White Paper

Deployments of O-RAN-based Non-Terrestrial Networks

White Paper: February 2025

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Executive summary

This Whitepaper provides an overview of the integration of Open Radio Access Network ALLIANCE's (O-RAN) network architecture and a 3GPP Non-Terrestrial Network (NTN), detailing their significance, current status, future challenges, and security considerations.

Integration Overview

The O-RAN ALLIANCE has developed an architecture to enhance 5G and 4G LTE- networks through openness and intelligence, leveraging RAN Intelligent Controllers (RICs) for optimized operations. NTNs, utilizing various satellite systems, provide connectivity in remote areas. Advances in technology have enabled direct user equipment access via satellites, leading to transparent and regenerative payload architectures [3GPP_NTN overview]. Ongoing 3GPP standardization efforts aim to introduce new capabilities and integrate NTNs into 6G networks, addressing challenges such as propagation delays and specialized interfaces [3GPP_TS38.300].

Network Architectures and Use Cases

The O-RAN ALLIANCE architecture builds on the 3GPP-defined disaggregated RAN, adding functionalities for openness, intelligence, and flexibility. Key components include O-CU-CP, O-CU-UP, O-DU, O-RU, Service Management and Orchestration (SMO), and RAN Intelligent Controllers (RICs) [O-RAN_Website]. The 3GPP NTN architecture supports various satellite platforms, with transparent and regenerative payloads for different applications [3GPP_NTN overview]. Integrating O-RAN network functions into an NTN allows for innovative use cases, focusing on sustainability and efficiency, such as enhancing RIC analytics with satellite data, optimizing beam management, and using AI for NTN handovers. O-RAN ALLIANCE is currently studying RAN Intelligent Controllers (RIC) enabled NTN deployment for transparent (Non-regenerative NTN). The Study of regenerative NTN deployment and support in O-RAN ALLIANCE is proposed but has not started at the time of publishing of this Whitepaper.

Architecture/Topology Options for an O-RAN-ALLIANCE-based NTN

The standardization of LTE/5G NTN has progressed through multiple 3GPP releases, with ongoing enhancements for regenerative NTN deployments. The current ongoing study of Transparent NTN use cases will require architectures cooperation between mobile network operators (MNOs) and satellite network operators (SNOs), integrating low-cost NTN functions with the existing network infrastructure. Regenerative NTN deployments address complexity, power consumption, and latency challenges through various O-RAN functional split topologies. A Low Earth Orbit (LEO) satellite-based NTN offers high-bandwidth, low-latency transport connectivity, and serving as primary or backup solutions for remote or disaster-affected areas. The O-RAN ALLIANCE Open Xhaul Transport Working Group 9 will be focusing on defining technical requirements and integration strategies for NTN-based Xhaul transport.

Security Considerations

Integrating NTNs with O-RAN ALLIANCE introduces unique security challenges, including data integrity attacks, unauthorized access, eavesdropping, jamming, kinetic threats, DoS attacks, and spoofing. Hybrid networks face additional challenges with frequent handovers and authentication during roaming. To address these threats, O-RAN ALLIANCE WG11 has defined security requirements and controls, focusing on access control, data protection, continuous monitoring, physical security, interference protection, regulatory compliance, and supply chain security. WG11 will continue to evolve the O-RAN ALLIANCE security posture and will address the security risks, requirements, and controls for NTN.

Conclusion

While the deployment of NTNs presents several challenges such as limitations in processing power, power consumption, propagation latencies, and end-to-end Quality of Service (QoS) optimization across multiple orbits and planes, these can be effectively mitigated. By selecting the appropriate function distributions for specific constellations, deployments, and target services, integrating the NTN architecture with the O-RAN ALLIANCE Intelligent Management and Orchestration (SMO) platform, and leveraging advanced RICs and SMO capabilities, these challenges are being studied in WG1 UCTG. This strategic approach ensures that the integration of NTN and O-RAN ALLIANCE architecture not only enhances network performance but also supports the seamless delivery of advanced services.

Abbreviations

5GC	5G Core
CBRS	Citizens' Broadcast Radio Spectrum
DDoS	Distributed Denial of Service
DoS	Denial of Service
GEO	Geostationary Earth Orbit
HAPS	High Altitude Platform Systems
HEO	High Elliptical Order
HMTC	High-Performance Machine-Type Communications
IHL	Inter-HAPs-Links
LEO	Low Earth Orbit
LDPC	Low Density Parity Check
MBS	Multicast and Broadcast Services
MAC	Medium Access Control
MEO	Medium Earth Orbit
MSP	Mobile Service Provider
NGSO	Non-Geostationary Orbit
NTN	Non-Terrestrial Network
NTN-G	NTN Gateway
O-Cloud	O-RAN Cloud
O-CU	O-RAN Central Unit
O-CU-CP	O-RAN Central Unit – Control Plane
O-CU-UP	O-RAN Central Unit – User Plane
O-DU	O-RAN Distributed Unit
O-RU	O-RAN Radio Unit
PDCP	Packet Data Convergence Protocol
RAN	Radio Access Network
RIC	RAN Intelligent Controller
RLC	Radio Link Protocol
RRC	Radio Resource Control
SAI	Satellite Analytics Information
SNO	Satellite Network Operator
SDAP	Service Data Adaptation Protocol

SMO	Service Management and Orchestration
TN	Terrestrial Network
UE	User Equipment

Acknowledgements

Special thanks must be given to the people contributing to the White Paper, including:

Leader/Editor: Nader Zein (NEC), Co-Leader Nishith Tripathi (Virginia Tech)

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Major reviewers: Marko Babovic (NEC)

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1 O-RAN and NTN: An Overview

1.1 O-RAN: A Concise Introduction

The O-RAN ALLIANCE [O-RAN_Website] has defined an Open Radio Access Network (O-RAN) architecture to realize a 5G or 4G LTE Radio Access Network [O-RAN_OAD]. O-RAN is characterized by openness and intelligence. Openness refers to the existence of open interfaces among multiple network nodes. As summarized in Section 2, O-RAN has increased degree of disaggregation compared to the 3GPP-defined 5G RAN architecture. Hence, there are more network nodes and interfaces in the O-RAN architecture compared to a non-O-RAN implementation of a RAN. O-RAN enables use of intelligence to enhance RAN operations by introducing RAN Intelligent Controllers (RICs).

The O-RAN ALLIANCE focuses its activities in the three work streams: O-RAN specifications, testing and integration, and O-RAN Software Community (OSC). O-RAN specifications define interactions among O-RAN entities. Testing and integration efforts facilitate testing of compliance of O-RAN nodes to O-RAN specifications. Testing and integration efforts also include PlugFests, where interoperability of products from different vendors is verified. The OSC releases O-RAN software that reflects the work done by work groups on O-RAN specifications such as Near-Real-Time RIC software. The OSC typically releases software every six months

1.2 Status of the NTN

NTN types

Satellite communication systems is a sustainable solution for providing connectivity to remote or rural areas unserved or under-served by terrestrial communications systems. The Satellite communications coverage is already global, composed of geostationary orbit GEO satellites, medium Earth orbit (MEO), Low Earth Orbit (LEO), and Highly Elliptical Orbiting (HEO) constellations. On top of the satellite systems, under the umbrella of non-terrestrial networks, High Altitude Platform Systems (HAPS) have been added to provide non terrestrial but local service coverage [3GPP_TR38.821].

GEO satellites match the rotation of the Earth as they travel, at an altitude of 35,786 km, in a position fixed relative to a point on the ground. Their height means that data transmitted to and from the satellite have a relatively high latency, with an average round-trip latency of around 500 ms. Having a large beam footprint means that only few satellites are needed to span the entire globe. Hundreds of GEO satellites are in orbit today, delivering services such as weather data, broadcast TV, and some low-speed data communication

MEO satellites are found at altitudes between LEO and GEO satellites historically been used for GPS and other navigation applications. MEO lower height means that more satellites are needed to have a global footprint, with anywhere from 5 to 30 satellites required depending on their altitude

LEO satellites are an emerging category of satellite that promises to deliver very low latency service to users, comparable to that of terrestrial networks. Operating at altitudes between 300 to 1500 km above ground, LEO satellites can have a round-trip latency as low as 20 ms. LEO satellites having significant lower beam footprint with a range between 50 to 500km.

Table 1 below summarizes the characteristics of each NTN platform [3GPP_TR38.821]

Platforms	Altitude range	Orbit	Typical beam footprint size (diameter)
Very Low Earth Orbit (VLEO) satellite	100 – 300 km	Circular around the earth	50 – 200 km

Low-Earth Orbit (LEO) satellite	300 – 1500 km		50 – 500 km
Medium-Earth Orbit (MEO) satellite	7000 – 25000 km		100 – 1000 km
Geostationary Earth Orbit (GEO) satellite	35,786 km	notional station keeping position fixed in terms of elevation/azimuth with respect to a given earth point	200 – 3500 km
UAS platform (including HAPS)	8 – 50 km (20 km for HAPS)		5 - 200 km
High Elliptical Orbit (HEO) satellite	400 – 50000 km	Elliptical around the earth	200 – 3500 km

Table 1: NTN platforms 3GPP [3GPP_NTN_Platforms]

3GPP and Non-3GPP NTNs: deployment options

The use of satellites within the mobile network ecosystem was historically for providing backhaul connectivity. Recent advancements in waveforms, allowed the direct UE access, NR over satellite, and led 3GPP to identify two architectures based on the satellite payload type (i.e., , transparent and regenerative) which are illustrated in **Figure 1** below [3GPP_NTN overview].

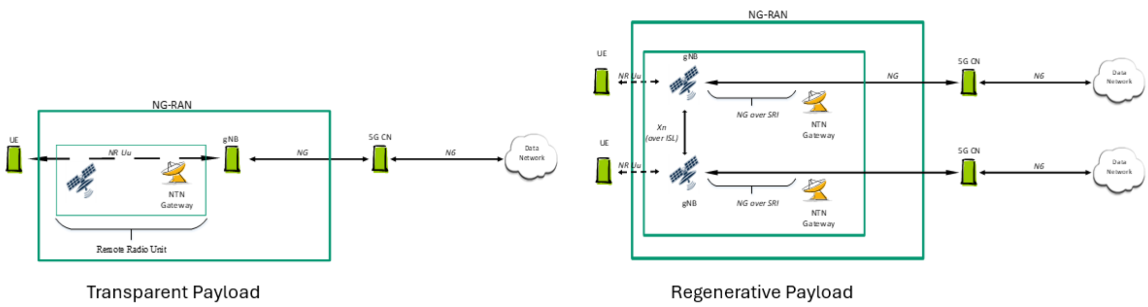

Figure 1: NTN architectures

In case of a transparent payload, the satellite provides connectivity between the users and the ground gNB. The satellite payload acts as an analogue RF repeater, repeats the NR-Uu radio interface, between the NTN gateway and the satellite (feeder link) and between the satellite and the UE (service link or access link).

On the other hand, in case of a regenerative payload, the signals received from Earth being regenerated on the satellite payload. In that scenario NR-Uu radio interface is on the service link while NG interface transports on the feeder link on the Satellite Radio Interface (SRI). In addition, regenerative payload, allows intersatellite link ISL communications, which is a key enabler for mobility procedures in case of a constellation of satellites. Within 3GPP Release 19, there are different scenarios currently under consideration, such as a gNB on the satellite, split gNB (DU and RU on the satellite and CU on ground), with or without ISL as well as the UPF on board.

Key NTN features from Release 17 to Release 19

The ongoing 3GPP standardization efforts for NTN will continue into Release 19 and subsequent releases. These proposals will aim to provide new capabilities and leverage regenerative satellites for enhanced features and topologies. Mobility enhancements, enhancements for F1 interface in case of DU on-board, NG interface enhancements, gNB with UPF on-satellite for mobility and Multicast and Broadcast Services (MBS) support are among the topics discussed in recent 3GPP meetings. [3GPP RAN plenary meeting (RAN#102, December, Edinburgh)]. **Figure 2** shows the historical timeline and topics from Release 17 to current and future releases.

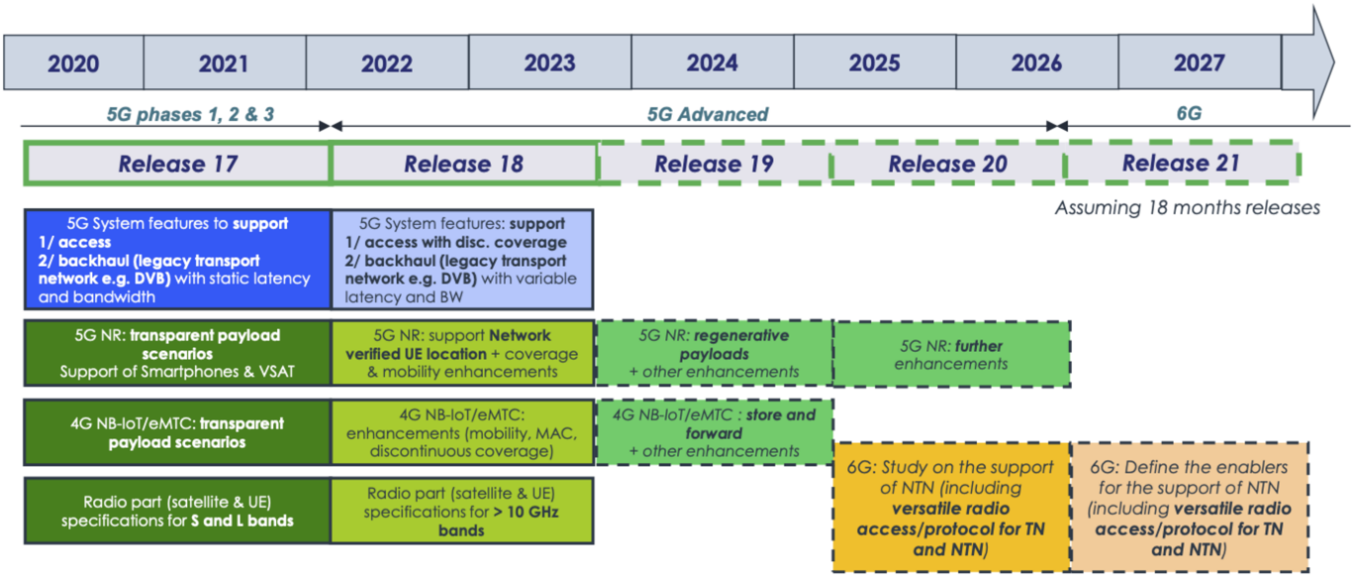

Figure 2: 3GPP Standardization Roadmap

Role of the NTN in 6G

6G is expected to seamlessly integrate multiple access types, Terrestrial Network (TN) and NTN, into a unified architecture. The vision for 6G involves NTN as a key enabler for extended coverage, security, and resilience. In addition, Positioning, Navigation and Timing (PNT) will be key challenges as well as in integrated management of unified networks and earth sensing services (Integrated Sensing and Communications - ISAC).

Within 3GPP, 6G standards, on which work will commence in 2025 (Rel. 20), are expected for a potential rollout in 2030. 3GPP RAN groups have started discussions on potential architectures and other aspects, towards 6G.

1.3 NTN Challenges Addressable by O-RAN

Some NTN challenges may be addressed by O-RAN ALLIANCE through architecture adaptations.

Several characteristics of the NTN are quite different from those of the Terrestrial Network (TN), creating the opportunity for O-RAN based implementation of the NTN as shown in Figure 3.

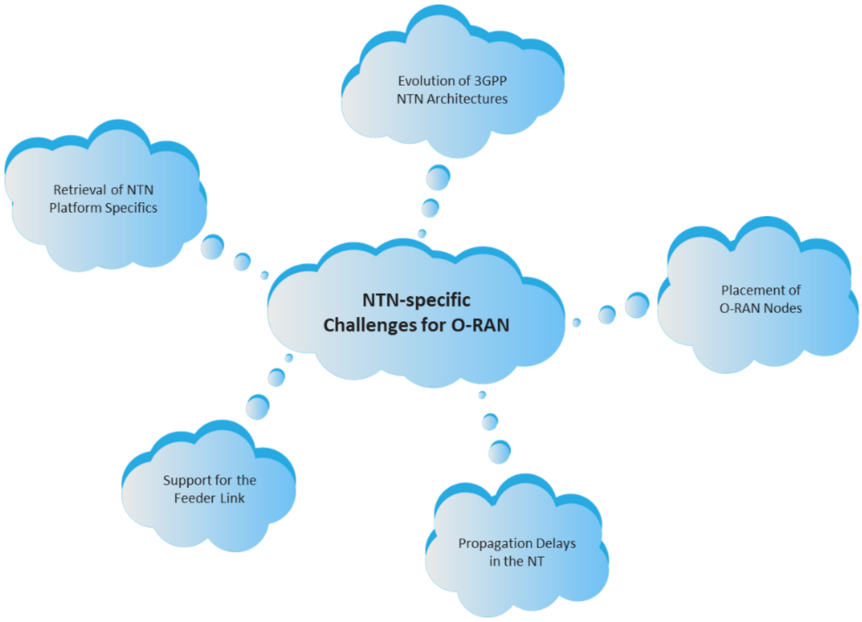

Figure 3: NTN Challenges Addressable by O-RAN

O-RAN ALLAINCE utilizes the 3GPP-defined NG-RAN as a baseline and adds O-RAN ALLIANCE specific functionalities. However, such need for the baseline creates a unique challenge to O-RAN for the NTN. The 3GPP initially defined a transparent payload architecture in Release 17 but is now considering a regenerative payload in Release 19. Hence, O-RAN- based NTN would need to reflect multiple types of payloads envisioned by the 3GPP. Furthermore, while one type of regenerative payload places the entire gNB on the NTN platform, another type of regenerative payload may place the gNB-DU on the NTN platform in a future 3GPP Release.

Placement of O-RAN nodes on the ground or the NTN platform needs to be determined carefully. In particular, timings of control loops for the Near-RT RIC and Non- RT-RIC should be compared against the expected delays in a given type of NTN architecture deployment.

The NTN often has long propagation delays and variable propagation delays depending on the type of the NTN platform and the type of the beams (e.g., Earth-fixed beams, quasi-Earth-fixed beams, and Earth-moving beams). These delay characteristics challenge may be addressed by O-RAN adaptation.

The feeder link interface between the NTN platform and the NTN-GW is beyond the scope of the 3GPP specifications. Furthermore, the interface between the NTN Control Function and the gNB is beyond the scope of 3GPP specifications. Hence, O-RAN would need to accommodate such NTN-specific interfaces. Additionally, depending on the type of the NTN architecture (i.e., transparent vs regenerative), certain information would need to pass through the feeder link for the use of the SMO and the RICs. Suitable provisioning of feeder link resources would be needed to ensure timely availability of relevant information.

Depending upon the NTN- specific optimizations, O-RAN would need to obtain NTN related information such as the satellite parameters and satellite coverage areas. Hence, suitable interfaces would be needed by the SMO and the RICs to obtain such NTN-specific information.

Organization of the paper

The rest of the white paper is organized as follows. Section 2 illustrates the Network Architectures of O-RAN defined by the O-RAN ALLIANCE and the NTN architecture defined by the 3GPP. Section 3 describes potential use cases where O-RAN can provide unique benefits for the NTN by exploiting intelligence, efficiency, and flexibility offered by O-RAN. The design impact of the NTN on O-RAN is discussed in Section 4. Security implications of an O-RAN based NTN are summarized in Section 5.

2 Network Architectures of O-RAN and NTN

2.1 O-RAN Architecture

Figure 4 illustrates the O-RAN architecture as defined by the O-RAN ALLIANCE [O-RAN_OAD].

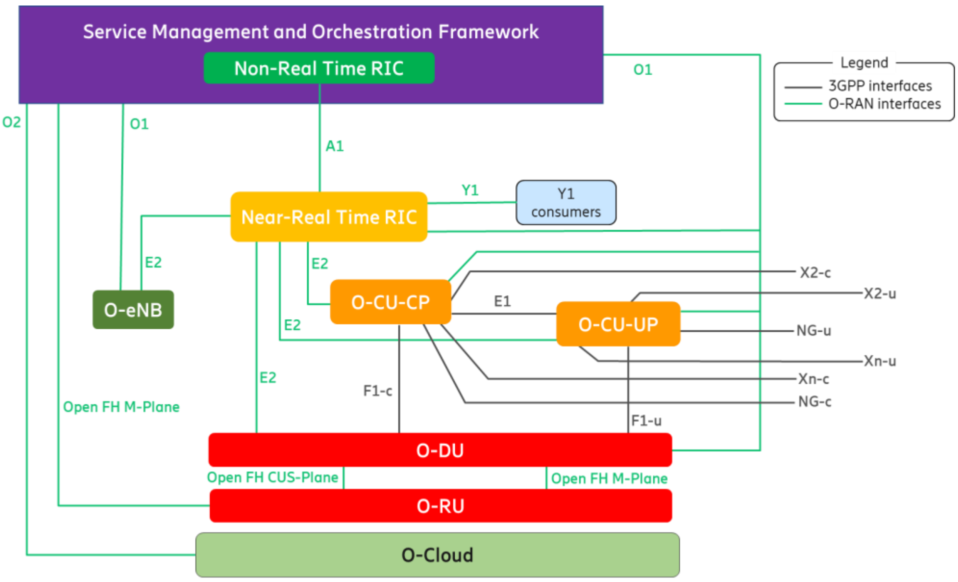

Figure 4: O-RAN Architecture

Source: O-RAN ALLIANCE (Reproduced with permission)

O-RAN utilizes 3GPP-defined disaggregated RAN architecture as baseline and adds new functionalities to further disaggregate the RAN architecture and add features such as openness, intelligence, and flexibility and support for new O-RAN defined interfaces. The O-RAN Central Unit Control Plane (O-CU-CP) implements the 3GPP-defined New Radio (NR) air interface protocols such as RRC and PDCP.[The O-RAN Central Unit User Plane (O-CU-UP) performs 3GPP gNB-CU-UP functions and hence implements the 3GPP-defined NR air interface protocols such as Service Data Adaptation Protocol (SDAP) and PDCP. The 3GPP gNB-DU functions are distributed in O-RAN between O-RAN Distributed Unit) O-DU) and O-RAN Radio Unit (O-RU). Specifically, the O-DU implements the 3GPP gNB-DU's Radio Link Protocol (RLC), Medium Access Control (MAC), and upper PHY layer, while the O-RU implements the 3GPP gNB DU's lower PHY layer. The NR PHY layer is split between the O-DU and the O-RU with the functions such as channel coding (e.g., Low Density Parity Check or LDPC coding) and digital modulation implemented at the O-DU and the functions such as the Inverse Fast Fourier Transform (IFFT) and RF functions (e.g., filtering and power amplification) implemented at the O-RU. The Open Fronthaul interface between the O-DU and the O-RU supports so-called functional split 7.2x that defines the distribution of the PHY later functions between the O-DU and the O-RU. Precoding may be implemented in the O-DU or the O-RU.

O-RAN facilitates AI/ML-based RAN optimization through RAN Intelligent Controllers (RICs). The Near-Real-Time RIC (Near-RT RIC) operates at the time scale of 10ms to 1s, and Non-Real-Time RIC (Non-RT RIC) operates at the time scale greater than 1 s. The Non-RT RIC resides in the Service Management and Orchestration (SMO). The Near-RT RIC facilitates intelligent RAN optimization through applications called xApps, while the Non-RT RIC facilitates intelligent RAN optimization through applications called rApps. The Non-RT RIC provides A1 policy to the Near-RT RIC to influence RAN optimization. The Near-RT RIC can obtain information about the RAN using the E2 interface and send commands to the O-RAN nodes (often referred to as E2 nodes) such as the O-CU-CP, the O-CU-UP, and the O-DU to influence target RAN operations. A suitable E2 Service Model (E2SM) is used for the interaction between the Near-RT RIC and an O-RAN node. The SMO manages the O-RAN Cloud (O-Cloud), which is the cloud infrastructure that can house various O-RAN nodes.

2.2 3GPP NTN Architectures

Figure 5 illustrates an example implementation of a Non-Terrestrial Network for transparent NTN payload [3GPP_TS38.300].

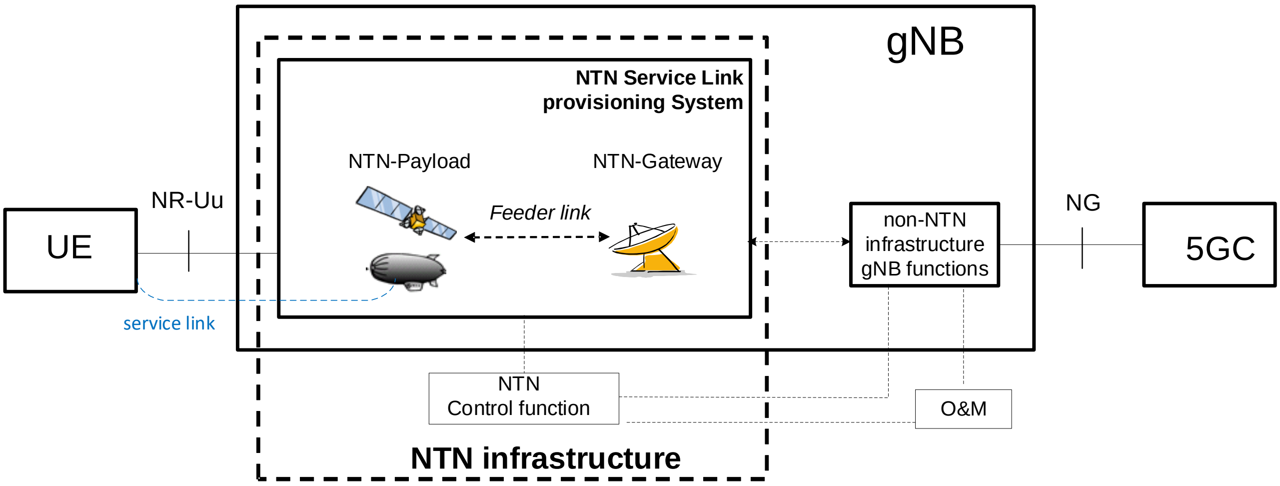

Figure 5: 3GPP NTN Based NG RAN implementation example

The NTN gNB communicates with the NTN UE using the NR air interface via the NTN-Gateway (NTN-GW) and the NTN payload. The NTN platform houses the NTN payload that supports radio communications. Examples of an NTN platform include a Geosynchronous Earth Orbit (GEO) satellite, Medium Earth Orbit (MEO) satellite, a Low Earth Orbit (LEO) satellite, and a High-Altitude Platform Station (HAPS). A GEO satellite-based NTN experiences very long delays (hundreds of milliseconds), while a LEO satellite-based NTN experiences variable but smaller propagation delays (e.g., tens of ms) and large and varying Doppler shifts. A HAPS resides in the stratosphere and maintains its position relative to a given point on the Erath's surface like a GEO satellite. The HAPS-based NTN has the least propagation delay.

The link between the UE and the NTN payload is called the access link or the service link, and the link between the NTN-GW and the NTN payload is called the feeder link. The 3GPP specifications focus on the access link; the feeder link is implementation specific. In the transparent payload architecture, the gNB resides on the Earth's surface and the NTN payload acts as a relay/repeater by performing functions such as the power amplification and (potentially) frequency translation. The 3GPP Release 17 and 18 support the transparent payload NTN architecture shown in Figure 2-2. At the time of this writing, the 3GPP is considering a regenerative payload, where certain gNB functionality resides on the NTN payload.

The 3GPP has defined NR-NTN and IoT-NTN. NR-NTN utilizers high-performance NR air interface and hence is suitable for high data rate applications. IoT-NTN supports LTE-M and NB-IoT air interfaces[1] and hence suitable for delay-tolerant and low data rate IoT applications.

3 Toward Intelligent, Efficient, and Flexible NTN: O-RAN's NTN Use Cases

Moving the network functions into space allows different implementation approaches for the existing O-RAN ALLIANCE architecture use cases but also gives the opportunity to O-RAN ALLIANCE community to propose new use cases. Moreover, the

1 LTE-M is Long Term Evolution- Machine Type Communication. NB-IoT is Narrowband- Internet of Things.

inclusion of the satellite elements requires further enhancements to existing O-RAN interfaces. The new use cases should primarily focus on the sustainability of the NTN networks. Reduced energy consumption by both satellites and the User Equipment (UE) as well as reducing the signalling overhead in the resource constrained satellite environment are key enablers. It is also without doubt that the unified TN/NTN deployments in the transparent or regenerative mode require the intelligent interaction between MNO and SNOs.

O-RAN ALLIANCE's new use cases for supporting NTN explore the various deployment topologies with various functional split and their corresponding requirements and benefits. In addition, below are few examples of potential use cases that demonstrate the O-RAN necessity in this unified TN/NTN ecosystem.

3.1 Enhancing RIC analytics with Satellite Data

In scenic rural areas, terrestrial towers are typically limited to tourist hotspots due to economic, environmental, and infrastructure constraints. User density fluctuates seasonally and is unpredictable. When demand surpasses terrestrial network capacity, offloading to the NTN network is beneficial. TNs need to be aware of the real time status and live location of the NTN segments to successfully handover and provide the required service continuity. Moreover, as there are multiple satellite options available, there is the need to choose the optimal NTN cell according to their real-time capabilities. Thus, a direct interface from RIC/SMO to SNO data analytics resources is essential.

The proposed use case integrates satellite network into the O-RAN ecosystem with a new northbound interface that allows exposure of satellite analytics to authorized O-RAN SMO consumers. The satellite performance analytics include important KPIs such as satellite orbit information, satellite ephemeris, beam pattern, payload health status as well as satellite network link performance and capacity. The O-RAN SMO would utilize the satellite enrichment data over the new interface, for enhancing RIC rApps or xApps deployment to improve radio resource management, mobility management, and service continuity.

The proposed interface is an open logical interface that allows satellite data analytics to be exposed to authorized consumers. The interface should be independent of specific implementations of satellite operators' data analytics solutions. The design of the proposed interface can follow O-RAN alliance interface specifications standards with consumers being able to perform subscribe, unsubscribe for Satellite Analytics Information (SAI) notifications, but also support query of SAI. The consumer could subscribe or query directly information that identifies the entity to which the SAI is related such as RU or UE location.

The SAI data types may be:

- Satellite ephemeris
- Satellite payload health status
- Satellite cell load
- Neighbouring satellite cells state, to guarantee service continuity after satellite handover
- Satellite network telemetry (e.g., link capacity, packet delay, and packet loss)

3.2 Beam Management

LEO satellite may cover large geographic areas due to the geometry of high altitude or orbital deployment, far above the earth's surface. The LEO satellite delivers many cells over the earth surface using beams to direct the radio energy.

The distribution of UEs across this service area is highly variable. To deliver appropriate capacity, it is not necessary to service every cell in every TTI. As a result, the LEO satellite may implement a number of beams that are moved in time over target cells. The scheduling of the beams to cells is complex, as it must support the periodic demands for idle mode UEs, system information, paging and PRACH loading and capacity, and the dynamic demands to provide data throughput to the connected UE. This complexity is increased for NTN applications such as LEO satellites, where the NTN gNB is moving relative to the earth.

The efficiency of the scheduling of the beams across the cells drives improvement in NTN gNB capacity, increasing the data traffic while maintaining the complete coverage. At its simplest, a round robin scheme can be employed, simply moving the beams on a fixed pattern that covers all cells with a period that maintain SIB broadcast period However, this would mean cells with higher UE density would have the same ceiling of throughput as those with lower or zero UE density. The scheduling of beams considers factors such as connected UE location and data traffic, satellite velocity, beam patterns, and satellite loading (power/temperature). Additional information on typical UE geographical distributions and time of day data traffic patterns may be considered to aid the scheduling of idle mode resources.

Beam management links to other NTN O-RAN ALLIANCE uses cases such as "RIC based triggering for NTN HO." In this use case, beams would be scheduled to support incoming NTN HO.

3.3 RIC-based Triggering for NTN Handover

Handover is a core function in wireless networks, essential for maintaining seamless connectivity and high-quality service as users move across the cellular network. In cellular networks, handover is triggered by the base station. The base station determines whether to perform a handover based on the MR (Measurement Report) data periodically reported by the UE and the predefined handover strategy. This measurement-based handover is effective for terrestrial networks but is not suitable for NTN (Non-Terrestrial Networks). For low-Earth orbit (LEO) satellite NTN communication, the network signaling overhead and UE power consumption associated with this handover mechanism are unacceptable.

The current 3GPP TR38.821 document explores handover triggering mechanisms for NTN, suggesting various mechanisms including Measurement-based triggering, Location (UE and Satellite) triggering, Time-based triggering, Timing advance value-based triggering, and Elevation angles of source and target cells-based triggering. While these mechanisms offer advantages in different NTN deployment scenarios, they are complex to implement and manage. Conversely, based on the O-RAN architecture, integrating RIC intelligent analysis and prediction capabilities into handover triggering mechanism for NTN can effectively address this challenge.

LEO satellites NTN services follow fixed orbital paths. At any given time, the satellite's position is known/predictable, resulting in a fixed coverage area. Additionally, depending on the geographic area being covered, satellite signals may not be subject to blockage, leading to stable signal strength with only unpredictable UE movement. By leveraging UE location prediction models, we can choose appropriate algorithms and train a handover decisions AI model using terminal location, satellite topology and orbital paths, MR data, and other relevant information. Leveraging the handover decisions AI model and the xApp's control over the E2 Nodes allows for proactive RIC-based triggering. This approach reduces reliance on UE MR information, enabling larger data collection and reporting intervals which in turn minimizes network signaling overhead and terminal power consumption. Additionally, it reduces the impact of air interface latency on handover operations and simplifies handover management.

4 Architecture/Topology options for an O-RAN-based NTN

4.1 Overview

Currently, 3GPP Release 17 and Release 18 NTN specifications are complete. Further enhancements are ongoing in Release 19 with focus on regenerative NTN deployments. In summary, the basic architectures for transparent payload and regenerative payload for LTE-based IoT NTN and 5G-based NR NTN are covered up to Release 19, and discussions on 6G NTN are expected to begin in 2025.

As the topic of 5G/6G NTN is increasing in velocity and magnitude, the requirement for the 5G RAN to incorporate fast moving NGSO platforms is giving rise to a series of questions about how these networks will be managed in real time, pertaining to:

1. How the TN and the NTN segments will intelligently coexist and provide a seamless experience to the users as they traverse between the two networks, while making sure that available spectral resources are optimally utilized.

2. Once in the NTN segment, how are the users and their traffic flows going to be intelligently managed by the SNOs such that they are assuring the types of services being sold while accounting for temporospatial variations in weather, spectral availability, onboard power availability, different terminal classes, and mobility between fast moving satellite platforms.

This intelligent management of the RAN and its operation is naturally addressed by the Non- and Near-RT RICs however while there are many use cases documented for their employment in terrestrial 5G networks, moving the network functions into space opens up completely different implementation approaches for the existing use cases (such as traffic steering and QoS optimization), as well as new ones which aim to intelligently employ the new control signaling features introduced for NTN in 3GPP Releases 17 and 18, which can be further enhanced to be applicable for the regenerative NTN deployment being standardized by 3GPP in Release 19 and onwards. The proposed transparent NTN architecture options in the following subsection are being studied by the WG1 work item on RIC enabled NTN deployment. These options are not yet adopted by the O-RAN architecture group, but they will be presented as the base line for future normative work on the support of NTN in O-RAN architecture and solution. As for the regenerative NTN deployments, a proposal is currently being considered to extend the NTN WI in WG1.

4.2 Transparent NTN architecture/topology options

Generally, NTN architectures generally have a single satellite network operator (SNO) in mind. Therefore, most mobile network operators (MNOs), which provide broadband wireless services in most countries by building numerous ground base stations, are using TN as their main network, and there is a need to think about an evolved open network architecture to utilize NTN as a supplement. In this section, we will focus on the architecture and topology of the 5G/6G-based mobile communication TN and NTN interworking or integrated networks and discuss their relevance to current and future O-RAN architectures. It is based on several key topologies and assumptions as below:

- It aims to integrate and operate low-cost NTN by making the most of MNO's TN infrastructure.
- TN is built and owned separately by MNO, and NTN is built and owned separately by SNO. Therefore, a business cooperation model based on the interworking between the MNO's terrestrial base station/core network and the SNO's NTN for bent-pipe is considered.
- TN can provide 5G/6G separately or together (LTE support for TN will be discussed later).
- It uses TN's single core network and can be linked to integrated base stations for TN and NTN or individual base stations for TN and NTN.
- Transparent NTN payload-based interworking architecture option is considered first.
- The user device can use TN and NTN services at the same time or by switching between them.
- The 5G RAN split structure of 3GPP and O-RAN is the baseline of the 6G RAN split structure.

The available capabilities of the O-RAN interfaces such as the E2/O1/A1 and the existing use cases defined in WG1, WG2, and WG3 are currently being studied to account for the inclusion of satellite assets in the context of 5G NTN architectures. New optimization use cases and enhancements to the O-RAN interfaces are being studied which would allow the SMO and RICs to address service-level operational enhancements to 5G NTN deployments and lower-level enhancements which would have a significant impact on the highly resource constrained satellite environment, relating to the overall signaling overhead in the networks as well as power consumption by satellites and UEs. In addition, there is a concrete opportunity to explore new optimization use cases and enhancements to the O-RAN interfaces which would allow RICs to not only address service-level operational enhancements to multi-RAT (5G/6G) NTN deployments, but also other lower-level enhancements which would have a significant impact in the highly resource constrained satellite environment, relating to the overall signaling overhead in the networks as well as power usage by the satellites and UEs.

The coexistence of an MNO and an SNO and their need to integrate their respective NTN and TN RANs will likely result in them also having their respective Near- and/or Non-RT RICs. In order to facilitate the intelligent interaction between the TN and NTN segments, a new open East/West interface between the SNO and MNO Near/Non-RT RICs is currently being considered. The enhancements for 5G NTN involve the definitions of novel optimization use cases as well as introductions of new functionalities of the utilized O-RAN interfaces will be the subject of normative work in O-RAN.

The 3GPP TS 38.300 specification describes an example implementation of the NTN-based NG-RAN with transparent NTN payload architecture (Figure 6). If this architecture is redesigned by applying the architecture and components of the O-RAN ALLIANCE, it is expressed as shown in Figure 7. In this figure, each entity is divided into MNO and SNO according to the owner and operator of the equipment, but it can be changed.

The NTN Control Function entity exchanges NTN control data (e.g., ephemeris, satellite's radio resources, transmit power and beam control, NTN delay control, TN-NTN mobility control, service link control, feeder link control, etc.) to control the NTN satellite (airborne) and NTN infrastructure (NTN payload and NTN gateway), and exchanges the relevant data with the ground base station.

Therefore, the existing vendor-proprietary NTN control function and TN O&M function are replaced by NTN SMO/RIC and TN SMO/RIC, which are standard entities of O-RAN, respectively, and can be reused by extending or updating the corresponding O-RAN interface. NTN's and TN's SMO and RIC can be separated, if required. In order to support this architecture, the following changes could be considered:

① The NTN SMO/RIC and the TN SMO/RIC will require the introduction of new interfaces or the extension of existing O-RAN interfaces (e.g., the A1 interface).

② New interfaces will be introduced or existing E2 and O1 interfaces will need to be extended to support seamless standards-based interoperability between NTN SMO/RIC and NTN entities.

③ The interworking between NTN SMO/RIC and ground base station equipment will require the introduction of new interfaces or the extension of existing O-RAN interfaces (e.g., E2/O1 interfaces).

④ The TN SMO/RIC and ground base stations will require an extension of the existing O-RAN interface (e.g., the E2/O1 interface).

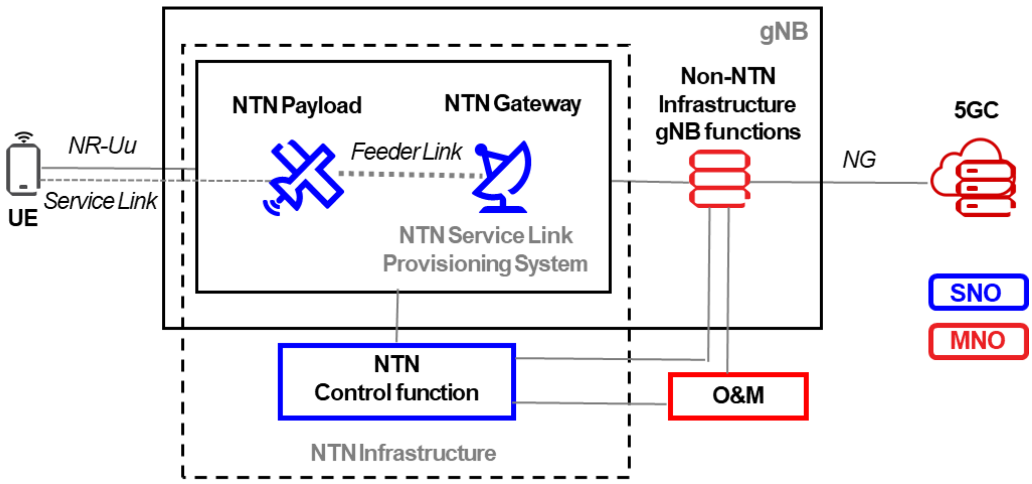

Figure 6: Transparent NR-NTN based NG-RAN (Reference: TS 38.300)

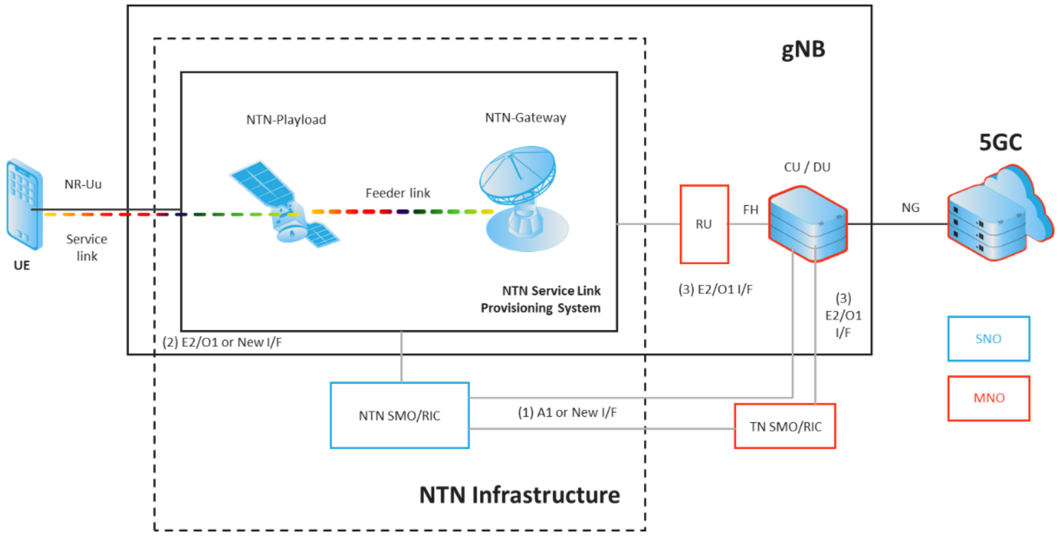

Figure 7: Proposed example of integrating Transparent NR-NTN based with ORAN MNO infrastructure.

4.3 Regenerative NTN architecture/topology options

Regenerative NTN deployments have its challenges related to complexity, power consumption, and latency constraint. Applying O-RAN functional split deployment can alleviate these constraints; however, these split topologies have different advantages and disadvantages depending on the requirements in the Inter Satellite Links (ISL) and feeder capacities and inherent latencies. Furthermore, consideration in the satellite transport network (encompassing ISL and feeders links) must consider multi orbits/planes and routing across the NTN in space. The NTN needs to be integrated with a terrestrial network, which imposes additional optimization requirements taking into consideration the end to end communication path across the integrated NTN and the TN.

In order to facilitate O-RAN standardization of the NTN O-RAN deployments in the future, a proposal is submitted to extend the RIC NTN WI to study the various O-RAN split topologies and deployment scenarios analyzing its advantages and disadvantages, requirements and impact on NTN transport network (ISL and feeders). Some of the initial O-RAN functional split topology options are presented below.

Figure 8: O-RAN-based Terrestrial Network as a reference

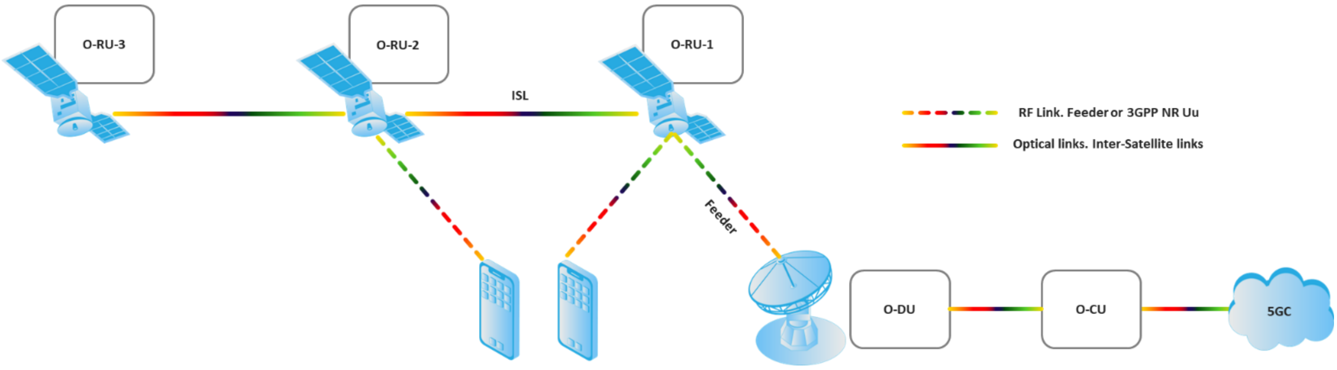

Figure 9: Topology Option 1: O-DU collocated with the Earth station GW

Advantage: The O-DU anchor to the O-CU is fixed

Disadvantage: In this option, the feeder conveys fronthaul traffic to a cluster of O-RUs connected via a daisy chain of optical inter satellite links. the feeder requires large bandwidth (> 100 Gbps links). Strict latency requirements may be difficult to fulfil over the feeder link and over the optical intersatellite links as the latency becomes larger as the fronthaul propagate through to the last satellite in the chain.

In the second option shown in Figure 10, the O-DUs/O-RUs are moving fast in their LEO with a fixed time window attachment to a fixed O-CU.

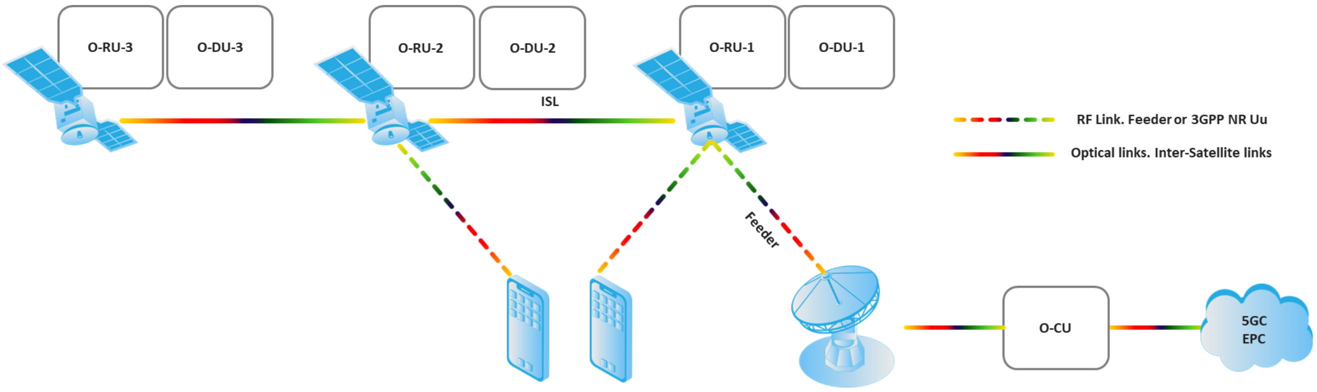

Figure 10: Option 2: O-DUs embedded onboard of the satellite

Advantage: Feeder conveys midhaul F1 interface signal which requires much less bandwidth (reduction of up to 95% compared to Option 1) and have relaxed latency requirements. Midhaul traffic from other satellites in the orbit will be conveyed over the Inter Satellite Links (ISL).

Disadvantage: The O-DUs need to handover to different O-CUs as the satellite fly past different O-CUs in their LEO.

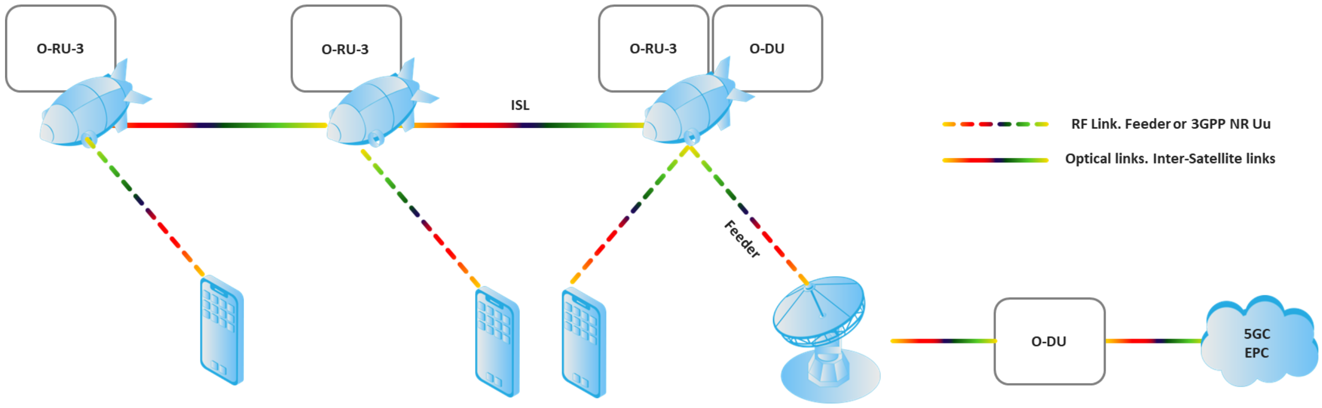

Figure 11: Option 3: Stationary HAPS with an onboard O-DU with F1/midhaul interface connection over the feeder and fronthaul interface over the inter HAPS links

Advantage: The feeder conveys midhaul F1 interface signal which requires much less bandwidth and have relaxed latency requirements. Just one O-DU is needed to feed fronthaul interface to multiple HAPS. The Inter.HAPs-Links (IHL) could be either Radio or optical. There are no requirements for the O-DU to perform HO with a different O-CU.

Disadvantage: HAPSs are stationary and localised constraining the geographical service area.

4.4 NTN Transport Networks

LEO satellite networks are now poised to offer high-bandwidth, low-latency transport connectivity with global coverage. SNOs are building fully interconnected, high-capacity space networks designed to deliver resilient, high-performance services. This development presents a significant opportunity for Mobile Network Operators (MNOs) to collaborate with SNOs, expanding network capacity and extending coverage to previously unconnected populations.

NTNs can play a critical role in providing backhaul connectivity for base stations located in remote or sparsely populated areas, where deploying traditional terrestrial infrastructure such as fiber optic cables or microwave towers is either too costly or impractical. In such scenarios, LEO satellites offer a cost-effective alternative to traditional terrestrial backhaul solutions. Additionally, in the aftermath of natural disasters or emergencies where terrestrial infrastructure may be damaged or unavailable, NTNs can provide rapid restoration of connectivity, ensuring minimal service disruption.

Given these advantages, there is an urgent need to evolve the O-RAN Xhaul transport architecture to seamlessly integrate NTNs as a viable backhaul option placing a requirement on the WG9. In this section, we will examine the role of an NTN as a connectivity solution for Xhaul and their significance within the broader O-RAN framework.

Key Considerations for NTN-based Xhaul Connectivity:

- Carrier Ethernet over NTN: MNOs will continue to leverage traditional carrier Ethernet services over NTN transport to support Xhaul, ensuring compatibility with existing network operations and protocols.
- Primary Connectivity for Remote RAN Sites: MNOs will use NTN-based transport as the primary Xhaul solution for RAN sites located in rural or hard-to-reach areas where deploying terrestrial infrastructure is not feasible.
- Backup Connectivity for Terrestrial RAN Sites: NTNs will be utilized as a backup transport solution for radio sites that are primarily connected via fiber or microwave, providing a layer of redundancy and enhancing network reliability.
- Integrated Network Framework: The TN will be built, owned, and operated by MNOs, while the NTN infrastructure could be managed by SNOs. This requires seamless interworking and integration between the TN and the NTN to enable simplified business operations, dynamic service provisioning, and effective service monitoring and assurance.
- Support for Evolving Wireless Technologies: NTNs will provide connectivity option for wide range of wireless technologies, including LTE, 5G, and future wireless standards, ensuring the scalability and adaptability of NTN-based Xhaul solutions as MNOs evolve their networks.

The architecture of LEO satellite- based NTN may evolve, transitioning from a traditional gateway-based model to a more flexible, gateway-less architecture. This shift is designed to enhance performance by enabling faster service deployment, more flexible bandwidth provisioning, and reduced latency, as shown in Figure 12 below.

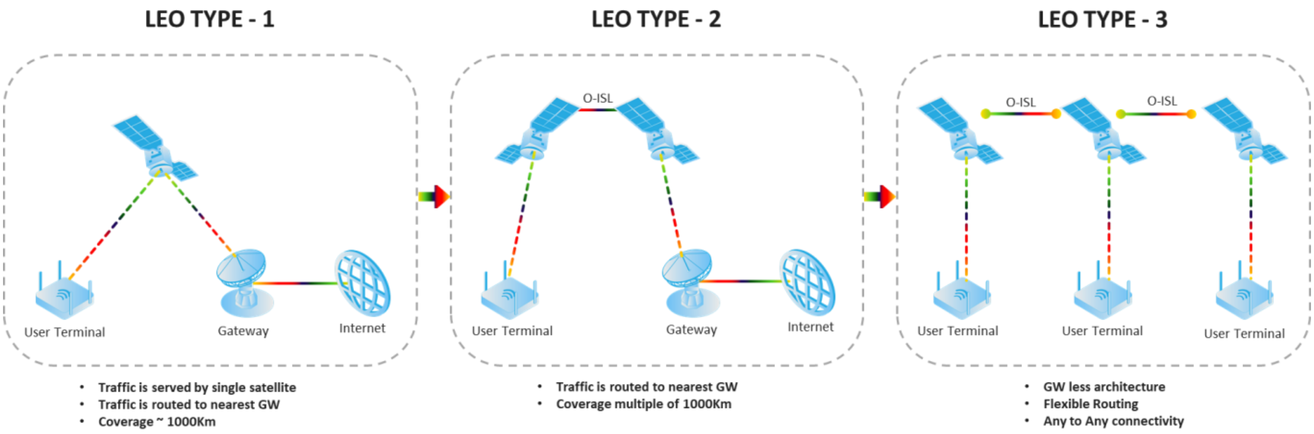

Figure 12: LEO satellite communication

SNOs are preparing to offer robust carrier ethernet services, such as E-Line, E-LAN, and E-Access, with full resiliency and redundancy. This capability enables SNOs to partner with MNOs to deliver Xhaul transport solutions, for example as shown in Figure 13 below.

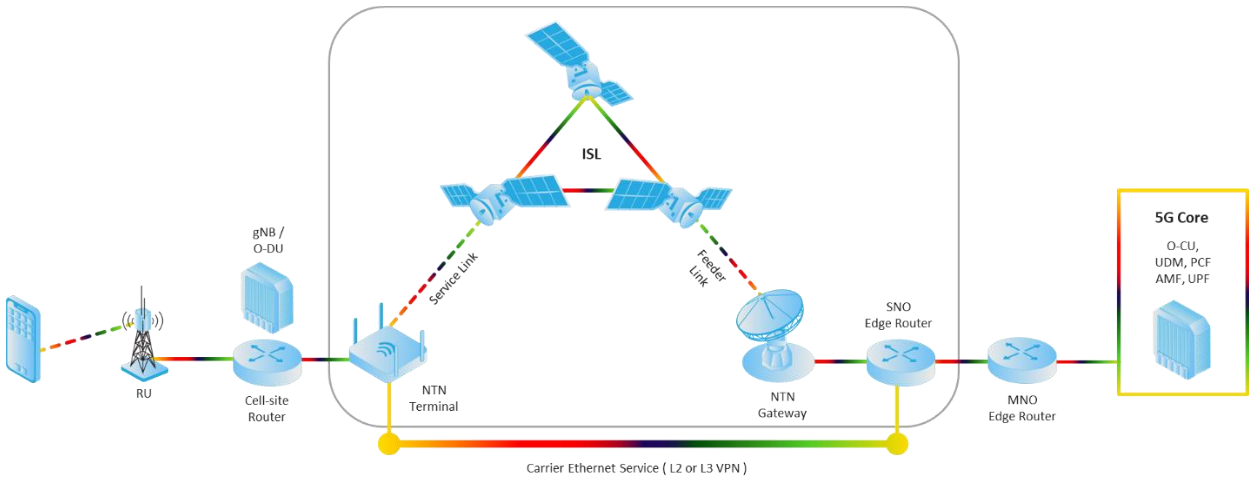

Figure 13: Carrier ethernet over NTN based Xhaul transport

To help MNOs to seamlessly integrate NTN-based Xhaul transport with traditional terrestrial network (TN)-based Xhaul transport, the O-RAN Open Xhaul Transport Working Group (WG) needs to focus on the following areas:

- NTN Transport Specifications: Defining technical requirements for NTN-based Xhaul transport, including bandwidth, latency, packet loss, and Quality of Service (QoS) parameters.
- Redundancy, Resiliency, and Performance: Exploring redundancy and resiliency models for NTN-based Xhaul transport to ensure high availability and optimal performance.
- Network Architecture: Developing a framework that supports multi-constellation and multi-vendor deployment scenarios to ensure scalability and flexibility in NTN-based Xhaul solutions.
- Service Integration: Defining a comprehensive integration framework for NTN and TN services, enabling seamless interoperability between the two networks.

- Security Framework: Establishing security definitions and protocols for the NTN-based Xhaul transport domain to ensure safe and secure data transmission.
- Interference Mitigation: Developing strategies for interference mitigation in NTN networks to enhance signal quality and minimize disruptions to service.

5 Security Considerations

The deployment of NTNs with the O-RAN architecture represents a significant advancement in telecommunications, particularly as the industry moves toward 5G advanced and 6G.

Integrating O-RAN with the NTN presents unique security challenges and risks.

Key Security Threats:

- Data threats:
  - Data integrity attacks involve altering transmitted data to compromise its integrity, leading to incorrect data processing and potential system failures. This threat is universal across all satellite types.
  - Unauthorized access to sensitive data can result in privacy breaches, with legal and regulatory consequences.
- Network threats:
  - Eavesdropping involves intercepting communication signals to gain unauthorized access to sensitive information, compromising data confidentiality. This risk is heightened for LEO and HAPS due to their lower altitudes and broader coverage areas.
- Physical threats:
  - Jamming attacks involve deliberate interference with communication signals, which can disrupt the communication between ground stations and satellites, leading to service outages. This risk is particularly significant for LEO and HAPS deployments due to their lower altitudes and closer proximity to potential sources of interference.
  - Kinetic threats, on the other hand, stem from space debris or hostile satellites that can physically damage satellite components. This threat is more pronounced for LEO satellites, which operate in a more congested orbital space.
- Operational threats:
  - Denial of Service (DoS) attacks aim to overwhelm network resources, making services unavailable to legitimate users, which can lead to significant downtime and affect network reliability.
  - Spoofing attacks, where attackers impersonate legitimate network entities to gain unauthorized access, can lead to data breaches and unauthorized control over network components.

Hybrid networks face additional security challenges, such as frequent handovers and authentication during roaming. Frequent handovers between ground users and satellites can lead to security vulnerabilities, including eavesdropping, falsification, or fabrication of signaling messages. This is particularly relevant for LEO and HAPS, which have more frequent handovers due to their lower orbits and mobility.

Security Considerations:

O-RAN WG11 has been working on defining security requirements and controls through various working groups within the O-RAN ALLIANCE. These security requirements and controls are specific to O-RAN interfaces and components. Additional security requirements may be necessary due to the integration of open, disaggregated network components with satellite and other space-based communications that include:

- Access Control:
    - Implement robust authentication mechanisms to prevent unauthorized access and ensure that only legitimate entities can communicate with NTN components.
    - Implement strict access control policies, including role-based access control (RBAC), to enforce the principle of least privilege, limiting access to authenticated and authorized users only.
    - Use micro-segmentation techniques to create isolated critical components, which can help to limit potential breaches and lateral movement by attackers.
- Data Protection and Availability:
    - Given the potential for interception in satellite communications, robust encryption methods using protocols (e.g., TLS and IPSec) should be employed to protect data transmitted between terrestrial and non-terrestrial components.
    - Implement mechanisms to ensure data integrity during transmission, such as cryptographic checksums or digital signatures, to detect any unauthorized changes to data packets.
    - Use strong encryption methods for data transmitted between terrestrial and non-terrestrial components to protect against eavesdropping and interception.
    - Implement measures to ensure the availability of both the NTN and Terrestrial O-RAN, such as Denial of Service (DoS)/Distributed Denial of Service (DDoS) protections.
- Continuous Monitoring and Threat Detection:
    - Implement continuous monitoring systems capable of detecting anomalies and potential security incidents in real-time. This is particularly important for NTNs, where latency and geographical distribution can complicate traditional monitoring approaches.
    - Engage in threat intelligence sharing among stakeholders, including MNOs, SNOs, and vendors, to stay informed about emerging threats specific to NTN deployments in O-RAN systems.
- Physical Security:
    - Ensure that satellites and HAPSs have robust physical security measures to prevent tampering or unauthorized access.
    - Secure ground stations and ensure they are protected against physical attacks.
- Interference and Jamming Protection:
    - Implement techniques to detect and mitigate jamming attacks, which can be more prevalent in non-terrestrial environments.
    - Use dynamic spectrum management to avoid interference with other satellite systems and terrestrial networks.
- Regulatory Compliance:
    - Ensure compliance with relevant regulatory requirements and standards to avoid legal penalties and maintain trust.

- **Vendor Management and Supply Chain Security:**
    - Implement robust vendor management and supply chain security practices to ensure the integrity and security of all components used in the network.

Conclusion on Security Considerations:

Securing O-RAN deployments with NTNs requires a comprehensive strategy that includes strong authentication, data protection, zero trust principles, continuous monitoring, regulatory compliance, supply chain and operational resilience. Advanced security solutions are crucial to mitigate risks and ensure the successful deployment of O-RAN NTN systems. WG11 will continue to evolve the Open RAN ALLIANCE security posture and will address the security risks, requirements, and controls for NTN.

By focusing on these key areas, MNOs and SNOs can enhance their security posture while leveraging the unique capabilities offered by NTNs within the O-RAN systems.

6 References

[3GPP_TS38.300] 3GPP, TS 38.300 V18.3.0 (2024-09), "NR and NG-RAN Overall Description", https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3191.

[3GPP_NTN overview] 3GPP Non-Terrestrial Networks (NTN), https://www.3gpp.org/technologies/ntn-overview

[O-RAN_Website] The O-RAN ALLIANCE, https://www.o-ran.org/ .

[O-RAN_OAD] O-RAN ALLIANCE, " O-RAN Architecture Description," O-RAN.WG1.OAD-R003-v12.00, https://specifications.o-ran.org .

[3GPP_TR38.821] 3GPP TR 38.821 V16.2.0 (2023-03), "Solutions for NR to support non-terrestrial networks (NTN)", Specification # 38.821[3GPP_NTN_SAN] 3GPP TS 38.108 v18.4.0 (2024-09) Technical Specification Group Radio Access Network, NR, Satellite Access Node radio transmission and reception (Release 18)