured together with one of the measurement-based trigger conditions (CHO events A3/A4/A5).

A detailed system level simulation study evaluating CHO for LEO satellites and a comparison with the baseline NR HO can be found in [11].

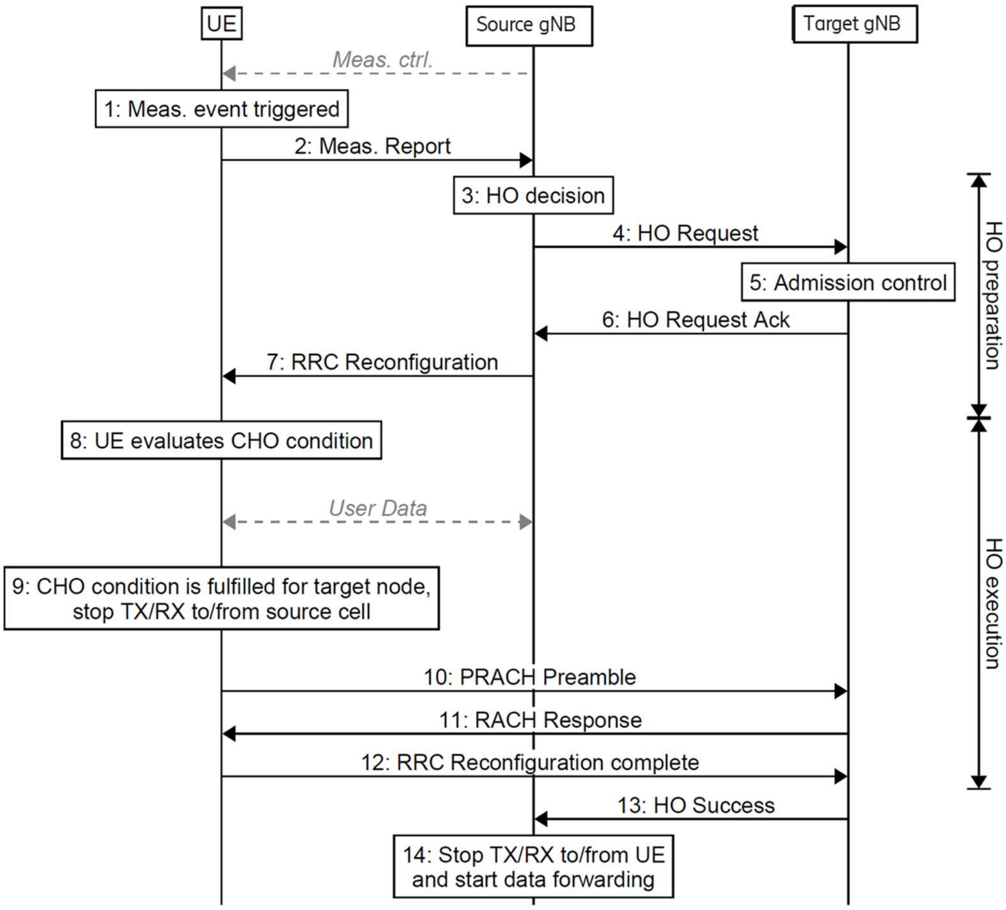


Figure 11 Conditional Handover (CHO) procedure.

7 Results and Analysis

DT can provide beam configurations and simulation results from their previous studies, which can serve to validate the SLS performance.
EAB will provide some results wrt to handover and backhaul capacity evaluations, where the former results can be used as a basis for the coexistence scenarios that will be evaluated.

7.1 Evaluation of mobility event frequency

For a better understanding of the impact of signaling overhead due to mobility procedures it is important to evaluate how often these mobility procedures are triggered.
We can summarize the discussion in Section 6 by defining two possible mobility events: PCI Change and gNB ID change. This depends on the fact that the overall Cell ID is a combination of PCI and gNB ID, therefore if one of the two changes the UE should perform a mobility procedure to connect to the new Cell ID.

- PCI Change: Typically a gNB manages multiple physical cells (i.e.: defined by their own SSB). Even if the gNB is not changing, the new cell may have different configuration. In some cases the new cell may be illuminated by a different satellite requiring a new pre-compensation setting
- gNB Change: Since different gNBs manage a different set of physical cells, if this change it is likely that the PCI also changes requiring a new configuration

Even if the users are not moving, from a system level simulators we can detect when the user attaches to a new ground station (SINK) a new satellite (SAT) or a new cell intended as the coverage area illuminated by a beam and associated to a PCI (CELL). Note that the cell may change if the system uses Earth-Moving cells, while this does not happens with Earth-Fixed cells. These changes happen when, due to satellite motion, the optimal path from the user position to the closest sink changes.
It is possible to connect these "simulator events" to the two types of mobility events depending on where the gNB is located. In fact if the system has a "RRH on-board" functional split, the gNB is located at the ground station, whereas with "gNB on-board" functional split, the gNB is located at the satellite. So the gNB change event may happen either when the satellite or the ground station changes, depending on the functional split assumed.
Table 7 summarize how the simulator events are interpreted based on the functional split.

Table 7: Interpretation of simulator events in terms of mobility events for different functional splits (orange represents "PCI change" and green "gNB ID change")

Simulator Events			Mobility Event description	
CELL	**SAT**	**SINK**	**RRH on-board**	**gNB on-board**
			Nothing is happening	
X			PCI Change (pre-compensation settings unchanged)*	PCI Change (pre-compensation settings unchanged)*
	X		**SL switch**: PCI Change (new pre-compensation settings)**	Inter-gNB mobility -> gNB ID change**
X	X		PCI Change (new pre-compensation settings)*	Inter-gNB mobility -> gNB ID change*

Simulator Events			Mobility Event description	
CELL	SAT	SINK	RRH on-board	gNB on-board
		X	**FL switch**: Inter-gNB mobility -> gNB ID changes	NG rerouted: nothing happens from UE perspective
X		X	Inter-gNB mobility -> gNB ID change*	PCI Change (pre-compensation settings unchanged)*
	X	X	SL + FL Change: Inter-gNB mobility -> gNB ID change**	Inter-gNB mobility -> gNB ID change**
X	X	X	Inter-gNB mobility -> gNB ID change*	Inter-gNB mobility -> gNB ID change*

* only Earth-moving cells
** only Earth-fixed cells

Assuming a baseline scenario characterized by 510 satellites in a Walker Star configuration at 600 km of altitude, 100 ground station evenly distributed around the world, 4.4 degrees of HPBW corresponding to 30 dB satellite antenna gain and considering a mapping between serving satellite and cell so that the time the same satellite serves a given cell is maximized, we can extrapolate some statistics about the frequency of mobility events.

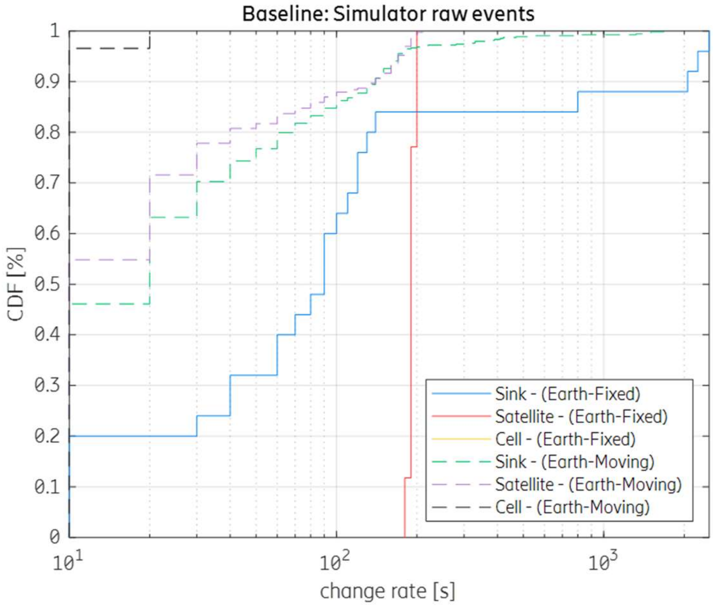


Figure 12: Frequency statistics of raw simulator events in the baseline scenario

Earth-moving cells - The most frequent event is cell change in the case of Earth-moving cells, which happens every 10 seconds. The satellite also changes every 10 seconds for half of the users, while the other half are served by a new satellite every 10 seconds to 2 minutes. This is due to the fact that Earth-moving cells from different satellites are interleaved and no coordination exists to assign a certain area to a specific satellite, therefore in most cases changing cell likely means changing the serving satellite. Finally, the ground station (sink) changes every 10 seconds to 3 minutes, for similar reasons.

Earth-fixed cells - By definition, no cell change event happens in case of Earth-fixed cells (no user movement is assumed). The serving satellite changes almost regularly every 3 minutes for all users. This is due to the unique assignment of a certain geographical area to a specific user according to the mapping method described above. The serving time is maximized and so this KPI only depends on the altitude and speed of the satellite (i.e.: when its elevation angle will be too low to continue service). The sink changes every 10 seconds to 2 minutes for most users, while for 20% of the users it changes every 30 minutes. This much lower frequency is due to the fact that the satellites flying over a given area near the users are likely to be connected to the same ground station also close to the user position.

In conclusion the Earth-moving cell scenario seems to be much more dynamic than the Earth-fixed scenario.

In terms of overall mobility frequency, where mobility is intended as either a PCI or gNB change, we can observe the following.

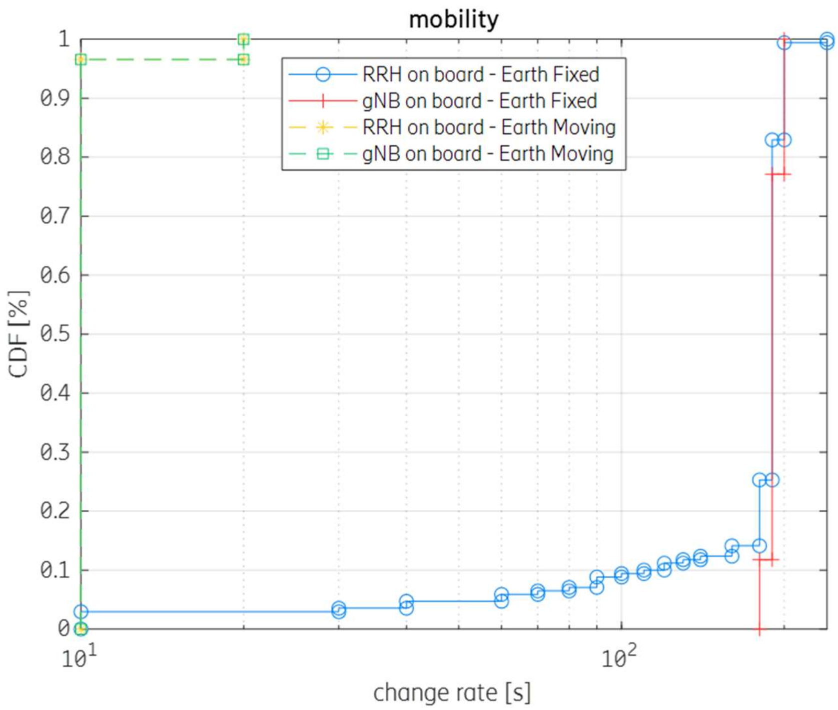


Figure 13: Frequency of mobility procedures in the baseline scenario for different functional splits

It is clear that in the Earth-moving cell scenario, the frequency is dominated by the high mobility of the cells. When a new cell passes across the user position, the user has to perform a mobility procedure to synchronize to the satellite providing such cell. This happens every 10 seconds for almost all users. This may be mitigated by keeping the user connected to a cell that is not the closest for longer amount of time, but the signal quality will be sub-optimal. Nevertheless it could be interesting to address this particular technique.
For Earth-fixed cells the mobility events happen much less often, every 3 minutes with little difference with respect to the functional split chosen. While gNB on board provides almost constant mobility event frequency, with RRH on-board around 15% of the users will need to perform handovers more frequently (between 10 seconds - 3 minutes).
This confirms what was already observed above, the Earth-moving case may be problematic since very frequent handovers are needed, each of them implying a certain amount of overhead traffic.

In Figure 14 we show the impact of a different number of satellites in the constellation and a different mapping methods where signal quality is maximized rather than duration of serving time.

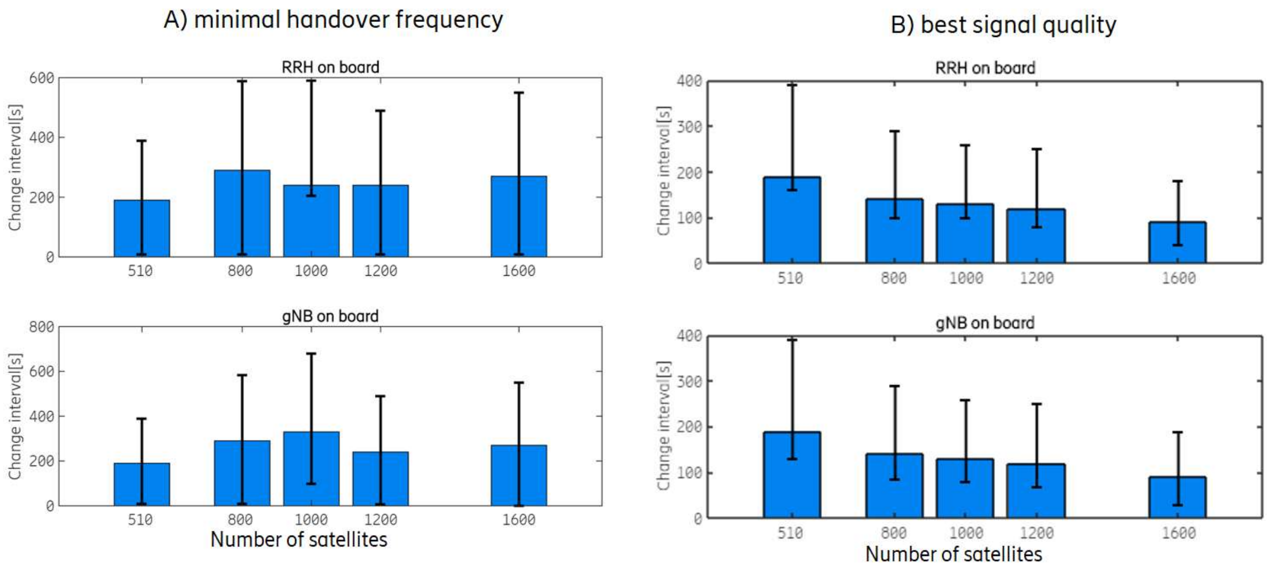


Figure 14: Impact of constellation size and cell-to-satellite method on handover frequency for different functional splits

We can observe that, as expected, the best signal quality mapping method makes the handovers more frequent although the user is always connected to the satellite with the highest elevation angle, and thus, best signal quality.
For the minimal handover frequency mapping method there is not a clear pattern of the handover frequency as function of the number of satellites, while for the best signal quality method the handovers become more frequent as the number of satellites increases. This is due to the fact that with more satellites there are more options for the “best satellite”, and thus the user move to these different options more often.

In 28 the authors, beside providing a discussion on pros and cons of different functional split, they provide an estimation of signaling overhead of different handover procedures in different NTN scenarios.
It would be possible to combine these two results and estimate the actual traffic due to handover procedures flowing in the network.
It is anyway possible to conclude that the Earth-Moving scenario does not provide any clear benefit, beside being the only option if the satellite does not have beam steering capability, but instead it implies very frequent handovers and consequent high amount of overhead traffic in the network. Note that it is likely that all the users in the cell will have to perform the handover procedure at the same time. It may be possible to distribute these handovers in time but it is still an amount of overhead that all users will generate.

7.2 Evaluation of the System-Level Simulator

Simulation Parameters:

The table below provides some of the simulation parameters considered.

Parameter	Value
System Bandwidth	20MHz
TN Bandwidth	20 MHz (Extended Coverage (TN only), coexistence) 10 MHz (Extended Coverage (TN-NTN))
NTN Bandwidth	10 MHz (Extended Coverage (TN-NTN) 20 MHz (coexistence)
Subcarrier Spacing (SCS)	15kHz
Scenario	Dense urban EMBB
Region of Interest	Tennenlohe- Boxdorf
Terrestrial Channel Model	Urban Macro [38.901]
Channel characteristics for vehicle to Satellite	38.811 [17]
Channel characteristics for vehicle to HAPS	TSG R4-2115751
gNodeB type	TN, NTN (LEO, HAPs)
TN gNB Tx Power	46 dBm
NTN gNB Tx Power (LEO)	46.8 dBm
NTN gNB Tx Power (HAPS)	44.77 dBm
NTN gNB altitude (LEO)	600 km
NTN gNB altitude (HAPS)	28 km
TN gNB antenna gain	30 dBi
NTN gNB antenna gain (LEO)	30 dBi
NTN gNB antenna gain (HAPS)	4.02 dBi
UE Tx Power	23 dBm
Application Type (Remote Driving)	400B per 30ms(DL), 34kB per 30ms(UL)

Scenario Description:

To study the hybrid flexible network with terrestrial and non-terrestrial layers, we have considered a scenario with different deployments over the village Boxdorf, in this case. We consider1 terrestrial, 5 LEO satellites and a HAP node (non-terrestrial) to serve the region of Interest, as shown in Figure 15 Simulation Scenario: Tennenlohe Boxdorf . The base stations (or gNBs) are interconnected via the Xn links. The handover process from one gNB to another is executing using the standard interface, ensuring seamless connectivity and mobility. Since the focus of the simulations are on the user link side, it is assumed that all the base stations are connected to a single core network.
The vehicular traffic is simulated using SUMO (Simulation of Urban Mobility) simulator.

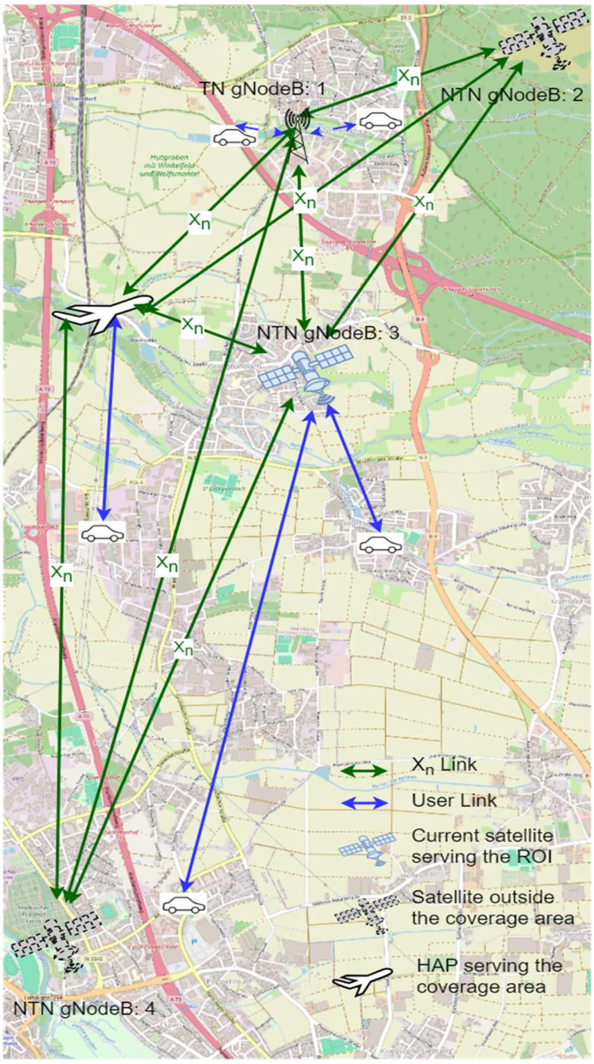


Figure 15 Simulation Scenario: Tennenlohe Boxdorf

The simulator is developed to be able to simulate mobility scenarios and demonstrate handover between terrestrial and non-terrestrial nodes which include the LEO satellites and HAPs platform. We have identified two potential use cases for analysis. Firstly, extended coverage scenario where the system bandwidth is divided between the TN and NTN and no interference is assumed. Then we have the co-existence scenario where the total system bandwidth is shared by the TN and NTN.

To assess each use case, we have simulated following three scenarios:

- TN-only: The TN gNodeB serves the region and all users are connected to TN gNodeB.
- TN+LEO: The region is served by a TN gNodeB and LEO satellites which serve the area in succession.
- TN+HAPS: The region is served by a TN gNodeB and a HAP.

Using the simulator, we were able to generate the following results, the analysis being categorized by the use case.

Use case: Extended Coverage

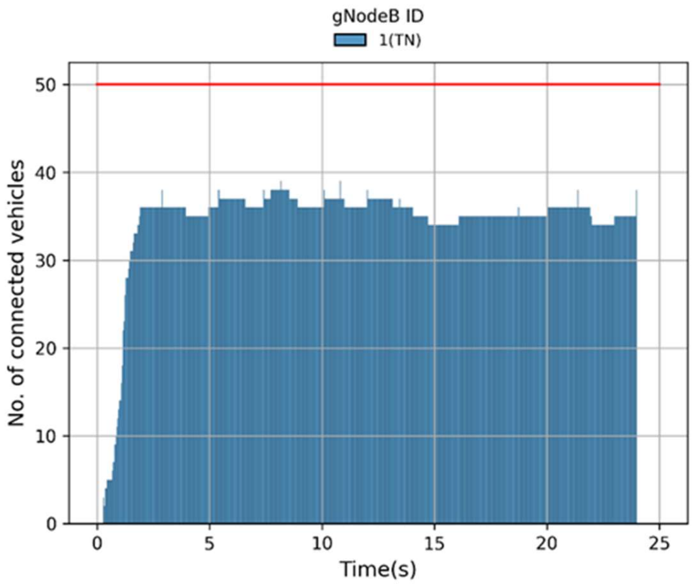
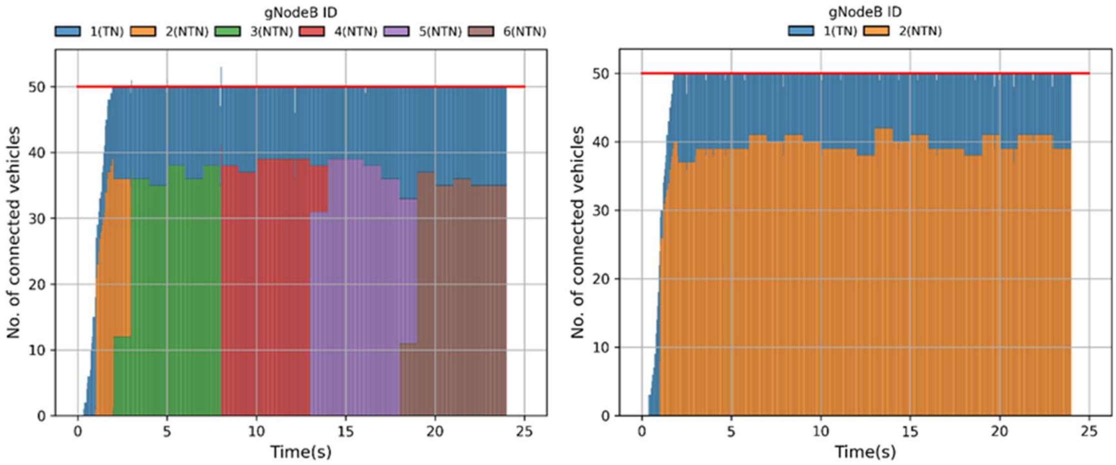


Figure 16 Histogram representation of users connected to TN gNodeB, for TN-only case

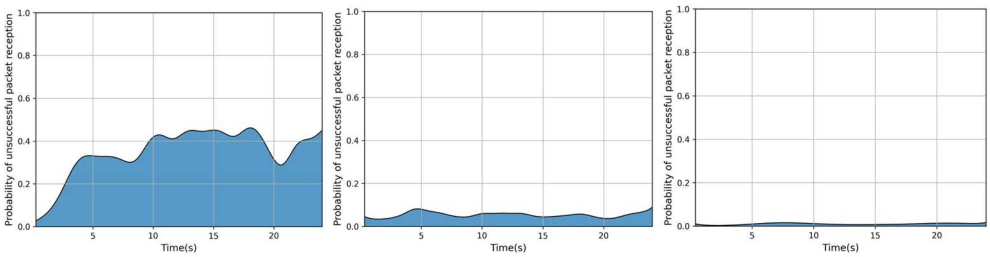
In Figure 16, we have a histogram of the UEs connected to the serving cell. In this scenario we have 50 cars deployed which is served by 1 TN gNodeB. Here, we observe that most of the users or cars try to connect to the terrestrial gNodeB but not all are successfully served. In the scenario where LEO or HAPS serve the region along with TN, we observe that all the UEs are served by either the TN node or the NTN (LEO or HAPS). In **Error! Reference source not found.**, we also observe the time instance at which the UEs are handed over to the serving gNodeB, indicated by the change of color.



(a) (b)

Figure 17 Histogram representation of users connected to TN+LEO(a) and TN+HAPS(b)

Each LEO satellite with gNodeB on board serves the region for around 4-6s, which can be seen in Figure 17 , ensuring all UEs are served. In the scenario with HAPS, we observe that UEs try to connect to HAPS during the simulation as it measures better SINR from the HAPS node in comparison to the terrestrial gNodeB. Along similar lines, we notice from Figure 18 that in the TN-only scenario, the probability of unsuccessful packet reception is high as the users may be located further away from the base station and may experience suboptimal channel conditions. We observe that when NTN nodes are deployed along with the TN gNodeB, the probabilty of unsuccessful transmission reduces significantly, which clearly indicates that NTN nodes are essential in extending the coverage area to serve maximum number of users.



(a) (b) (c)

Figure 18 Probability of unsuccessful packet transmission in TN-only(a), TN+LEO(b) and TN+HAPS(c) scenario

To analyze the signal quality, we have the following boxplot where the downlink SNR for 4 different UEs/cars are studied and compared against in different deployments. The selected cars are located at the following distances from the TN gNodeB:

- Car ID 2: 200 m
- Car ID 7: 2 km
- Car ID 10: 1.7 km
- Car ID 22: 1.55 km

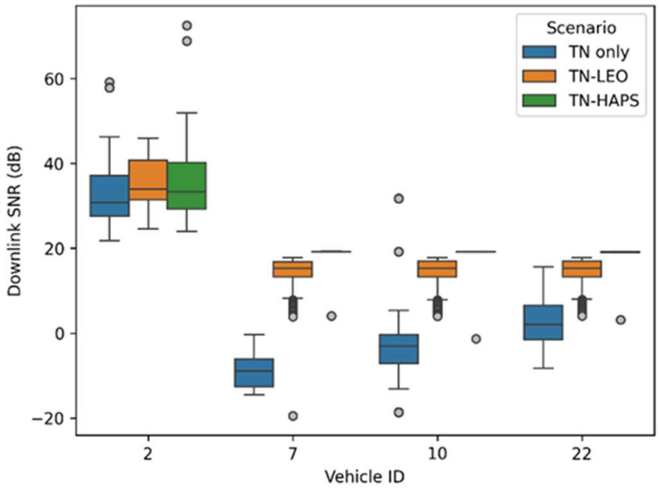


Figure 19 SNR measurement by individual users/cars

We observe in Figure 19 that the SNR for TN-only scenario is much less than that observed when NTN nodes are available. However, we observe a slightly higher value of SINR for Car ID 2 due to its proximity to the terrestrial gNodeB, in comparison to other users. For HAPS, the variation in SNR observed by the user is minimal and is depicted in the figure above. The grey circles here indicate outliers.

To reinforce the earlier analysis, we include the following plot, Figure 20, which shows the SNR measured by an individual user, placed at around 1.7 km from the terrestrial gNodeB.

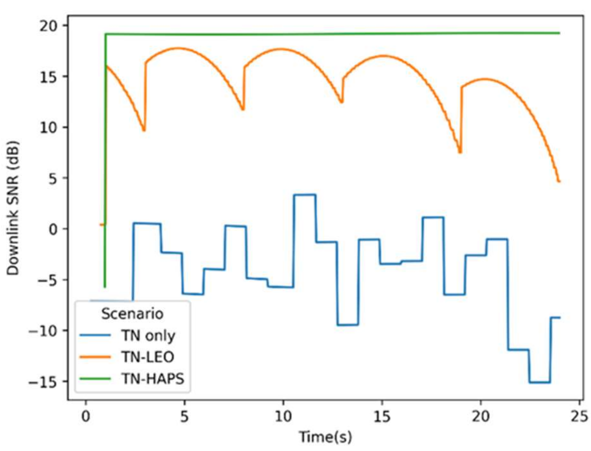


Figure 20 SNR measured by vehicle ID 10

We observe better signal quality when TN-NTN are serving the cell as compared to TN-only scenario. The SNR measure is persistent in the TN-HAPS scenario and hence the horizontal line can be observed, whereas in TN-LEO scenario, we have the curve which indicates the time each LEO satellite serves the region and indicates the user handed over to the next gNodeB or the LEO satellite.

The network sum-rate, a weighted sum of the throughput at each node, is one of the prominent KPI measured as seen in Figure 21. The figure represents the sum-rate for different deployments scenarios where 25, 50 and 100 users are considered. The figure here illustrates that the network sum-rate is higher in scenarios where TN and NTN nodes are deployed in comparison to when only TN nodes are deployed, supporting the fact that more users, not necessarily located at a proximity to the terrestrial gNodeB, can be served by NTN nodes and help extending the coverage to remote areas as well.

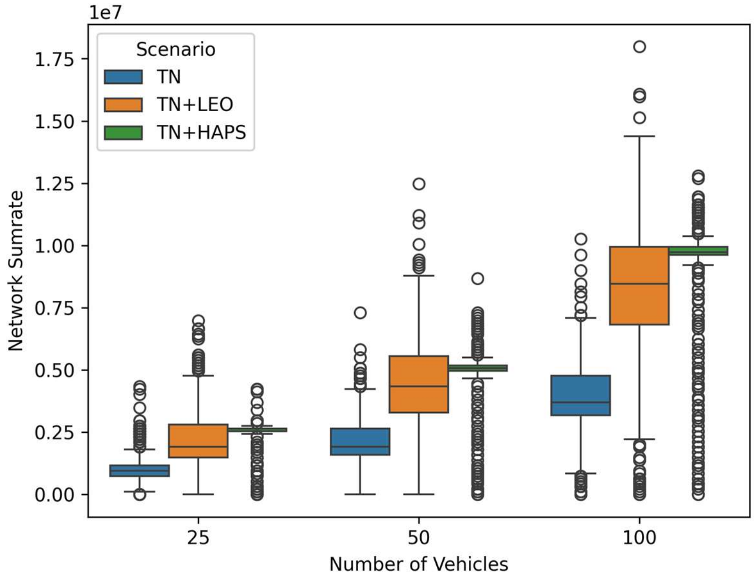


Figure 21 Network Sum Rate (bits/s) observed for different simulation scenarios

During the simulation, the LEO satellites cover the region for around 4 seconds each and move out of the area. During such a phase, handover is triggered where UEs try to connect to the next serving gNodeB. We have considered 50 users in the network served by 1 TN gNodeB and 5 LEO gNodeBs for our simulation scenario. The Figure 22 depicts the total number of handovers that can occur at a time instance for all users, the mean value is indicated by the blue solid line. In this figure, we also notice that some users may observe more than 6 handovers, which indicates a ping-pong effect as the users try to connect back and forth to TN and NTN nodes based on SINR measured by the users. This can be further optimized to have adequate number of handovers and avoid ping-pong effect using efficient AI/ML algorithms as future work.

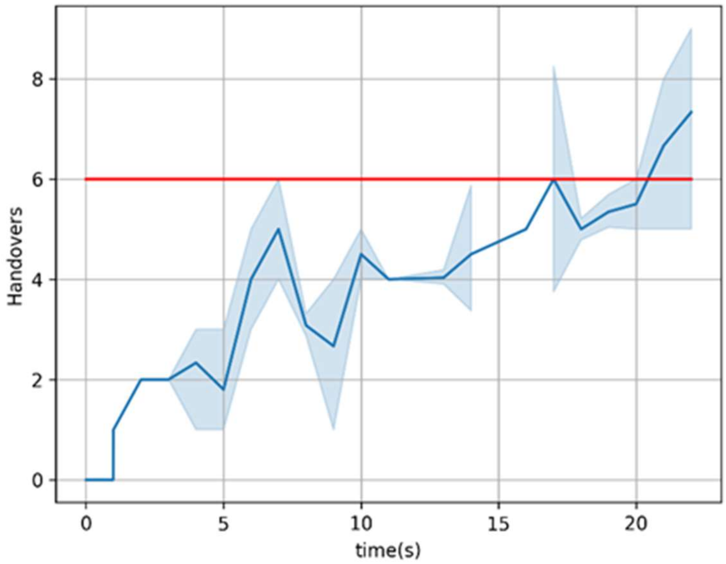


Figure 22 Time series plot of total number of handovers across all users

Use case: Co-existence

To study the network performance in a co-existence scenario, we have considered two scenarios where NTN nodes are deployed along with TN and interference among the TN and NTN gNodeB is considered. The Figure 23 shows the range of SINR measure by some of the users. We observe that the SINR measured in the scenario when HAPS or LEO are present is lower than when we have only the TN gNB serving the region. This is because of the interference caused by the NTN gNodeB, especially for user ID 2, which is at a proximity to TN gNodeB. Additionally, we observe that the interference caused by a HAPS gNodeB deployed close to the TN gnodeB causes substantially higher interference than that by the LEO gNodeB. For the other cars that are located further away, the interference caused by TN is significantly less and hence measures better signal quality when connected to an NTN gNodeB.

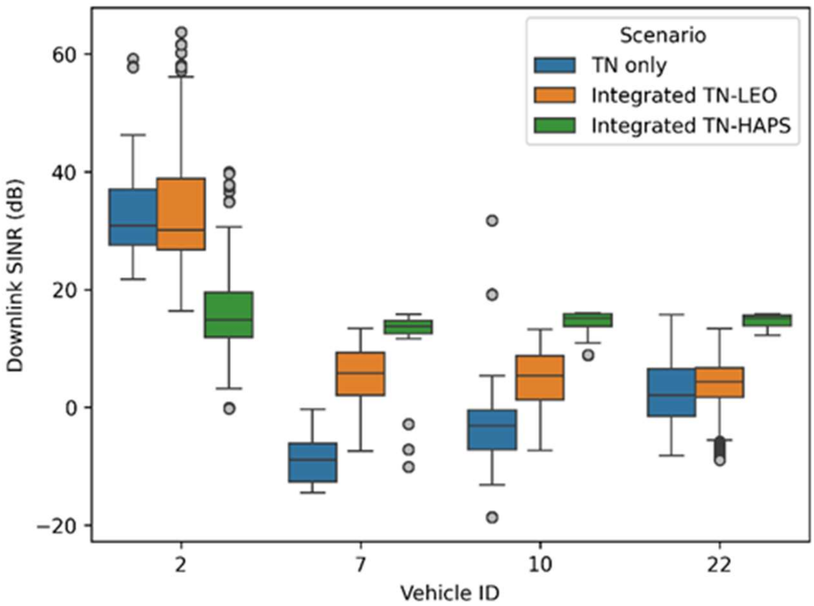


Figure 23 Co-existence scenario: SINR measured by individual users

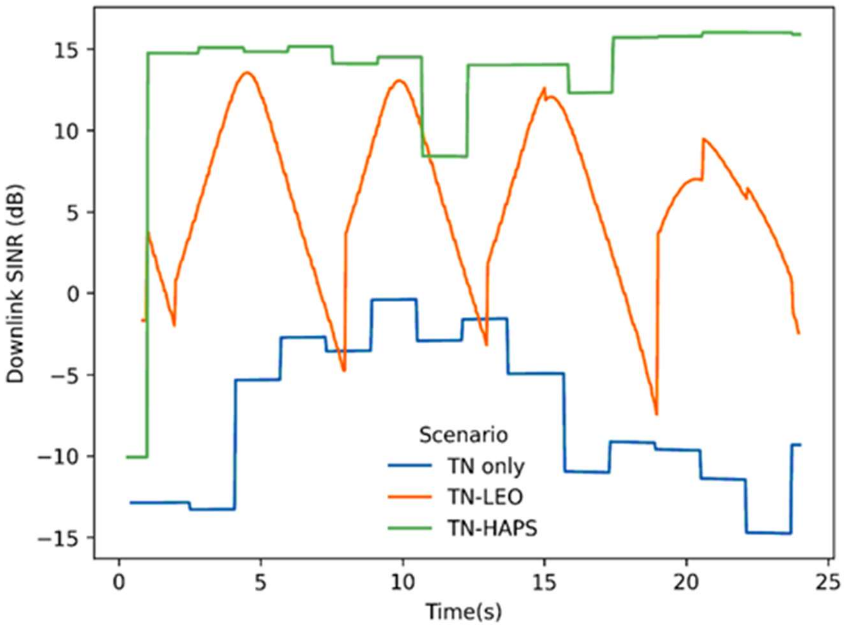


Figure 24 Co-existence scenario: SINR measured by vehicle ID 7

In the Figure 24, we analyze the SINR measure by an individual user/car located at around 2 km from the TN gNodeB. We observe that the SINR measure from HAPS is no longer persistent and is slightly affected by the interference caused by TN gNodeB. Moreover, the SINR measured by the user/car served by LEO has a significant variation subject to interference. Hence in these cases, the classical approach of handover based on RSSI measurements might need some enhancement.

The Figure 25 represents the network sum-rate for the TN-NTN scenarios for different deployment scenarios with 25, 50 and 100 users. Here, we observe that the sum-rate is higher with HAPs when compared to that of LEO, but marginally higher than that of TN-only scenario due to the interference experienced. The overall SINR measured from LEO is severely affected by the interference caused by the terrestrial gNodeB leading to a lower rate of packet transmission.

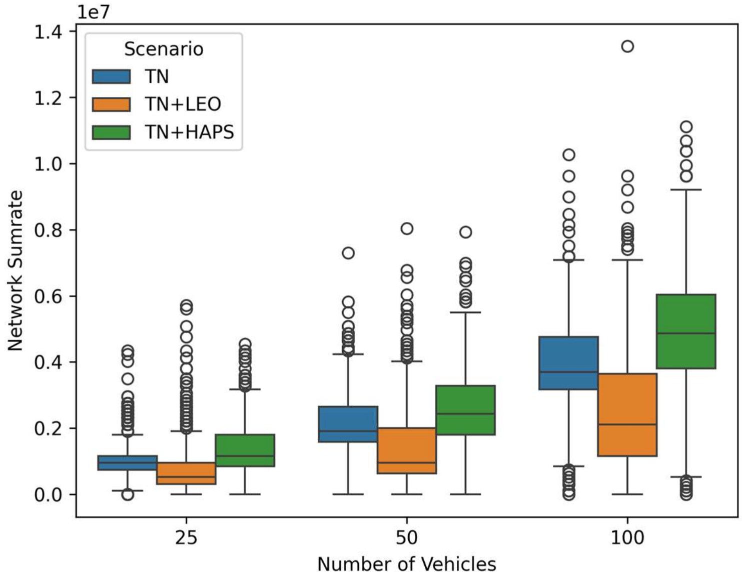


Figure 25 Co-existence scenario: Network Sum Rate(bits/s) observed for different simulation scenarios

8 Application of AI for optimization

Artificial Intelligence (AI) is expected to play a crucial role in 6G communications by enhancing network performance which cannot be achieved by traditional optimization techniques. With the increasing number of network nodes deployed at multiple layers, traditional optimization methods may not be able to handle the accompanying vast amount of network data. The NTNs also present unique challenges due to their dynamic (moving network nodes) and complex (multi-layered) nature. AI-based algorithms can provide intelligent, adaptive and proactive solutions by fully exploiting the large amount available data to extract information like user behavior, traffic patterns and network demands. It is also capable of giving quick feedback based on real-time data. AI can also enable autonomous operations that are currently not possible with traditional methods, reducing the operation cost with less need for human intervention and increasing network reliability for different network conditions and configurations.

Reinforcement learning (RL) is a specific subset of AI that has shown promise for applications in NTN, such as LEO satellite and UAV-enabled networks. An RL agent learns a near-optimal policy by interacting with an environment based on the predefined rewards or penalty functions [10]. In each step, the Deep RL (DRL) combines RL with deep neural network (DNN) to approximate the policy or value function. By tuning the weight of each neuron, NN approximates the policy and value function that can be difficult to represent analytically. The NN usually consists of multiple layers that are fully or sparsely connected and can learn hierarchical features of the input data. This multi-layered structure also allows the agent to learn increasingly abstract features of the environment, which will enhance its performance when applied to more generalized situations.

One potential application of DRL in NTN is for trajectory design of UAVs when executing certain tasks, such as data collection for IoT nodes or coverage recovery due to malfunctioned base stations. One of the advantages of using DRL to design UAV's trajectory in NTN is that it can handle complex, non-linear, and non-convex optimization problems that traditional methods cannot [11]. For instance, the dynamic stochastic properties of NTN result in many random variables, however, the models of these random properties are often unknown or do not belong to any known models, which prevents the use of traditional optimization algorithms such as Dynamic Programming (DP) to solve such problems. Another example is that RL can obtain a near-optimal solution through sufficient training, even for non-convex and non-linear problems. However, these problems would require the use of Successive Convex Approximation (SCA) or other non-equivalent transformations if traditional optimization methods are used. Obviously, the optimality of such results cannot be guaranteed. RL agent learns the optimal path of the UAV by interacting with the environment and receiving rewards or punishments based on its actions. To maximize the long-term rewards, the agent can learn to sequence actions over time to achieve a desired goal, which makes RL a well-suited solution to solving trajectory design of the UAV in a dynamic NTN. Another advantage of DRL is that it can handle uncertain environments. In NTN, the UAV may encounter unexpected situations that can disrupt its pre-designed trajectory. DRL allows the UAV to learn how to adapt its trajectory to maintain optimal communication performance. Furthermore, DRL can handle multiple objectives simultaneously. Taking unmanned aerial vehicle path planning as an example, there are often multiple objectives, such minimizing energy consumption and maximizing throughput. Traditional methods solve these problems by optimizing the weighted sum of the multiple objectives or putting some of the objectives into the constraints with predefined thresholds, which may not be feasible or optimal. By properly defining the reward function, DRL handles multiple objectives by learning a policy that optimizes all objectives simultaneously.

The management of radio resources and mobility of mobile users in a cellular network is a complex problem that involves determining when and where to handover a user from one base station to another, while ensuring that the quality of service (QoS) requirements are met. The decisions made at any particular time can impact the network's performance in later epochs, making it a dynamic decision-making problem. Moreover, the solutions must be adaptive to the dynamic nature of the cellular network environment.

Reinforcement learning, specifically Deep Q-Networks (DQN), is a suitable approach for solving the mobility management and radio resource allocation problems. DQN optimizes decisions in a dynamic and uncertain environments by learning from experience through trial and error [12]. It adapts to the dynamic nature of the cellular network environment and can handle the balance between short-term and long-term QoS measures by tuning hyper parameters such as the learning rate and discount factor.

However, using reinforcement learning also has limitations. It requires a large amount of data to train the agent, and the learning process can be slow and computationally expensive. Furthermore, the agent may not always make optimal decisions, and the reward function may not capture all the nuances of the problem.

In conclusion, AI has the potential to significantly enhance the capabilities and performance of 6G NTN, enabling new applications and services that are not possible with existing traditional methods.

9 Sustainability

Sustainability means to exist and develop without compromising the natural resources and longevity of human life on Earth. Space applications, communications and technology are positively impacting in providing communication aid in areas which are heavily impacted by natural disasters. It is also proving to be a key enabler in providing healthcare benefits to countries which are cut-off from main communication networks.
Recognizing the benefits of space technologies for the benefit of humankind, during its seventy-sixth session in October 2021, the United Nations General Assembly adopted the Space2030” Agenda: space as a driver of sustainable development.

- Enhance space-derived economic benefits and strengthen the role of the space sector as a major driver of sustainable development;
- Harness the potential of space to solve everyday challenges and leverage space-related innovation to improve the quality of life;
- Improve access to space for all and ensure that all countries can benefit socioeconomically from space science and technology applications and space-based data, information and products, thereby supporting the achievement of the Sustainable Development Goals; and
- Build partnerships and strengthen international cooperation in the peaceful uses of outer space and in the global governance of outer space activities.

In [12], the concept of space technology as a sustainable technology is further discussed from different aspects such as space debris, global coverage and carbon footprint.

United Nations Sustainable Development Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
6G-SKY provides technologies to integrate and advance communication infrastructure for future networks providing services to un-served and under-served areas and additionally to different flying vehicles. With the help of the system-level-simulator, these integration approaches can be studied, and overall system parameters can be extracted to determine the possible benefits of such infrastructures.

10 Way Forward

This document is the report summarizing the overall architecture of the SLS, assumptions made in the simulator, the enhancements that will be made during the course of the project, different parameter configurations that will be used in the SLS and a list of different performance indicators.
As a way forward, the simulator will be enhanced as suggested in the document and the results obtained from the simulations will be added as a supplement to this report for the final version. The document will also be updated with respect to new specifications that are currently in discussion in other work packages of the project.

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