6G for Connected Sky
"6G-SKY"

Work Package 4

NTN for Terrestrial Users

Task 4.2

NTN System Level Performance Analysis

Deliverable D.4.2

Initial Report on NTN System Level Simulations

6G-SKY Project
June 15, 2023

Abstract

This D4.2 provides an initial draft of the system level simulator (SLS) focusing on non-terrestrial-networks (NTN) for terrestrial users. This report outlines the SLS architecture, the current limitations and the new functionality that will be 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 will form the basis for the further development of the SLS and will be supplemented with results and analysis at the end of this work package.

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

Task 4.2: NTN system level performance analysis

Initial report on NTN system level simulations

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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.

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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 4 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 8 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 OMNET++. OMNET++ 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

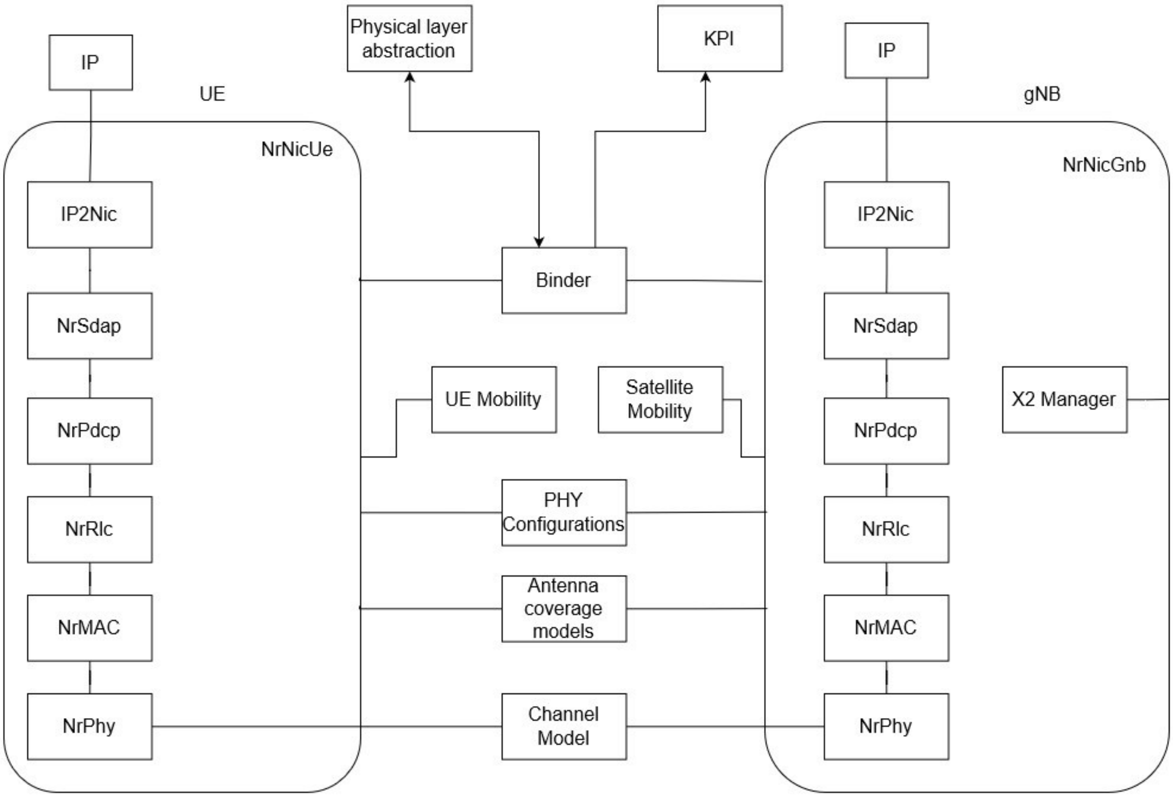

Figure 1 Overview of the SLS components.

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.

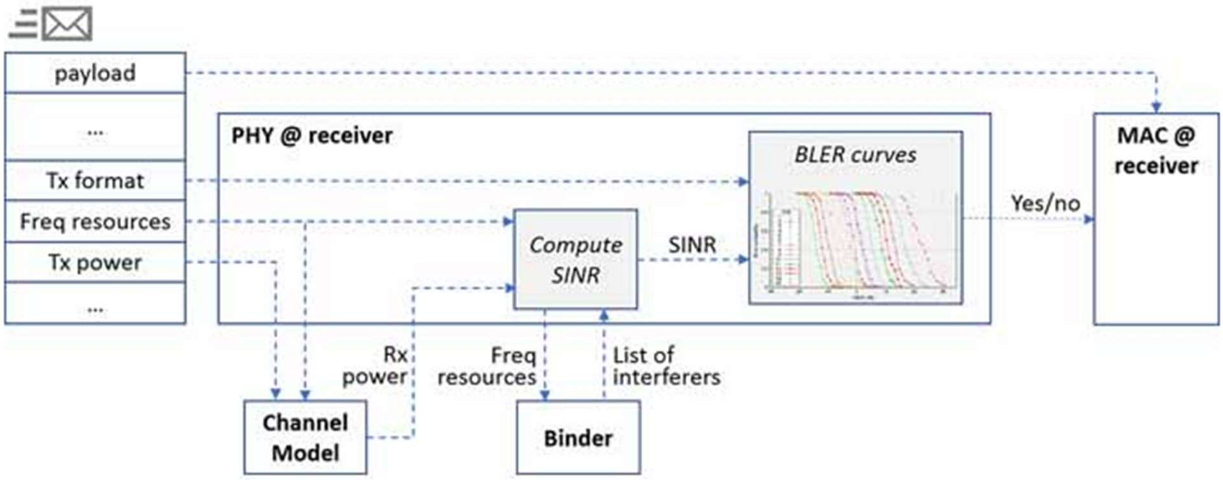

Figure 2: Physical layer abstraction model ***Fehler! Verweisquelle konnte nicht gefunden werden..***

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.

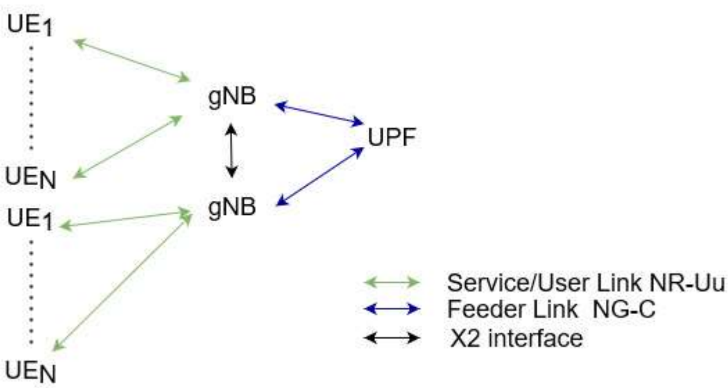

Figure 4: Communication links between nodes.

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.

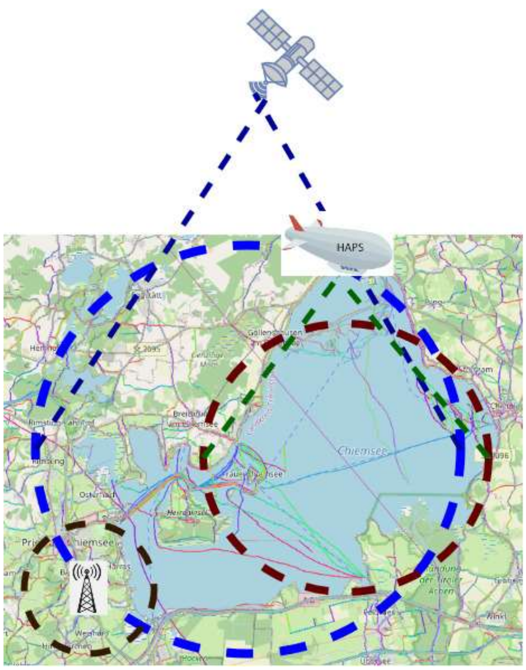

Figure 5: Visual representation of the coverage enhancement scenario.

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.

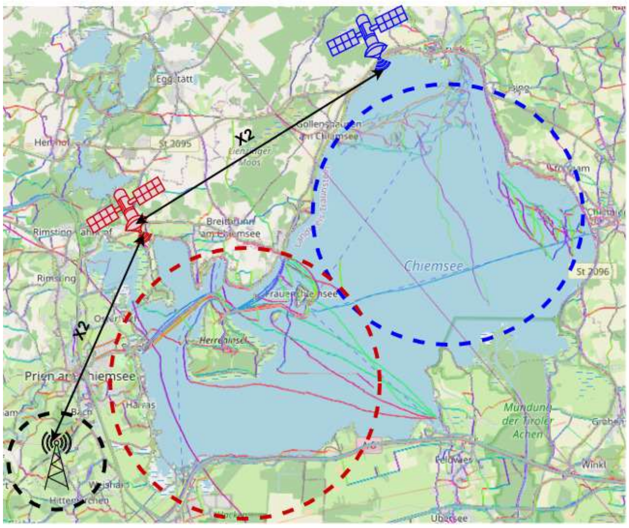

Figure 6 Visual representation of the co-existence scenario

4 Scenario Specifications

The simulator needs to be initialized using a set of parameters to run and evaluate a specific network scenario. Section 4 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	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	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.

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.

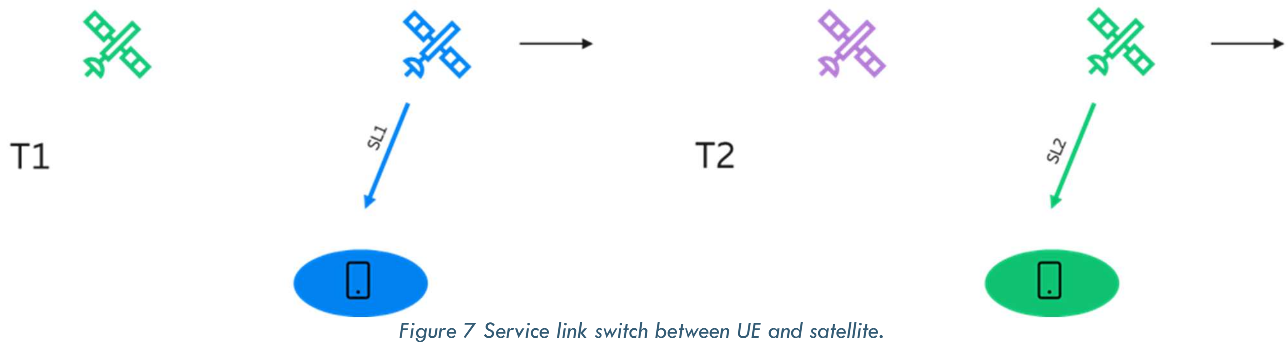

Figure 7 Service link switch between UE and satellite.

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.

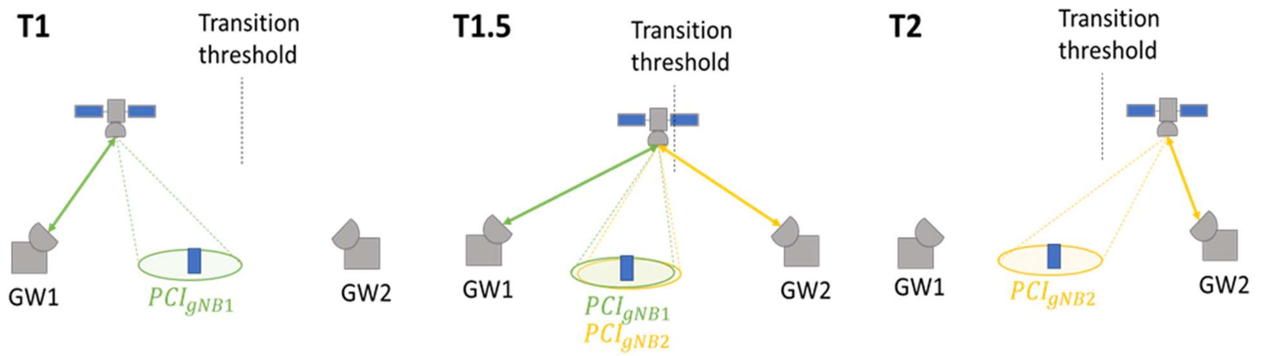

Figure 8 Soft Feeder link switch for transparent payload.

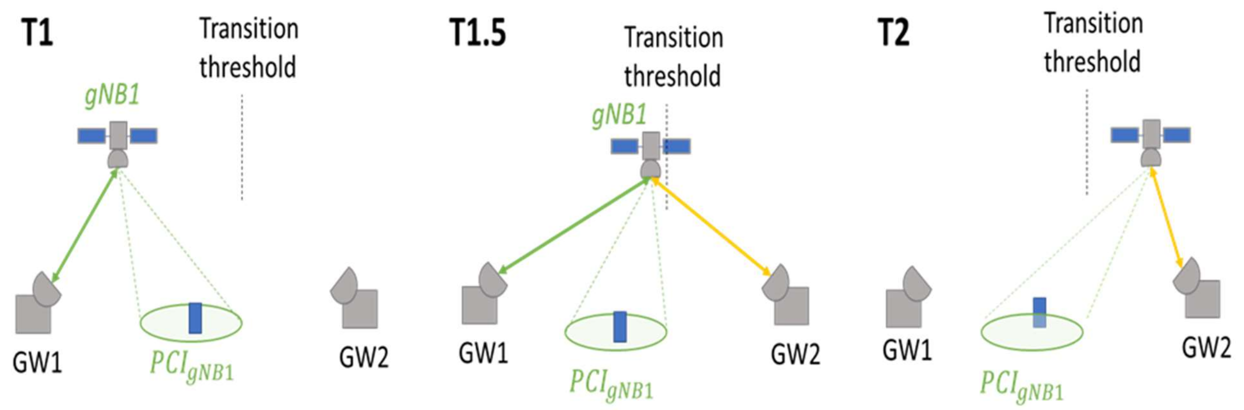

Figure 9 Soft Feeder link switch for regenerative payload.

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.

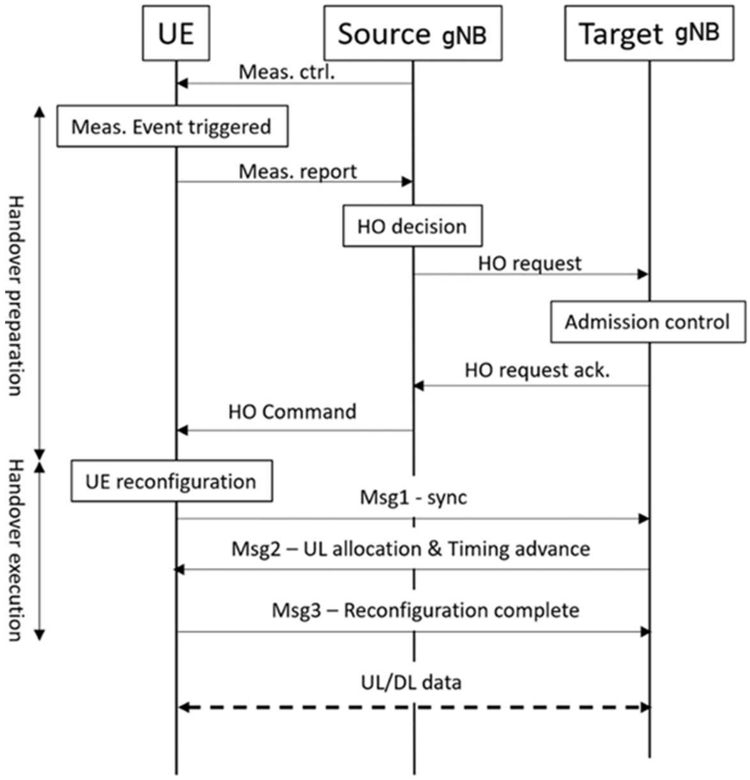

Figure 10 Conventional UE assisted network Handover.

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].

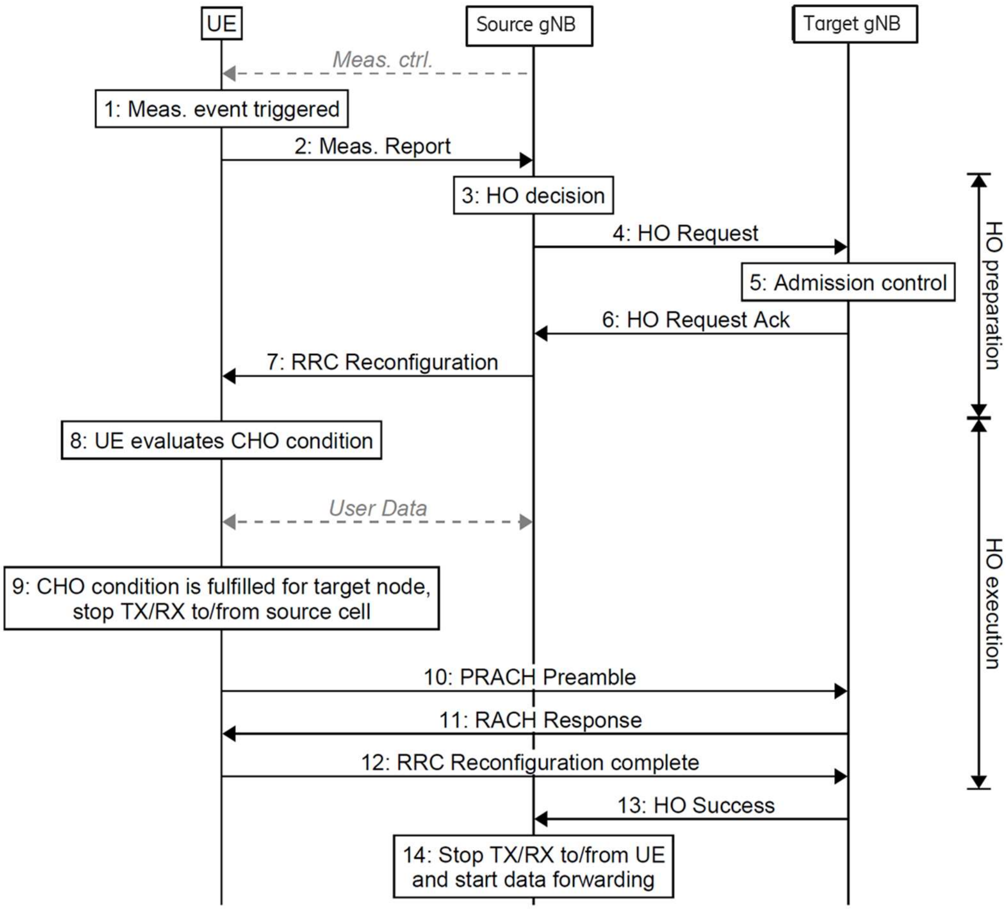

Figure 11 Conditional Handover (CHO) procedure.

7 Results and Analysis (To be updated for the final report D 4.3)

Fraunhofer will update this section with the results and findings from the evaluations of the described scenarios.
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.

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 feedbacks 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 an initial report summarizing the overall architecture of the SLS, current 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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