Integrated Handover Simulation Framework for Non-Terrestrial Network

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***Abstract*—The importance of satellite-based Non-Terrestrial Networks (NTNs) is increasing to ensure connectivity in areas where terrestrial networks alone cannot provide service. In particular, handover technology for seamless service in NTN environments is critical, but real-world testing incurs significant cost and time. To address this, this paper presents an integrated simulator, combining NS-3 and Cesium ion, based on 3GPP Release 18 (Rel. 18) and beyond, for simulating and evaluating NTN handover performance. The simulator enables realistic handover scenario implementation and quantitative analysis, contributing to future research and development of 5G-Advanced NTN handover technologies.**

Keywords—5G NR, Non Terrestrial Network, Handover, Simulation

I. INTRODUCTION

As 5G mobile communication technology continues to evolve, there is a growing demand for reliable connectivity in areas where terrestrial networks alone are insufficient, such as maritime regions, remote areas, and disaster-stricken zones. Against this backdrop, satellite-based Non-Terrestrial Networks (NTNs) are emerging as a key technology to complement the limitations of terrestrial infrastructure and to enable global connectivity. In the NTN environment, seamless handover between satellites, or between a satellite and a terrestrial base station (gNB), is critical for ensuring uninterrupted service. The performance of such handover mechanisms has a direct impact on the overall quality of service [1].

Considering the complexity of NTN environments and the unpredictable mobility characteristics of satellites, conducting tests in real-world settings entails substantial costs and time. Therefore, the development of a sophisticated simulator is essential for efficient and accurate analysis of handover performance[2]. In this paper, we present an integrated simulation platform capable of modeling and evaluating NTN handover procedures based on 3GPP Release 18 (Rel. 18) and beyond. The proposed simulator combines the network simulation capabilities of NS-3 with the 3D visualization features of Cesium, enabling realistic emulation of handover scenarios and quantitative performance analysis under various RF/PHY dynamics. This simulation framework is expected to support ongoing research and development of NTN handover technologies in alignment with the evolution of 5G Advanced standards.

The remainder of this paper is organized as follows. Section II describes the integration process of satellite and terrestrial networks, along with a review of existing research on 5G network simulators. Section III provides a detailed explanation of the developed NTN handover simulator based on the integrated NS-3 and Cesium environment, highlighting the integration efforts among key simulation components and presenting preliminary performance results obtained from comparative scenario analyses. Finally, Section IV concludes the paper and outlines directions for future work.

II. RELATED WORKS

The challenges, opportunities, key characteristics, architecture, and standardization of 5G NTN have been extensively discussed in numerous studies [3]–[6]. In an effort to address these challenges, several research initiatives have focused on developing 5G communication and network simulators with diverse functionalities. For instance, the Korea Institute of Science and Technology (KIST) developed the “5G KSimulator,” which is designed to operate within a cloud computing environment [7]. However, as of the time of writing, the source code has not been made publicly available, thereby limiting further evaluation. The University of Pisa developed a 5G extension for the Simu5G OMNeT++ simulator, which represents an evolution of the SimuLTE (4G LTE) network simulator by incorporating 5G NR (New Radio) access capabilities [8]. The core idea behind Simu5G is to provide researchers with an easy-to-use framework for simulating and benchmarking their own solutions. Leveraging the modularity concept of OMNeT++(a C++ simulation library and framework widely used for building network simulators)Simu5G offers high extensibility. However, a commercial license is required for commercial use. In addition, the Polytechnic University of Bari proposed a tool called “5G-air-simulator” [9]. This open-source, event-driven simulator models key elements of the 5G air interface at the system level. It enables flexible configuration, arrangement, and extension of functionalities for modeling new scenarios and technological components. However, it is primarily focused on air interface technologies.

Finally, one of the most widely used open-source platforms for 5G/6G wireless communication research is Open Air Interface (OAI). OAI provides full access to both the RAN (gNB) and Core (5GC) stacks, allowing frequent updates and contributions from a broad user community. It supports both software-based simulation and deployment on real hardware testbeds. However, since OAI is primarily designed for terrestrial networks, features specific to NTN environments are not natively supported and must be implemented by developers or users themselves.

III. 5G SATELLITE-TERRESTRIAL HANDOVER SIMULATOR

This section presents a simulation framework that integrates the NS-3-based 5G-LENA module, which supports gNB and core network functionalities, with the SNS3 module, which incorporates satellite-specific RF/PHY characteristics, and the Cesium ion visualization tool.

A. Architecture of the TN/NTN Handover Simulation Framework

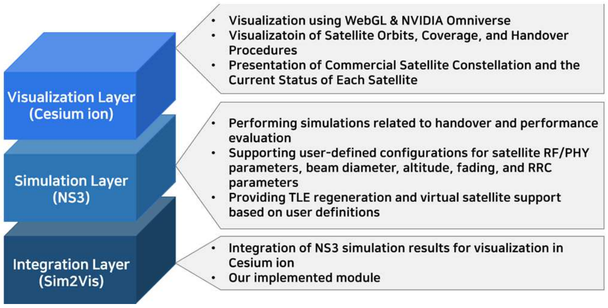

Figure 1. Layered architecture of the TN/NTN Handover Simulation Framework

The TN/NTN handover framework is structured into three layers, as illustrated in Figure 1. The roles of each layer are described as follows:

- **Visualization Layer(Cesium ion) :** This layer provides 3D visualization of satellite orbits, coverage areas, and handover procedures. It also provides SIB19, based on 3GPP Release 18, which delivers the necessary information for user equipment to access satellite networks, and presents the simulation results over a 24-hour period starting from the requested simulation time.
- **Simulation Layer(NS-3) :** This layer implements the gNB and core network using the 5G-LENA module and models LEO satellites using the SNS3 module. Since these two modules do not support native integration, additional development is required to enable interaction between them.
- **Integration Layer(Sim2vis) :** This layer processes the simulation results from the NS-3 environment into a format compatible with the visualization layer. The raw outputs from NS-3 are simple text-based logs and cannot be directly visualized. Therefore, they must be converted into a data structure suitable for rendering within Cesium ion.

B. Visualization Layer

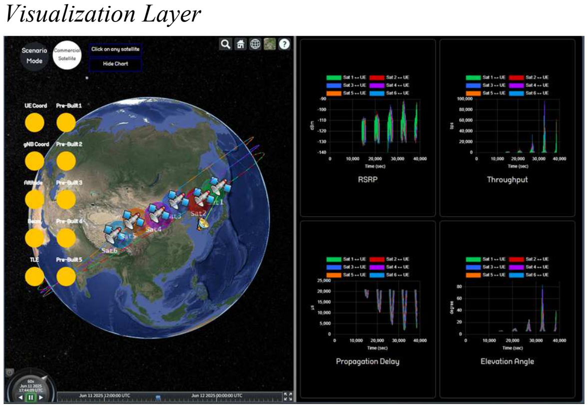

Figure 2. Scenario Mode

The visualization layer provides two main functionalities. First, it offers a user-defined interface that allows input of various satellite parameters. Second, it visualizes the data generated by the integration layer.

Two modes are available within the user-defined interface. The first is the **Scenario Mode**, which allows detailed simulation of a specific satellite. The second is the **Commercial Mode**, which simulates constellations of commercial satellites. Users can select several satellites in Commercial Mode and then operate them in Scenario Mode for more detailed simulations. In Scenario Mode, users can input and override Two-Line Elements (TLE), configure beam coverage, adjust altitude, and modify the positions of UEs or gNBs to conduct comprehensive analyses.

C. Simulation Layer

The simulation layer consists of three main functions, whose integration is essential for producing the results.

- **Satellite Mobility Model :** This model extracts satellite orbits from the input Two-Line Elements (TLE) and computes parameters such as velocity and altitude.
- **Fading Model:** It simulates variations in signal quality that occur in NTN environments. In environments where both line-of-sight(LOS) and non line-of-sight(NLOS) coexist due to the presence of buildings, mountains, and terrain, signal quality variations are induced and must be accounted for in satellite-to-ground communication systems.
- **Handover Model:** Providing both TN/NTN location-based and signal-based handover functionalities, this model operates in conjunction with the Satellite Mobility and Fading models to generate simulation results.

The satellite mobility model takes TLE, start_time, stop_time, and delta_time as inputs. The start_time corresponds to the user-requested simulation start point, while the stop_time is set to 24 hours after the start_time. The delta_time defines the time interval for position computation, with a default value of 100 ms. These input parameters are processed using the Simplified General Perturbations Model 4 (SGP4), which outputs the satellite's position in the Earth-Centered Earth-Fixed (ECEF) coordinate system, as well as its velocity components along the x, y, and z axes.

The fading model utilizes Rician fading to simulate the channel conditions in environments featuring both line-of-sight and multipath signal components.

$$\textit{K-factor} = \frac{P_{LOS}}{P_{NLOS}} \tag{1}$$

P_{LOS} denotes the average power of the Line of Sight (LOS) component, while P_{NLOS} represents the average power of the Non-Line of Sight (NLOS) multipath components. The Rician K-factor is proportional to P_{LOS} ; thus, a stronger LOS component results in a higher K-factor. As K-factor increases, the signal-to-noise ratio (SNR) improves, leading to enhanced transmission performance.

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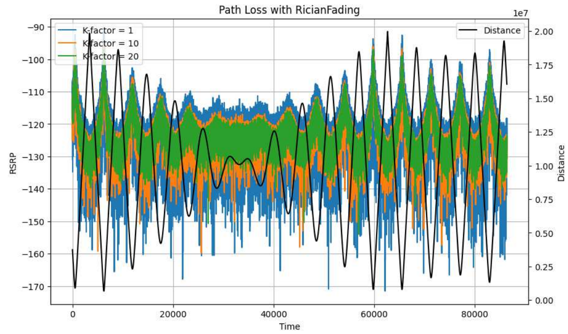

Figure 3. The variation in signal strength depending on the K-factor

Figure 3 illustrates the variation in signal strength between the UE and the satellite as a function of the K-factor. The distance between the UE and the satellite is represented by the black line. As the distance decreases, the signal strength increases. Furthermore, higher K-factor values correspond to smaller fluctuations in signal strength, indicating more stable signal conditions.

This paper focuses on the location-based handover model. A critical dataset for location-based handover is the satellite's position and velocity information, known as ephemeris, which can be obtained via System Information Block 19 (SIB19) as defined in 3GPP Release 18. However, handover cannot be performed solely based on ephemeris data. Since terrestrial UEs must remain within the beam coverage to maintain service via the satellite, it is necessary to account for the movement of the beam coverage in addition to the satellite ephemeris. The movement of the beam coverage can be predicted by computing the satellite's mobility using ephemeris data along with the beam's central coordinate, referred to as the "ReferenceLocation". The "ReferenceLocation" is provided within the RRC Reconfiguration message during the RRC procedure.

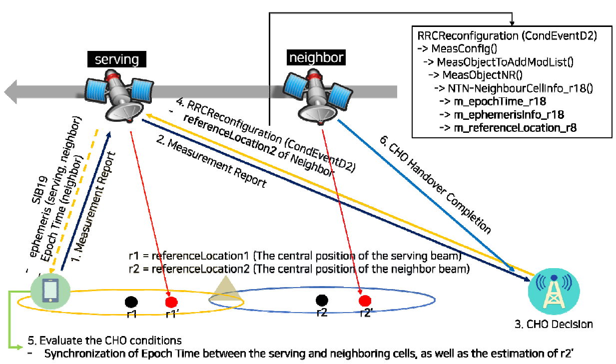

Figure 4. Location-based Handover Procedure

Figure 4 illustrates the timing and sequence of transmission and reception of the ReferenceLocation and ephemeris during location-based handover.

D. Integration Layer

The data derived from the simulation layer include key performance indicators relevant to handover, such as RSRP, throughput, propagation delay, and elevation angle. Additionally, based on the RRC messages designed according to with the 3GPP Release 18 specification, the handover procedure and timing are derived, while satellite orbit information and velocity components along the x, y, and z axes are obtained through SIB19. Since these outputs are in text format, the integration layer is responsible for synchronizing the data with the visualization tool's timeline and converting them into a format suitable for visualization. Furthermore, for orbit representation, the Lagrange interpolation algorithm is employed to achieve smooth trajectory rendering.

IV. Conclusion and Future Work

This paper emphasizes the critical importance of handover technology in Non-Terrestrial Network (NTN) environments, which serve as a key solution to overcome the limitations of terrestrial networks and provide global connectivity with seamless service continuity. We developed an integrated simulation platform by combining the NS-3-based 5G-LENA and SNS3 modules with the 3D visualization tool Cesium ion. Based on the 3GPP Release 18 (Rel. 18) standard, the platform successfully models NTN handover procedures and enables quantitative performance evaluation. The simulator can emulate realistic handover scenarios reflecting various RF/PHY dynamic changes in complex NTN environments, providing a valuable foundation for future research and development of NTN handover technologies in line with the evolution of 5G-Advanced standards.

Acknowledgment

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