FEB 2022

A 5G Americas White Paper

5G & NON-TERRESTRIAL NETWORKS

Contents

Executive Summary

The evolution and large-scale deployment of fifth generation “5G” wireless networks over the next few years will require complementary 5G services by offering ubiquitous and reliable coverage across numerous geographies. Terrestrial networks are currently focusing on delivery of 5G services to areas already being served by existing cellular technologies, but the unique capabilities of non-terrestrial networks can help expand the reach of 5G technology in the realization of new use cases.

The satellite communications industry is picking up pace with new constellations of satellite deployments available today that are offering services to consumers, in addition to ongoing research into making these deployments serve larger footprints, providing more reliable service and becoming more cost-effective as more satellite are deployed. Currently, there is increasing interest and participation in industry forums from the satellite communication industry, with companies and organizations convinced of the market potential for an integrated satellite and terrestrial network infrastructure in the context of 5G communications.

This white paper focuses on various aspects of 5G satellite-based communications. From architecture (Geostationary Earth Orbit (GEO)/Medium Earth Orbit (MEO)/ Low Earth Orbit (LEO) constellations of satellites), to deployment options in partnership with Mobile Network Operators (MNOs), as well as possible co-existence with terrestrial networks involving spectrum usage and the complexities involved in the deployment of a 5G satellite-based network. The paper also looks at potential use cases complementing terrestrial networks offering broadband coverage and coverage to rural areas where terrestrial networks have limited coverage.

1. Overview

Throughout 2021, 5G deployments have been steadily ramping up across the globe with dozens of terrestrial network operators. While initially, 5G services have been offered to consumers with smart phones, there is also a significant desire by network operators to offer 5G services to enterprise and massive IoT (internet of Things) and MTC (machine type communication) devices. Demand for service continuity is expected to further drive the network evolution and expansion into non-traditional areas. Non-Terrestrial Networks, or NTN, have been part of gradual shift of research focus and the industrial push towards 5G-Advanced leading into sixth generation (6G) systems.

Satellite-based communication can potentially play an important role in leveraging communication infrastructure to deliver 5G services in the future and bridge the digital divide. Generally, satellite-based architecture leverages Geostationary Earth Orbit (GEO), Medium Earth Orbit (MEO), and Low Earth Orbit (LEO) systems which can collectively provide coverage across altitudes ranging from 36,000 km to 400 km. These satellites can be either stationary or can orbit around the Earth in the form of constellations to provide services. Overall, there are tradeoffs in performance and deployment cost among different satellite systems (LEO, MEO, GEO) that need to be taken into consideration.

This white paper discusses the progress in NTN standardization at 3GPP (3rd Generation Partnership Project), the consortium responsible for defining technical specification for mobile communication systems. 3GPP also works on various aspects of wireless networks, including use cases, network impact, QoS (quality of services), security, interworking between NTN and terrestrial networks (TN), as well as deployment challenges, complexities, and potential solutions.

2. Industry Overview for Non-terrestrial Networks

Adapting 5G to support non-terrestrial networks requires holistic and comprehensive design that spans across numerous areas, including radio access networks (RAN) to services, as well as specific aspects in the core network and on terminal devices.

2.1 Standards Evolution

3GPP is a primary international body responsible for defining the technical specifications for mobile wireless networks. 3GPP was initially formed in December 1998 when the European Telecommunications Standards Institute (ETSI) partnered with other standard development organizations (SDOs) from around the world to develop new technologies (or more specifically, technology specifications) for the third generation (3G) of cellular networks. Each round of technical specifications work culminates in a release.

After initial delivery in late 2017 of 'Non-Stand-Alone' (NSA) NR new radio specifications for 5G, much effort focused in 2018 on timely completion of 3GPP Release-15 – the first full set of 5G standards – and on work to pass the first milestones for the 3GPP submission towards IMT-2020. 3GPP 5G standards continue to advance as the organization works toward 3GPP Release 17 and 18 in future years.

2.1.1 NTN in 3GPP Standards

The work on Non-Terrestrial Networks (NTN) started in 3GPP in 2017, with a Study Item in Release-15 in 3GPP RAN WG1 [RP-171450[1]]that focused on deployment scenarios and channel models for NTN.

After this initial study, the 3GPP SA (Systems Aspects) workgroup started to discuss the use cases for Satellite-based NTN as part of the Study Item on Satellite Access in 5G [SP-170788]. The study identified three main categories of use cases for satellite-based NTN:

- *Service Continuity: Use cases where 5G services cannot be offered by terrestrial networks alone, and how a combination of terrestrial and non-terrestrial networks combined provides service continuity for such cases. Some examples are airborne platforms (e.g., a commercial or a private jet) and maritime platforms (e.g., a maritime vessel).*
- *Service Ubiquity: Use cases address unserved or under-served geographical areas, where terrestrial networks may not be available. Examples of ubiquity use cases are IoT (e.g., agriculture, asset tracking, metering), public safety (i.e., emergency networks), and home access.*
- *Service Scalability: Use cases that leverage the large coverage area of satellites and uses multicasting or broadcasting a similar content over a large area. An example of such use case is the distribution of rich TV content (i.e., Ultra High-Definition TV).*

The work in Release-16 also included a study in Radio Access Network (RAN) working groups on solutions for New Radio (NR) to support non-terrestrial networks with the objective to determine the necessary features to enable NR support for NTN [RP-190710[2]]. Key aspects are discussed in this white paper in Chapters 4 through 6.

These studies provided a baseline for NR functionalities needed to support LEO and GEO satellites. Using that as a baseline, 3GPP is now concentrating on the normative work for support of LEO and GEO satellites using 5G. The following assumptions, which will be covered in further detail throughout the remaining chapters of this white paper, are now being made in standards:

- *5G-NR Frequency Division Duplex (FDD) is used.*
- *Earth fixed Tracking area is assumed with Earth fixed and moving cells.*
- *UEs with Global Navigation Satellite Systems (GNSS) capabilities are assumed.*
- *Transparent payload is assumed.*

In 3GPP RAN, the Work Item on Solutions for NR to Support Non-Terrestrial Networks (NTN) [RP-211784[3]] is specifying feature enhancements such as:

- *In RAN WG1 and WG2, feature enhancements to address issues related to satellite's long propagation delays, large Doppler effects, and moving cells are being specified. These involve enhancements on timing relationships, Hybrid Automatic Repeat Request (HARQ), and uplink synchronization.*
- *Some protocol stack functionality is also being enhanced in RAN WG2. In the user plane, normative changes involve aspects such as the adjustment of allowed values for timers to take into consideration larger latency, improvements on Random Access Channel (RACH) access procedure, and enhancement of uplink scheduling. In the control plane, mobility procedures are enhanced to better support satellite use cases.*
- *RAN WG3 is considering architectural enhancements such as feed link switch over, as well as cell related aspects, such as Automatic Neighbor Relation (ANR), User Equipment (UE) registration and paging.*
- *RAN WG4 is specifying UE Radio Resource Management (RRM) and RF requirements*

In SA, WG1 is specifying the Stage 1 requirements when considering the use cases described in TR 22.822[4]. These requirements are being added directly to the existing SA1 5G specification, TS 22.261[5]: Service Requirements for the 5G System.

SA WG2, which encompasses the system architecture, started their satellite study in Release-17, with the creation of the Study Item on Architecture Aspects for Using Satellite Access in 5G [SP-181253[6]]. The scope of this work was to identify key issues for satellite-based NTN in the 5G system architecture and provide solutions for both direct satellite access and satellite backhaul. The result of the work is captured in the Release-17 Technical Report TR 23.737[7]. In November of 2019, SA2 approved the Release-17 normative work associated with this TR [SP-191335[8]]. The aspects that are being addressed by SA2 in the normative work are as follows:

- *Mobility Management with large coverage areas and with moving coverage areas*
- *Delay in satellite*
- *QoS with satellite access and with satellite backhaul*
- *RAN mobility with Non-geostationary (NGSO) regenerative-based satellite access*
- *Regulatory services with super-national satellite ground station*

SA WG5 addressed management and orchestration aspects in their study [SP-190138[9]], with results captured in TR 28.808[10].

3GPP Core and Terminals workgroups CT WG1, WG3, and WG4 created a study item [CP-203235[11]] to address aspects of 5GC (5G core network) architecture for satellite networks. The work in CT working groups concentrates on aspects related to Public Land Mobile Network (PLMN) selection, and the results are captured in Technical Report TR 24.821[12]. The study phase is completed and the normative work will follow, with the Stage 2 solutions and requirements for public land mobile network (PLMN) selection for satellite access.

3GPP also approved a study item for enabling the operation of the Internet of Things (IoT) NTN [RP-193235[13]]. This work is based on the existing 3GPP features of Narrowband IoT (NB-IoT) and enhanced Machine Type Communication (eMTC), which were introduced in Release-13, over satellite communications. The study assumes that the bands utilized are in the sub-6 GHz frequency range, with both LEO or GEO satellite orbits, assuming a transparent payload. The following scenarios are considered:

- *Scenario A: GEO based*
- *Scenario B: LEO based, altitude of 600km and 1200km, with steerable beams*
- *Scenario C: LEO based, altitude of 600km and 1200km, with fixed beams*

- *Scenario D: MEO based, altitude of 10000km, with fixed beams*

In addition, standalone operation is prioritized, and the following assumptions are made:

- *UEs have Global Navigation Satellite System (GNSS) capability*
- *IoT features specified up to Release-16 are supported*
- *Narrow Band IoT (NB-IoT) single-carrier and multi-carrier operation are supported*

The results of the study are captured in TR 36.763[14]. The Technical Report contains aspects related to RACH procedure, mobility, Radio Link Failure, HARQ operation, time and frequency adjustments, and general aspects related to timers.

The 3GPP Release-17 specifications are scheduled to be completed in the second quarter of 2022. The ASN.1 freeze is scheduled for the third quarter of 2022.

3. Use Cases Evaluation with Non-Terrestrial Networks

Chapter 3 summarizes potential use cases and scenarios for satellite service for non-terrestrial networks. Those use cases are identified in the following table below:

Table 3.1 NTN Use Cases Evaluation

5G Service enabler	5G Use case	5G Use case description	Satellite service
eMBB	Multi connectivity	Users in underserved areas (home or in Small Offices, big events in ad-hoc built-up facilities) are connected to the 5G network via multiple network technologies and benefit from high data rates. Delay sensitive traffic may be routed over short latency links while less delay sensitive traffic can be routed over the long latency links.	Broadband connectivity to cells or relay node in underserved areas in combination with terrestrial wireless/ cellular or wire line access featuring limited user throughput.
eMBB	Fixed cell connectivity	Users in isolated villages or industry premises (Mining, offshore platforms) access 5G services and benefit from high data rates.	Broadband connectivity between the core network and the cells in un-served areas (isolated areas).
eMBB	Mobile cell connectivity	Passengers on board vessels or aircrafts access 5G services and benefit from high data rates.	Broadband connectivity between the core network and the cells on board a moving platform (e.g., aircraft or vessels).
eMBB	Network resilience	Some critical network links requires high availability which can be achieved through the aggregation of two or several network connections in parallel. The intent is to prevent complete network connection outage.	Secondary/backup connection (although potentially limited in capability compared to the primary network connection).

Table 3.1 NTN Use Cases Evaluation (cont.)

5G Service enabler	5G Use case	5G Use case description	Satellite service
eMBB	Trunking	A network operator may want to deploy or restore (disaster relief) 5G service in an isolated area (not connected to public data network). A network operator may want to interconnect various 5G local access network islands not otherwise connected	Broadband connectivity between the public data network and a mobile network anchor point or between the anchor points of two mobile networks.
eMBB	Edge network Delivery	Media and entertainment content such as live broadcasts, ad-hoc broadcast/multicast streams, group communications, Mobile Edge Computing's Virtual Network Function updates are transmitted in multicast mode to a RAN equipment at the network edge where it may be stored in a local cache or further distributed to the User Equipment. The intent is to off load popular content from the mobile network infrastructure (especially at backhaul level).	Broadcast channel to support Multicast delivery to 5G network edges.
eMBB	Mobile cell hybrid connectivity	Passengers on board public transport vehicles (e.g., high speed/regular trains, buses, river boats) access reliable 5G services. They are served by a base station which is connected by a hybrid cellular/satellite connection. The cellular connectivity may be intermittent and/or support limited user throughput.	Broadband connectivity between the core network and the cells in un-served areas (isolated areas).
eMBB	Direct To Node broadcast	TV or multimedia service delivery to home premises or on board a moving platform	Broadcast/Multicast service to access points in homes or on-board moving platforms.

Table 3.1 NTN Use Cases Evaluation (cont.)

5G Service enabler	5G Use case	5G Use case description	Satellite service
mMTC	Wide area IoT service	Global continuity of service for telematic applications based on a group of sensors/actuators (IoT devices, battery activated or not) scattered over or moving around a wide area and reporting information to or controlled by a central server. These sensors and/or actuators may be used for example the following telematics applications: • Automotive and road transport: high density platooning, HD map updates, Traffic flow optimization, vehicle software updates, automotive diagnostic reporting, user base insurance information (e.g., speed limit, driving behavior), safety status reporting (e.g., air-bag deployment reporting), advertising-based revenue, context awareness information (e.g., neighboring bargain opportunities based on revenue), remote access functions (e.g., remote door unlocking). • Energy: Critical surveillance of oil/gas infrastructures (e.g., pipeline status) • Transport: fleet management, asset tracking, digital signage, remote road alerts • Agriculture: livestock management, farming	Connectivity between IoT devices (battery activated sensors/actuators or not) and spaceborne platform. Continuity of service across spaceborne platforms and terrestrial base stations is needed.
mMTC	Local area IoT service	Group of sensors that collect local information, connect to each other and report to a central point. The central point may also command a set of actuators to take local actions such as on-off activities or far more complex actions. The sensors/actuators served by a local area network may be in a smart grid sub-system (Advanced Metering) or on board a moving platform (e.g., container on board a vessel, a truck or a train).	Connectivity between mobile core network and base station serving IoT devices in a cell or a group of cells.

Table 3.1 NTN Use Cases Evaluation (cont.)

5G Service enabler	5G Use case	5G Use case description	Satellite service
eMBB	Direct to mobile broadcast	Public safety authorities want to be able to instantaneously alert/warn the public (or specific subsets thereof) of catastrophic events and provide guidance to them during the disaster relief while the terrestrial network might be down. Automotive industry players are interested to provide instantaneously Firmware/Software Over The Air services (FOTA/SOTA) to their customers wherever they are. This will include information updates such as map information including points of interest (POI), real-time traffic, weather, and early warning broadcasts (e.g., floods, earthquakes, and other extreme weather situations, as well as terror attacks), parking availability, infotainment, etc. Media and entertainment industry can provide entertainment services in vehicles (cars, buses, trucks).	Broadcast/Multicast service directly to User Equipment whether handheld or vehicle mounted.
eMBB	Wide area public safety	Emergency responders, such as police, fire brigade and medical personnel can exchange messaging and voice services in outdoor conditions anywhere they are and achieve continuity of service whatever mobility scenarios.	Access to User Equipment (handset or vehicle mounted).
eMBB	Local area public safety	Emergency responders, such as police, fire brigade, and medical personnel can set up a tactical cell wherever they need to operate. This cell can be connected to the 5G system via satellite to exchange data, voice and video-based services between the public safety users within a tactical cell or with the remote coordination center.	Broadband connectivity between the core network and the tactical cells.

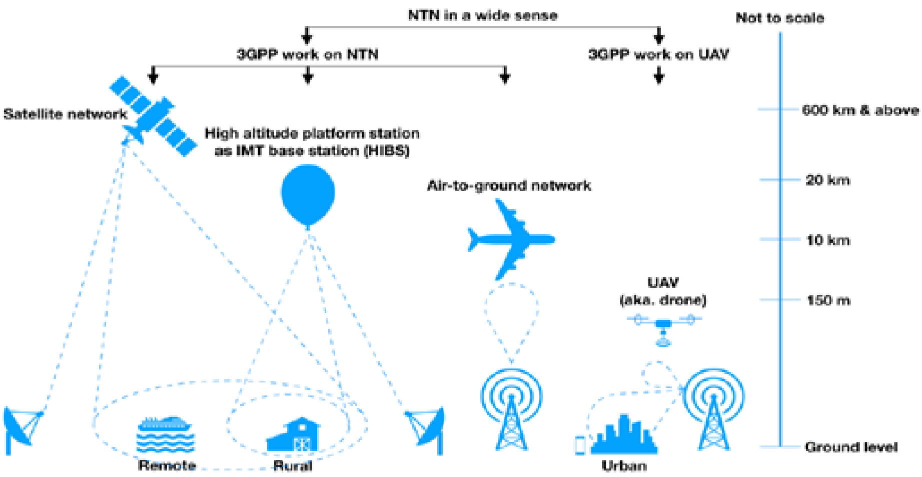
4. 5G & Non-Terrestrial Architecture

Satellites could be complimentary to 5G and improve the value of 5G networks by addressing coverage challenges and complex use-cases that ground-based infrastructure alone cannot address. 5G standards make Non-Terrestrial Networks (NTN) and satellite segments part of the ecosystem of the 5G connectivity infrastructure. This whitepaper focuses on satellite networks as support for 5G networks.

4.1 NTN overview

3GPP completed the standardization of the first global fifth generation (5G) wireless technology in its Release-15 in mid-2018. The first evolution step of the 5G system was finalized in Release-16, and 3GPP is working on further evolution of the 5G system in Release-17. Enabling 5G systems to support non-terrestrial networks (NTNs) has been significant area under exploration in 3GPP. NTN has also become an umbrella term for any network that may involve non-terrestrial flying objects. The NTN family includes satellite communication networks, high altitude platform systems (HAPS), and air-to-ground networks, as illustrated in Figure 4.1.[15]

Figure 4.1 Different types of non-terrestrial networks[16]



According to 3GPP TR 38.821[17], the two typical scenarios of a satellite-based NTN providing access to user equipment are depicted below:

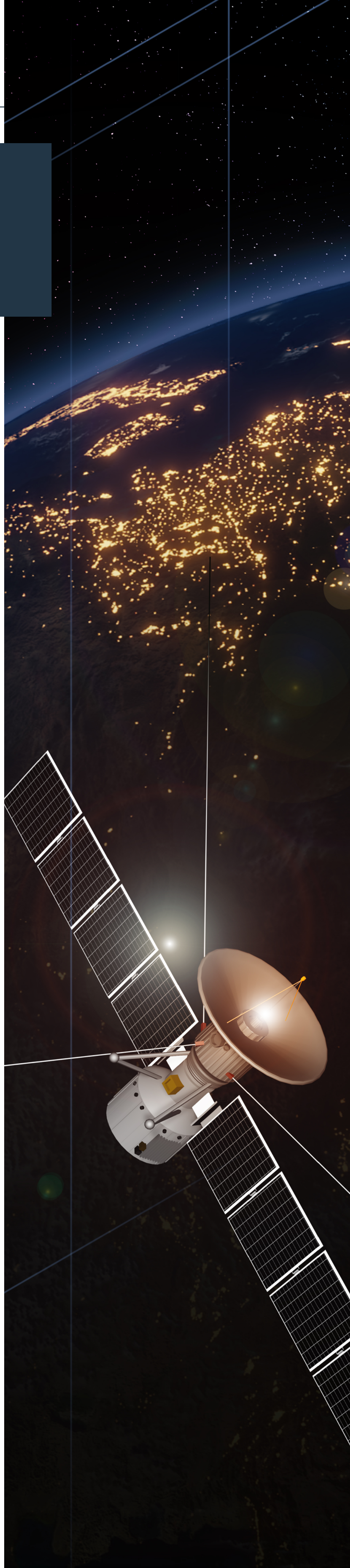


Figure 4.1-2 Satellite NTN typical scenario based on transparent payload (source: 3GPP TR 38.821-g00)

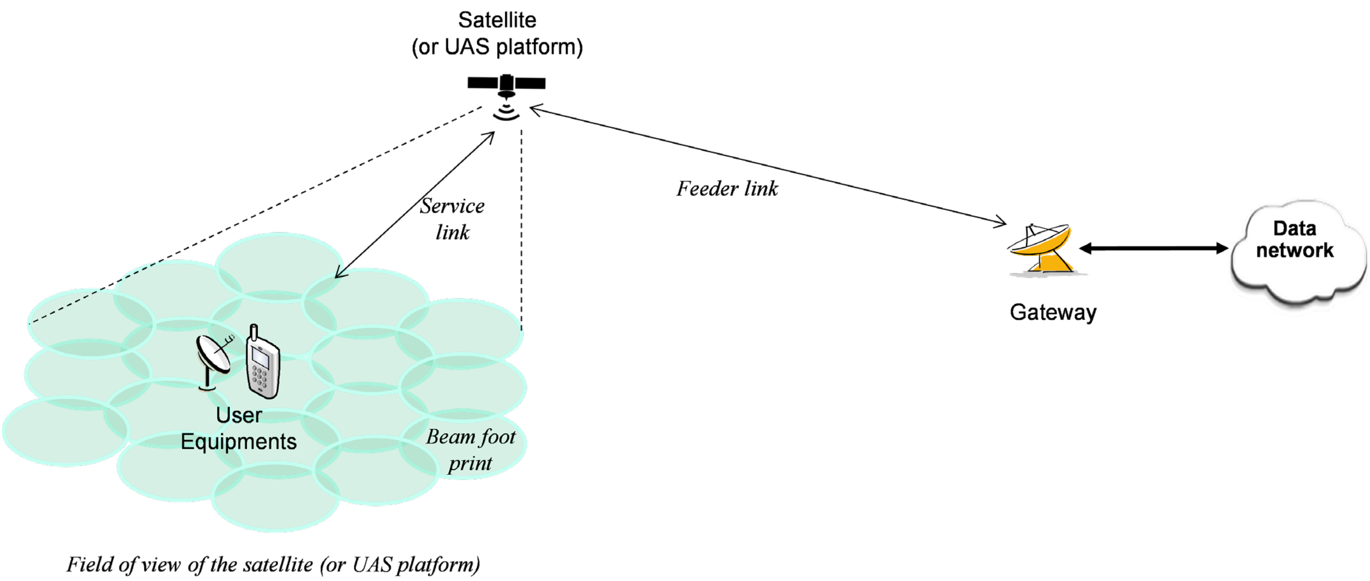
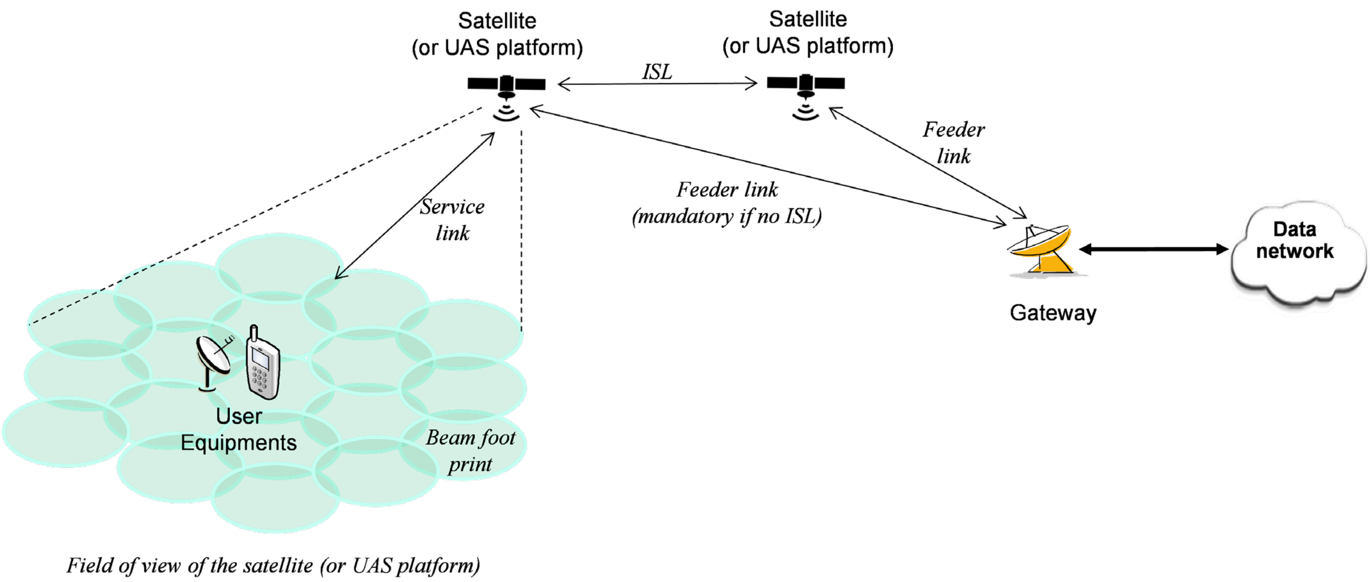


Figure 4.1-3 Satellite-based NTN typical scenario based on regenerative payload (source: 3GPP TR 38.821-g00)



As defined in 3GPP TR 38.821[18], a satellite-based Non-Terrestrial Network typically features the following elements:

- *One or several satellite gateways that connect the Non-Terrestrial Network to a public data network:*
  - » *A GEO satellite is fed by one or several sat-gateways which are deployed across the satellite targeted coverage (e.g., regional, or even continental coverage). We assume that UEs in a cell are served by only one satellite gateway.*
  - » *A Non-GEO satellite served successively by one or several sat-gateways at a time. The system ensures service and feeder link continuity between the successive serving sat-gateways with sufficient time duration to proceed with mobility anchoring and hand-over*
- *A feeder link or radio link between a sat-gateway and the satellite*
- *A service link or radio link between the user equipment and the satellite.*

- *A satellite which may implement either a transparent or a regenerative (with on board processing) payload. The satellite typically generate several beams over a given service area bounded by its field of view. The footprints of the beams are typically of elliptical shape. The field of view of a satellite depends on the on-board antenna diagram and minimum elevation angle.*
  - » *A transparent payload: Radio frequency filtering, frequency conversion and amplification only at the satellite. Hence, the waveform signal repeated by the payload is unchanged.*
  - » *A regenerative payload: Radio frequency filtering, frequency conversion and amplification as well as demodulation/decoding, switch and/or routing, coding/modulation at the satellite. This is effectively equivalent to having all or part of base station functions (e.g., gNodeB or "gNB") on board the satellite.*
- *Inter-satellite links (ISL) are optional in case of a constellation of satellites. This will require regenerative payloads on board the satellites. ISL may operate in RF frequency or optical bands.*
- *User Equipment are served by the satellite within the targeted service area.*

The different types of satellites are listed here:

Table 4.1 Types of satellite-based NTN platforms

Platforms	Altitude range	Orbit	Typical beam footprint size
Low-Earth Orbit (LEO) satellite	300 – 1500 km	Circular around the earth	100 – 1000 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

For more details on satellite-based NTN reference scenarios, see 3GPP 38.821[19] section 4.2.

3GPP Release-16 included studies on both architecture options (transparent and regenerative payload). The workgroup decided to work on standardization of the transparent payload option, and not to standardize the regenerative payload option in Release-17 due to various technical reasons. Thus this white paper focuses on the transparent payload option.

This regenerative payload option is under consideration for standardization for Release-18 with three potential design options: 1) full gNB on board 2) gNodeB Centralized Unit (gNB-CU) on the ground, gNodeB Distributed Unit (gNB-DU) on board, which face challenges in handling the F1 interface, as defined in 3GPP between CU and DU) 3) gNB on the ground, LLS (Low layer split), RU (Radio Unit) on satellite, which is faced with challenges in the Common Public Radio Interface (CPRI) interface that is not standardized in 3GPP.

4.2 Satellite-based NTN Architectures

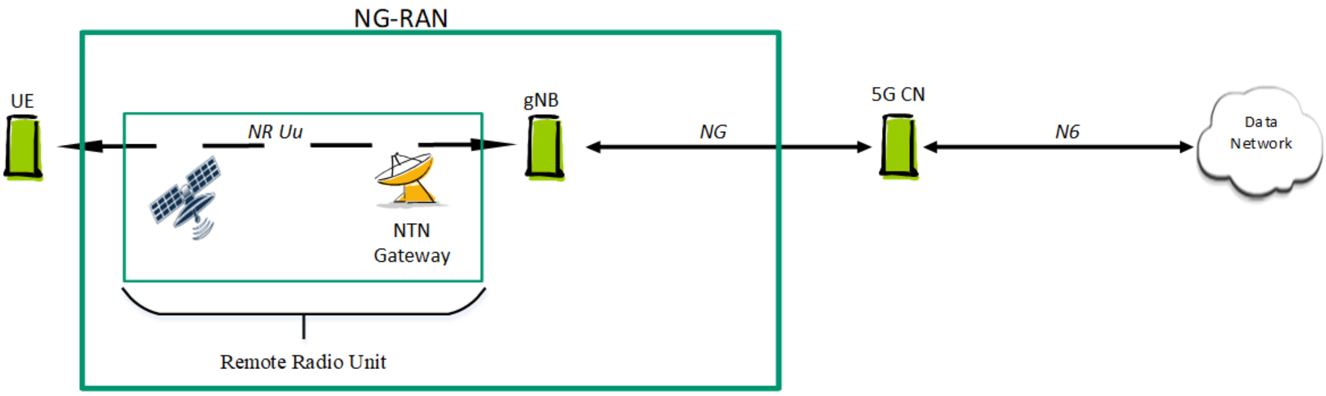
As mentioned earlier, although there were several types of network architecture studied in Release-16, only Transparent mode has been chosen to be pursued in Release-17.

4.2.1 Transparent Satellite based architecture

According to the architecture outlined in 3GPP TR 38.821[20], the satellite payload implements frequency conversion and a radio frequency amplifier in both uplink and downlink direction. It corresponds to an analogue RF repeater.

> "the electromagnetic wave that are transmitted from Earth surface are converted by a satellite receive antenna into an electric signal which is channel filtered and amplified by low-noise amplifier (LNA). The signal is then frequency converted. A high-power amplifier (HPA) delivers finally the signal to a transmitting antenna generating a reconditioned electromagnetic wave towards the Earth surface where receive station are located"

Figure 4.2 Networking-RAN architecture with transparent satellite (source: 3GPP TR 38.821-g00)

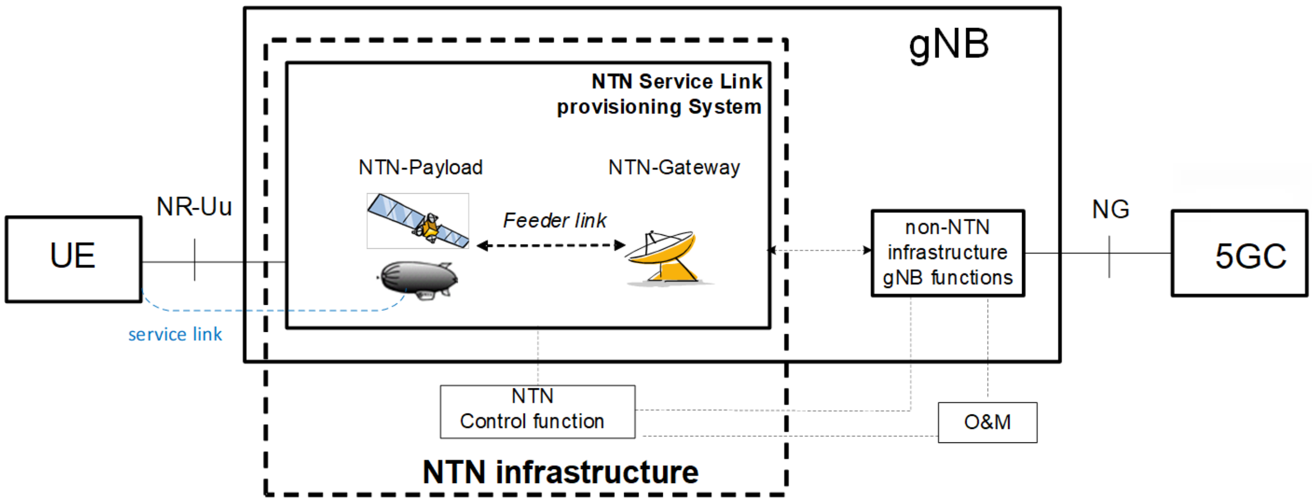


Hence the satellite repeats the NR-Uu radio interface from the feeder link (between the satellite-based NTN gateway and the satellite) to the service link (between the satellite and the UE) and vice versa. The Satellite Radio Interface (SRI) on the feeder link is the NR-Uu. In other words, the satellite does not terminate NR-Uu. The satellite-based NTN Gateway (GW) supports all necessary functions to forward the signal of NR-Uu interface.

Different transparent satellites may be connected to the same gNB on the ground. Note: While several gNBs may access a single satellite payload, the description has been simplified to a unique gNB accessing the satellite payload, without loss of generality.

3GPP has decided to implement transparent architecture as depicted below:

Figure 4.2-1 Satellite payload + feeder link + GW + Non-NTN infrastructure gNB (3GPP R4-2115640)[21]



Treat “payload + feeder link + gateway + gNB” as essentially everything between Uu and Next Generation (NG) interface as a single entity, that may be called a “satellite access node” instead of “gNB”. In this architecture, the interface between Satellite and Gateway, between gateway and gNB are not defined and may become proprietary.

NR-Uu timers may have to be extended to cope with the long delay of the feeder link and service link. In the context of a LEO scenario with ISL, the delay to be considered shall encompass at least the feeder link (SRI) and one or several ISLs.

Both CP (control plane) and UP (user plane) protocols are terminated on the ground.

- *With respect to CP, this scenario does not pose any particular issue, but there is a need to adapt to the much longer roundtrip times of the Uu that can be addressed by implementation.*
- *Concerning UP, apart from issues arising from the longer roundtrip time for UP packets, the UP protocol itself is unaffected. The longer delay on the Uu interface will, however, require more buffering for the UP packets into the gNB.*

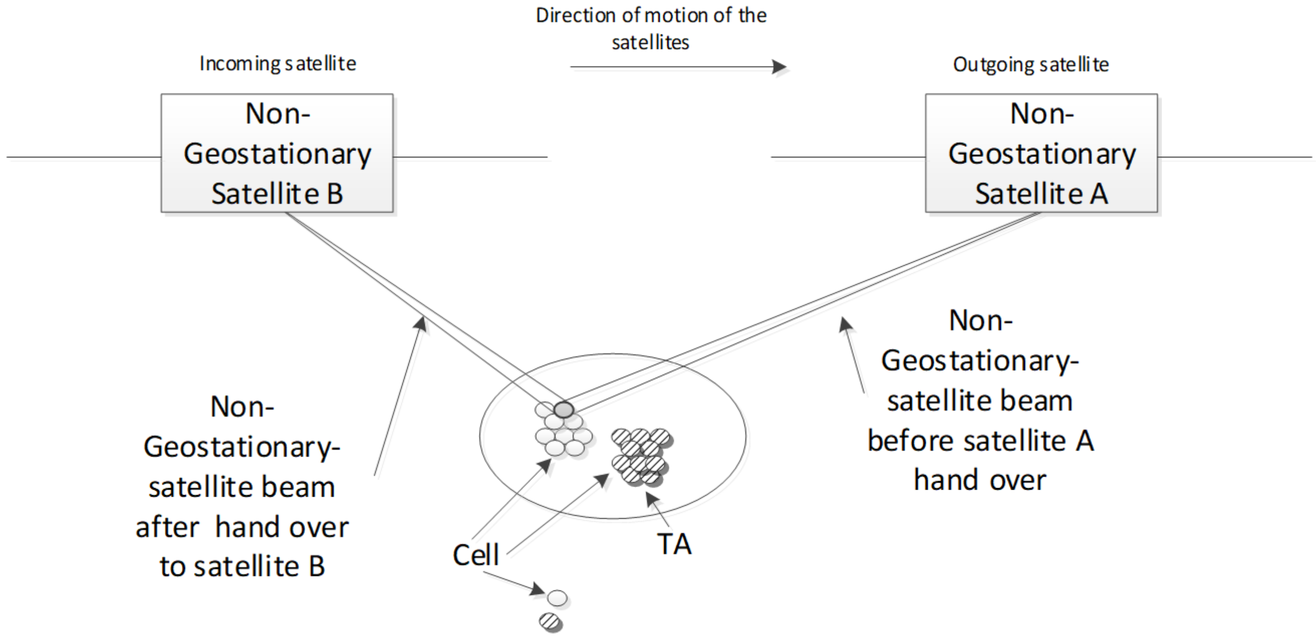
Satellite-based NTN will implement position-based and fixed tracking area (TA) satellite access. It is also assumed that UEs have the capability to determine their location.

According to 3GPP SA2 Study Report 23.737[22], the following principles will be applied in satellite-based NTN networks:

1. *Fixed tracking area (TAs): As for terrestrial networks, tracking areas are defined as a set of cells. TAs are fixed with respect the surface of Earth. For non-geostationary orbit (NGSO) satellites, as time proceeds, the mapping between gNB and satellite beams will change (e.g., for transparent case due to the feeder link switch). For geostationary satellites (GEO), satellite beams are fixed and generate a fixed radio coverage pattern on Earth. Earth-fixed tracking areas can also be ensured with moving beams/cells as described in TR 38.821*[23]
2. *Mobility: The UE makes radio cell selection based on similar procedures as for terrestrial NG-RANs. Based on the selected radio cell, the UE determines the Tracking Area on which it is located. The Access and Mobility Management Function (AMF) determines Registration Area as per the existing specification.*
3. *CN (Core network) Paging: The 5G Core Network (5GC) still pages the UE in Connection Management Idle (CM-IDLE) within the allocated Registration Area, i.e., a list of TAs.*

For reference, figure 4.2-1 below is an illustration of a fixed tracking area and mobility for NGEO satellite:

Figure 4.2-2 Non-Geostationary Satellite Beam steering and Handover (source: 3GPP SA2 study report 23.737)



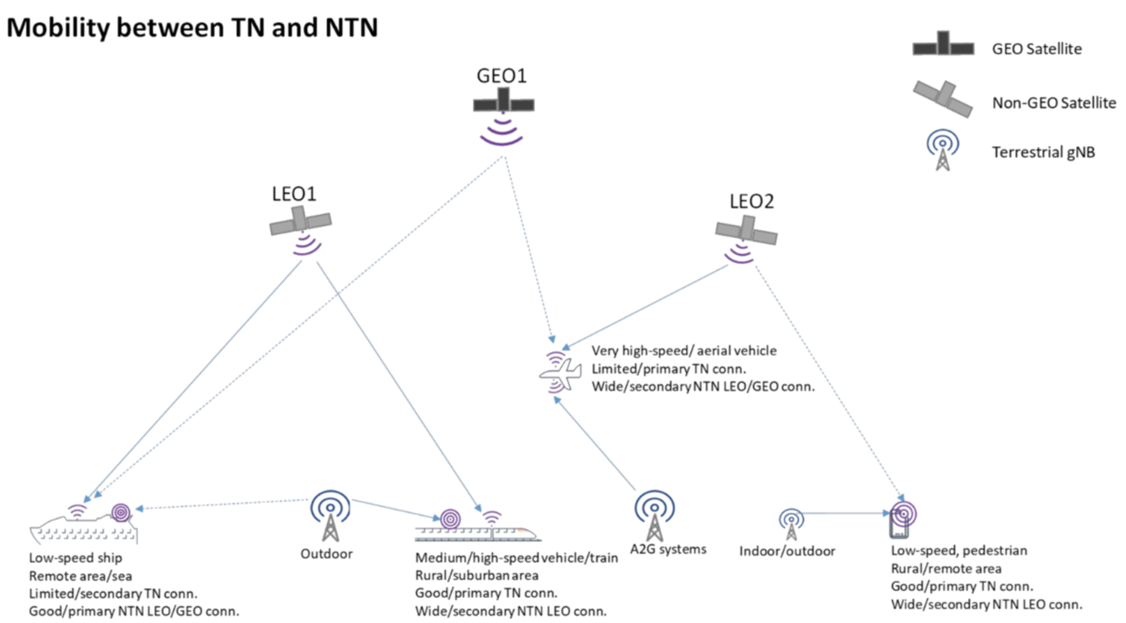
4.2.2 Multi connectivity involving NTN

3GPP has studied the simultaneous Protocol Data Unit (PDU) Session multi-connectivity of a UE over terrestrial RAN and satellite-based NG-RAN and decided not to include it in Release-17 specifications. However, it does not though preclude a device with two UEs that may simultaneously have separate Registrations and PDU Sessions in satellite and terrestrial networks with different PLMNs.

4.3 Interworking between TN and NTN

The 5G system is expected to support service continuity between 5G terrestrial access network and 5G satellite access networks owned by the same operator or owned by two different operators having an agreement.

Figure 4.3 Typical example of NTN-TN interworking (source: 3GPP 38.821[24])



In principle, NSA (Non standalone) operation between NTN and TN, such as running one leg connection with NTN and another leg connection with TN, is not precluded in standards, it can be potentially challenging. Running Xn connections between an NTN gNB and a terrestrial gNB is itself very challenging due to the many constraints like UP flow control and other factors.

NTN as currently considered does not support non-standalone (NSA): even MR-DC (multi radio dual connectivity) and New Radio to New Radio Dual Connectivity (NR-NR DC) would be problematic. Thus, currently the NSA based aspects (such as Xn mobility between NTN gNBs and terrestrial gNBs, MR-DC, secondary RAT data volume reporting, traces, etc.) are treated as low priority in 3GPP Release-17 activities. A number of Xn specifications are not expected to need explicit updates for NTN, so such support is left for vendor implementation.

It is expected the next generation (NG) based mobility should work to transition between NTN and TN. It is anticipated that NTN can interact with 5G, 4G or even 3G terrestrial networks via legacy inter-RAT (radio access technology) procedures. Detailed idle mode and connected mode procedures are currently left for vendor implementation.

4.4 RAN impact

3GPP Release-17 aims to specify the enhancements identified for 5G New Radio non-terrestrial network low-earth and geostationary earth orbiting satellites, according to the following principles:

- *Frequency Division Duplex (FDD) is assumed as the primary frequency duplex mode for New Radio to Non-terrestrial Network (NR-NTN) connections.*
- *Earth fixed tracking areas are assumed with Earth fixed and moving cells*

RAN features in physical layers need to be enhanced to address long propagation delays, large Doppler effects and moving cells in NTN. This includes timing relationships, UL time and frequency synchronization and HARQ procedures

Increased delays can also cause Channel Quality Indicator (CQI) reporting and Modulation Coding Scheme (MCS) assignment delays as channel conditions like rain fade on DL and UL can change. Therefore, the gNB needs to have robust algorithms to maintain the throughput performance to compensate for higher Block Error Rate (BLER) at the UE or gNB. The scheduler needs to compensate MCS and resource block (RB) assignment for various signal to noise (SNR) conditions.

In higher layers like the Media Access Control (MAC), Radio Link Control (RLC), and Packet Data Convergence Protocol (PDCP), idle mode and connected mode related procedures and signaling including system information, registration, paging, use of satellite ephemeris information, location information, measurement configuration, RRM (Radio resource management), and hand over procedures all need to be updated. These are part of ongoing Release-17 work item activities to update normative work, such as update specifications.

4.5 Core network impact

The goal in 3GPP Release-17 is to re-use the existing 5G Core Network functionality as much as possible for NTN. The transparent payload architecture with position based and fixed TA access does not modify the definition of TAs and RAs, so no impacts are identified on the core network's (CN)'s procedures or functional elements with regards to TA Update and RA updates.

However, to cope with longer delay introduced with satellite access, certain timers in session management and mobility management need to allow much longer values. These values will depend on "RAT type," which will have a new value in RAT types indicating the UE is accessing the Core network via satellite. It is proposed that UE capable only of connectivity via NTN RAN use extended timers defined to handle satellite delays. For UEs that can use both NTN RAT and terrestrial RAT, it is proposed that the UE uses regular timers or extended timers based on the RAT Type in use.

The table below is taken from 3GPP 23.737[25] (table 6.10.1.3-1), summarizing the timer impacted:

Table 4.2 Summary of timers impacted by satellite RTT and suggested timer value increase

	Timer #	RTTs propagation delay	(Minimum) Suggested Timer value increase
5GMM UE Side Timers	T3510	5 RTT	5 WCRTT
	T3517	3 RTT	3 WCRTT
5GMM AMF Side Timers	No need for changes, AMF determines appropriate values		
5GSM UE Side Timers	T3580	4 RTT	4 WCRTT
	T3581	1 RTT	1 WCRTT
	T3582	1 RTT	1 WCRTT
5GSM SMF Side Timer	No need for changes, SMF determines appropriate values		

(WCRTT: "Worst Case Round Trip Time")

Additionally, there are also enhancements needed in Access and Mobility management Function (AMF) that are related to UE positioning and registration. This is described in 3GPP SA2 study report 23.737 section 6.13.3

The Core network for 5G satellite (NTN) communication is expected to reuse the 5G NR terrestrial core network. Due to the unique nature of satellite communication that can cover multiple countries, the system needs to be able to support a mix of national roaming and RAN sharing and also have the possibility to support scenarios where the satellite operator has its own subscribers and where it does not.

4.6 Security in NTN

There is expected to be no impact to the existing 5G security requirements and procedures, including no impact to confidentiality and integrity protection of user or control plane traffic. There may be proprietary implementation of encryption on the interfaces between Satellite gateway and gNB to prevent man-in-the-middle attack.

4.7 End-to-End Quality of Service Aspects

Current plan in 3GPP is to avoid impacts to existing QoS framework and reuse it as much as possible also for NTN. The assumption is that most features can be re-used as-is. To cope with longer delays especially associated with GEO, 3GPP has recently agreed to define one new 5QI for best-effort services over GEO, with a PDB (packet delay budget) of 1100ms. For LEO however, the existing 5QIs should be applicable.

Network Slicing can be handled using the existing terrestrial network framework. There is expected to be no new elements added to 3GPP Network Slicing standard. Operators may create new slice based on NTN characteristics (coverage, speed, delay) and charge accordingly.

4.8 Positioning in NTN

According to 3GPP SA2 study report 23.737: the architecture framework for location management function (LMF) selection for the location services (LCS) procedures uses RAT Type as one of the input parameters and that LCS framework can also be re-used if satellite access is distinguished based on new RAT Type(s). The only method used for UE location today is provided by UE based global navigation satellite system (GNSS) or A-GNSS.

4.9 NB IoT/eMTC support in NTN

IoT operation is critical in remote areas with low or no cellular connectivity for many different industries, including, but not limited to:

- *Transportation (maritime, road, rail, air) & logistics*
- *Solar, oil & gas harvesting*
- *Utilities*
- *Farming*
- *Environment monitoring*
- *Mining*

Satellite networks can be used to complement to terrestrial network to provide IoT services for low or no coverage area. 3GPP has started a work item in Release-17 on NTN for NB IoT and eMTC. Its objective is to specify support of NB-IoT and eMTC over NTN with GNSS capability in the UE taken as a working assumption for both NB-IoT and eMTC devices. NB-IoT/eMTC design for terrestrial networks will be reused as much as possible in this case. Note that only EPC (Evolved Packet Core) connectivity is in scope in Release-17. For instance, 5GC connectivity is not considered and maybe be considered as part of Release-18 scope.

5. Deployment Options with Non-Terrestrial Networks Over Satellites

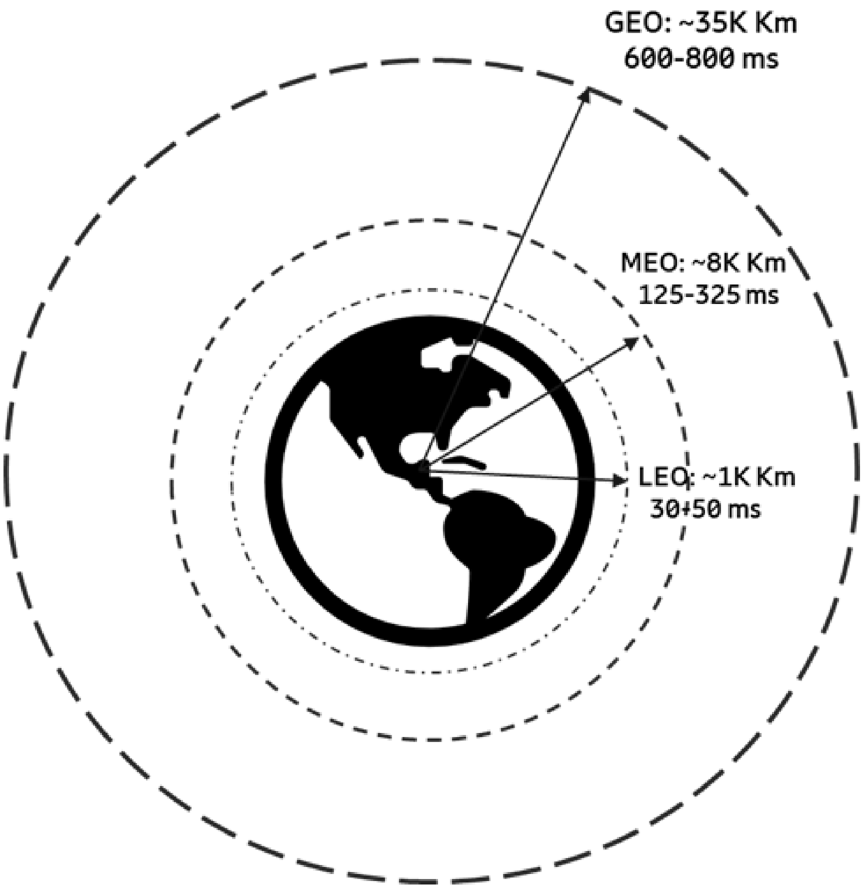
There are several options for network deployments involving non-terrestrial networks using a variety of different satellites. This chapter will look at some of the tradeoffs, spectrum considerations, co-existence with terrestrial networks, the user equipment eco-system, and connectivity with public land mobile networks.

5.1 LEO/MEO/GEO tradeoffs

Current satellite-based NTN networks primarily consist of backhaul of cellular services over GEO and MEO systems. These cellular services could be 3G/4G or 5G to remote areas where other forms of backhaul are a difficult to deploy whether it be terrain, remoteness or cost.

Traditionally with 3G/4G backhaul over the existing MEO/GEO satellites have been challenging due to the larger latency associated with the distance of satellites, as depicted below:

Figure 5.1 LEO, MEO and GEO satellite altitudes and latencies



These large latencies (125 – 800 ms) provide an inadequate user experience for real-time applications such as voice, video and gaming. MEO and GEO satellites require higher power on return link (RL/UL) thereby requiring robust end user devices.

With Release-17 and direct connectivity planned to UEs, the user experience should significantly improve when LEO satellites with lower latencies are deployed with 5G, compared to with MEO/GEO based.

As Release-17 is limited to a transparent/bent-pipe type of architecture instead of a regenerative payload, it will be crucial to determine which satellite system to use. Typical LEO orbits at ~1000 Km should provide one-way latency in the 30 to 50ms range depending on gateway, datacenter (application) location. Assume a co-located gateway and datacenter with minimal terrestrial L2/L3 backhaul with latencies less than 50ms, even if the MEO/GEO system is using a co-located gateway/datacenter, the latencies associated with physical distance constraints can still degrade user experience for certain applications. On the other hand, MEO/GEO have larger coverage and have lower deployment costs. Many of the GEO satellites can be software upgraded for transparent payload.

Other issues to consider with LEO compared to MEO and GEO include an increase of handoffs across satellites and possible beams depending on number of beams from a satellite to UE. For a LEO satellite, inter-satellite handoffs can be expected every 3 to 10 mins between 60 degrees latitude, depending on number of satellites that are visible and power constraints. Therefore, it is critical that the UE's know the ephemeris of the satellites and frequencies to use in a timely manner with precise time syncing. These are technical challenges that can be solved as satellite trajectories are quite predictable. Thus, there are tradeoffs between different satellite deployment considerations and the choice depends on the use case being considered.

5.2 3GPP spectrum frequencies used in satellite NTN

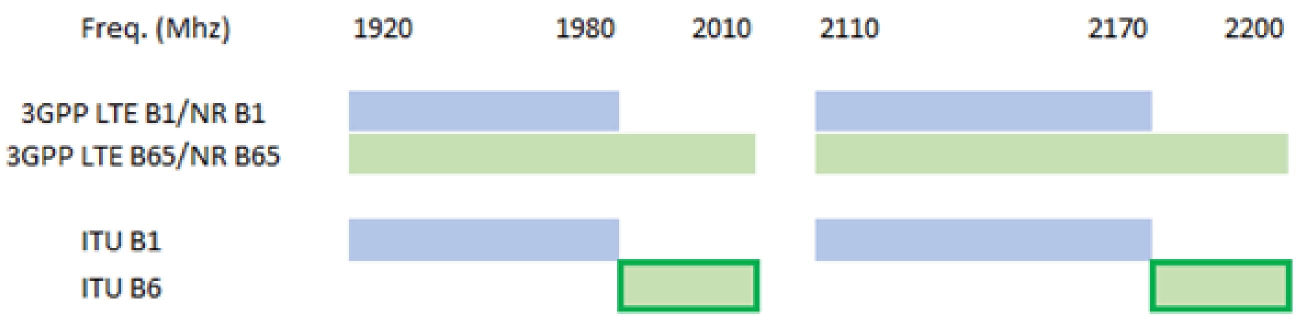
For 3GPP, spectrum has been generally defined in two different frequency range (FR) groups: FR1 - frequency range from 450Mhz to 6GHz, and FR2 – frequency range from 24.25GHz to 52.6GHz. For FR1, 3GPP reached an agreement for the following NTN bands:

- *1980-2010MHz / 2170-2200MHz is the "S-band"; In the International Telecommunications Union (ITU), this band is identified for both satellite and terrestrial component of the International Mobile Telecommunications (IMT) frameworks*
- *Part of the L-band is allocated to Maximum Segment Size (MSS), depending on GEO/non GEO composition*

However, defining these bands in 3GPP does not mean such spectrum will be used in commercial NTN networks. There are countries in different regions that want to use these bands for terrestrial use, so it still requires coordination between different countries and between countries and satellite operators to allow use of these bands for certain NTN networks. Such coordination should be done via the ITU.

For instance, there is a need to ensure that cross-border issues are solved between those countries that choose the NTN and those that choose the TN for spectrum in 3GPP frequency band 1 and band 65/n65. This frequency band of 3GPP band 1 and 65 is defined in the ITU Recommendation M.1036-6[26]. "Frequency arrangements for implementation of the terrestrial component of IMT in the bands identified for IMT in the Radio Regulations" as a combination of B1 and B6, where the B6 may also be used by the satellite component of IMT in some countries (both constitute n65 together while B1 equals 1/n1), as shown in the diagram below:

Figure 5.2 3GPP-identified frequencies for use by satellites in NTN's



Similarly, B7 defined in ITU with frequency range 2000-2020 Mhz (UL) and 2180-2200Mhz (DL) overlaps completely with Band 23 defined in 3GPP for ITU Region 2 (America). Spectrum coordination would be needed if such band is added to NR band list in 3GPP for terrestrial use and some satellite operators want to use it for non terrestrial network in the future.

As noted in the M.1036-6: A unique situation exists for the frequency arrangements B6 and B7 and parts of arrangements B3 and B5 in the bands 1 980-2 010 MHz and 2 170-2 200 MHz, which have been identified for the terrestrial component of IMT and the satellite component of IMT. .Co-coverage and co-frequency deployment of independent satellite and terrestrial IMT components is not feasible unless appropriate mitigation techniques are applied. When these components are deployed in adjacent geographical areas in the same frequency bands, technical or operational measures need to be implemented if harmful interference is reported.

During the WRC-19 an agreement was made with the development of Resolution 212 (Rev. WRC-19)[27]
"Implementation of IMT in the frequency bands 1 885-2 025 MHz and 2 110-2 200 MHz" and in the Annex of this Resolution "Guidance on the implementation of technical and operational measures to facilitate coexistence between terrestrial and satellite components of IMT in the frequency bands 1 980-2 010 MHz and 2 170-2 200 MHz" is given.

FR2 spectrum use for NTN is still being discussed and no agreement has been reached at the time of this document.

5.3 Co-existence with terrestrial networks

It is not possible to operate terrestrial networks (TN) and NTN in co-exist mode, for instance, over the same frequency used by both TN and NTN in same geographical area using FR1 spectrum. It would be up to regional/state level regulators to decide on whether a specific spectrum/band shall be used for TN or NTN network. Cross border coordination is mandatory since NTN using satellites cover areas that span different countries.

For higher frequencies above 24Ghz (FR2 range), there is possibility for co-existence with certain limitations, but this is to be studied further in 3GPP. It is too early at this stage to determine how feasible it is. Even if it is technically possible, co-channel or coexistence with adjacent services studies should be managed and regulated by regional regulators.

In 3GPP, the RAN4 Working Group will run coexistence studies on adjacent channels only (NTN-TN and NTN-NTN) and this work is expected to be completed by March 2022.

5.4 Roaming and RAN sharing

NTN and TN can operate in either roaming mode or sharing mode between Satellite Network Operator (SNO) and Terrestrial Mobile Network Operator (MNO). Satellite based NTN can extend a TN's coverage to where an MNO does not have presence and service backup, for example in the case where a TN loses coverage due to a natural disaster.

In roaming situations, a SNO maintains its own 5G NTN network (satellite, gNB, core network) but allows MNO users to connect to the SNO's network when there is no terrestrial coverage. MNO users still prioritize the MNO's TN and only use the SNO's NTN when there is no terrestrial network coverage.

The MNO's network should configure the SIMs of its users with SNO's PLMN ID so the mobile users can scan and access the SNO's network when it travels outside of the MNO's terrestrial network and be covered by SNO's NTN network. The MNO subscribers would re-register to its original MNO home network once it returns to the coverage of home network.

Lawful interception should be supported in the roaming case, like typical roaming operation among different MNOs. Emergency calls may be better handled by the SNO to avoid delay in call setup. Special consideration needs to be given for QoS and SLA (service level agreement) due to the difference in user performance (throughput, latency) between NTN and TN.

It should be noted the definition of the PLMN ID for the SNO operator is up to the SNO operator itself and is outside scope of this white paper. Optionally for the SNO, it could choose to broadcast the MNO's PLMN as Equivalent Home PLMN (EHPLMN) from its satellite network, while defining its HPLMN as a lower priority PLMN than the MNO's PLMN ID in the EHPLMN List. Per 3GPP standard (23.122 and 31.102[28]), the SNO subscriber will treat the MNO's network as higher priority network to camp, so the SNO subscriber can access the MNO's network to benefit from the greater speed and lower latency and only use the SNO's satellite network when it's outside of the MNO's terrestrial network coverage.

5.5 UE eco-system and availability

Ideally, UE should be capable of knowing its location within a certain country so it can limit its PLMN selection to PLMNs broadcasting the Mobile Country Code (MCC) of a given country. This requires the UE to have GNSS capability, especially for the GEO satellite case. If the UE receives a REGISTRATION REJECT message indicating that the requested PLMN is not allowed in the present UE location, then the UE attempts to select another PLMN instead. The UE may take the MCC hint received from the network into account in this fallback to another PLMN of the indicated MCC.

In addition, the UE also needs to pre-compensate for the Doppler shift and propagation delay, in order to align the forward link waveform and reverse link waveform at a specific point of the communication link such as at the satellite. A UE with GNSS capability can determine its frequency and time compensation through its location and the System Information Block (SIB)-broadcast satellite ephemeris. As a result, 3GPP Release-17 has focused on UE with GNSS capability. Having GNSS capability could also help for radio link synchronization, Tracking Area Code (TAC) assignment and paging, Tracking Area Identifier (TAI), forbidden PLMN list, etc.

Handheld devices in FR1 are supported (e.g., power Class 3 UE).

5.6 County specific PLMN selection

Per 3GPP 23.737[29], system complexities can be expected when a satellite's coverage crosses country borders and/or the UE's communications use terrestrial equipment (e.g., Earth stations) that are in a different country to the UE. This is illustrated in figure 5.3.

Another similar situation may arise with the use of satellite backhaul. A satellite transport would in this case interconnect a RAN with a 5GC. The satellite's coverage could overlap more than one country. This is illustrated in Figure 5.3-1.

This creates issues related to emergency call, lawful interception, charging & billing, and public warning notification. The current solution proposed in 3GPP (described in 23.737 chapter 6.13) uses county specific PLMN selection to address these issues.

On the UE side: if the UE is aware of its present location inside certain country, the UE should use that knowledge to limit its PLMN selection to only PLMNs of the country of the present UE location. In case of Visiting Public Land Mobile Networks (VPLMN), if the UE is aware that it has moved away from the country of the current registered VPLMN, then the UE should use that information to perform background scanning of higher priority PLMNs among those PLMN candidates that are available in the country of the present UE location.

On the network side: The network should verify the UE location during registration procedure over satellite access, as it cannot be guaranteed that the UE would always be aware of its present location. When the UE accessing over satellite RAT Type initiates Registration Procedure, the AMF can trigger UE positioning procedure to verify that the UE is accessing PLMN in the same country as the present UE location. If UE is attempting to register to PLMN that it is not allowed to access in the present UE location (e.g., PLMN of different country than the present UE location), the AMF responds with REGISTRATION REJECT, including suitable cause value to tell the UE that the selected PLMN is not allowed in the present UE location.

There may be additional RAN-related enhancements needed to handle these situations, as this is a work in progress at 3GPP.

Following these procedures, it is expected the UE will register in one of the PLMNs in the country of the UE location then existing network functionalities can be reused to handle emergency call, lawful interception, public warning and charging & billing. In addition, 3GPP is also conducting a study in Release-17 on extra-territorial systems that includes satellite systems, to ensure all necessary changes in the end-to-end systems are captured and documented.

Figure 5.3 Satellite access with satellite beams overlapping several countries

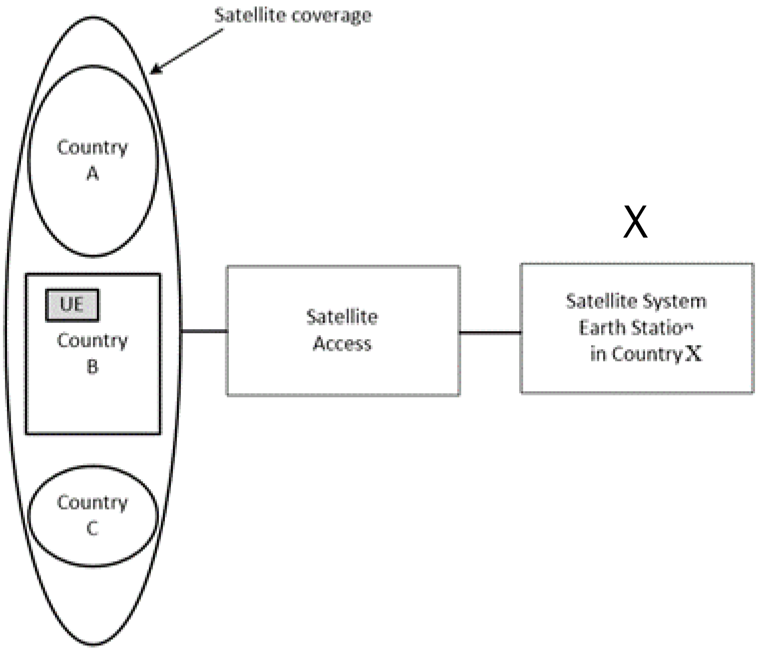
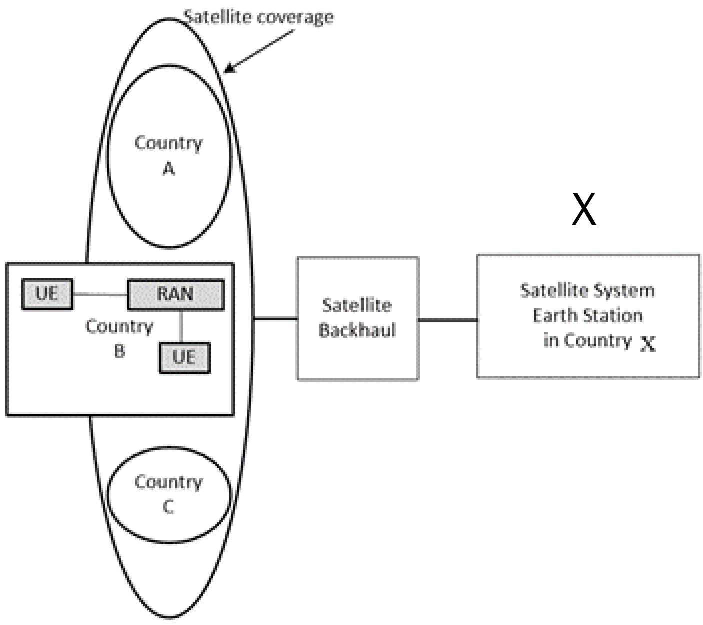


Figure 5.3-1 Satellite access with satellite beams overlapping several countries



6. Network Service Continuity

This chapter covers several aspects of maintaining network service continuity and satellite coverage in 5G networks utilizing non terrestrial network elements. These include initial cell selection, mobility in idle mode, and mobility management in connected mode.

Satellites in LEO orbits move with high-speed relative to a fixed position on Earth. The satellite beam towards the Earth defines the area on Earth that the satellite can provide services to the users. There are two cases on how the satellite beams can operate:

- *Moving-beam scenario: This is the case of a satellite with fixed beams, which yields a moving footprint on the Earth's ground. In this case the beam is moving relative to a fixed position on Earth.*
- *Fixed-beam scenario: This is the case of a satellite with steerable beams. As the satellites orbits the Earth, the satellite beams are adjusted so that it can continue to cover the same geographical area. In this case, as long as the satellite is above the horizon relative to the given geographical area, the beams can be adjusted to cover that area.*

The fixed-beam scenario yields the maximum time a UE may remain under the coverage area of the same satellite. This time is the time the satellite remains above the horizon relative to the UE location, which is approximately seven to ten minutes.

The times the UE remains under the coverage area of the same satellite for the moving-beam scenario are illustrated in the table below. The table shows that this time is dependent on the UE speed, the direction of the UE movement (i.e., same direction or opposite directions of the satellite movement), and the cell size (which is determined based on the satellite beam width: larger beam widths yield in larger cell sizes).

Table 6.1 Time the UE Remains in a Cell for a Moving-Beam Scenario

Cell Diameter Size (km)	UE Speed (km/hr)	Satellite Speed (km/s)	Time UE remains in the cell (s)
50 (lower bound)	+500	7.56	6.49
	-500		6.74
	+1200		6.33
	- 1200		6.92
	Neglected		6.61
1000 (upper bound)	+500		129.89
	-500		134.75
	+1200		126.69
	- 1200		138.38
	Neglected		132.28

- *For the smallest cell diameter (50km), the time a stationary UE remains under the coverage area of the same satellite is approximately 6.6 seconds. For the largest cell diameter, this time is increased to approximately 132 seconds. The table shows that the variation of this time as a function of the UE speed is relatively small (+/- 4%), so for analysis purposes, UE speeds can be neglected.*
- *The time the UE remains in the cell for the moving-beam scenario is quite short when compared to the fixed beam scenario or to the terrestrial systems. The implications in idle mode and connected mode UEs are discussed in the following sub-sections.*

6.1 Initial Cell Selection

This is a summary of the steps undertaken by an NTN in selecting an initial cell:

- *When the UE powers-on, it searches for the first satellite-based NTN cell that it can camp on. If the UE has the satellite orbital information (I.e., the ephemeris data), the cell search can be optimized and take lesser time. It is also beneficial if the UE knows the Round Trip Time (RTT) well enough to be able to do random access. For this, the initial system information may need to contain further ephemeris information on the exact location of the cell (or the satellite broadcasting the cell). This information can be given with respect to the orbital plane that the UE already has information about.*
- *The main concern for proving the satellite level orbital parameters is about the size of such information. The following solutions can be considered to provide orbital parameters per satellite:*
- *Pre-provision satellite level orbital parameters for all the satellites that may serve the UE in the UE uSIM, including a satellite ID or index. The satellite ID of the serving satellite is then broadcast in the System Information so that the UE can find the ephemeris data stored in uSIM.*
- *Broadcast satellite level orbital parameters of the serving satellite in system information and the UE derives the position coordinates of the serving satellite.*
- *Information of the neighbouring satellites can also be provided to UE via system information or dedicated RRC signalling to assist mobility handling.*

6.2 Mobility in Idle Mode

During idle mode, the UE location is known at the Tracking Area level. The Tracking Area is defined as a set of cells, each cell belonging to a Tracking Area identified by a Tracking Area Code (TAC). The TAC is sent in the System Information in the Broadcast channel. Multiple cells may belong to the same tracking area, in which case they broadcast the same TAC.

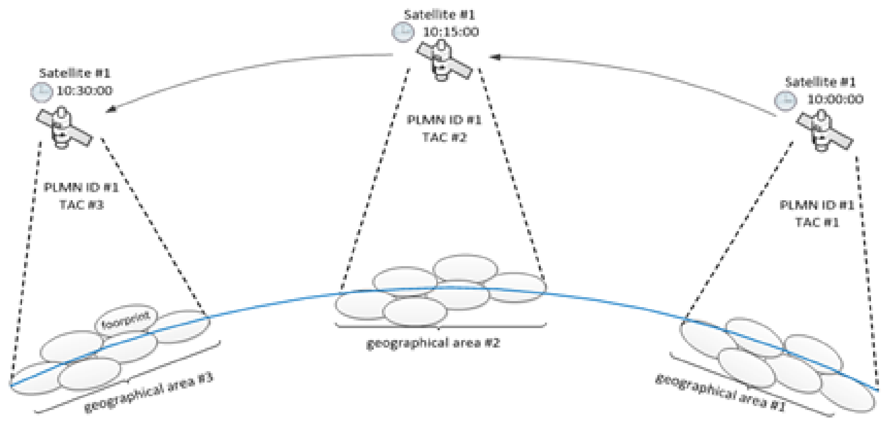
The UE location is known to the network as the UE performs the Registration procedure when it first turns on. The Registration Request message includes the TAC of the cell the UE is currently camped on. As the UE moves around and changes cells, it reads the System Information in the new cell to determine the Tracking Area of that cell. The UE is allowed to move within the same Tracking Area without performing any updates. If the UE enters a new cell with a different TAC, the UE must perform Registration in the new cell and send the new TAC in order to update the network of its location. Therefore, the larger the tracking area, the lesser is the signalling from the UE to the network, minimizing the UE power consumption.

When the network needs to reach the UE in idle mode (e.g., incoming call), the network pages the UE in all cells belonging to the last tracking area the UE performed a registration. If the Tracking Area is very large and includes many cells, there is an increase in the number of pages, as the network will page the UE in all cells belonging to the TAC. The operator strategy for network deployment usually involves considers the trade-offs between the number of pages required to find the UE versus UE power consumption. This optimization also takes into consideration the cell load, as the higher the number of UEs in the cell, the higher is the number of pages sent from the network.

If the same model is used for a satellite system, with each satellite broadcasting a TAC, as the satellite orbits the Earth, the tracking areas would sweep over the ground, as it is illustrated in the figure below. In this case, even a stationary UE would have to perform registration updates quite often, which would impact the UE battery life and increase uplink signalling.

To address this potential issue, the 3GPP body proposed the concept of a fixed tracking area. In the fixed tracking area concept, the system is designed so that the tracking area does not change its geographical location on Earth. Instead of the tracking area moving as the satellite moves, the satellite changes the Tracking Area as it enters the new

Figure 6.1 An example for Fixed Tracking Areas [TR 38.821]30



geographical area and the TAC broadcast by the satellite is updated to reflect the new geographical area covered. At the same time, when the UE detects a new TAC in the broadcast channel, the UE performs the tracking area update procedure. In this case, if the UE does not change its physical location on Earth, the Tracking Area for that UE remains fixed.

The solution proposed in further divided in two modes: hard or soft switch.

Hard Switch: One cell broadcasts a single TAC per PLMN. The gNB replaces the old TAC with the new TAC when the geographical area under coverage changes. This mode may create some TAC fluctuation at the border area, possibly resulting in some ping-pong behavior in the UE.

Soft Switch: One cell may broadcast more than one TACs per PLMN. The gNB adds the new TAC in its system information and broadcasts both TACs simultaneously for a given time length. The gNB then may remove the old TAC at a later time, when no longer serving the boundary of the geographical area. This mode may reduce the number of updates performed by UEs at the border area. A potential issue in this mode is a possible imbalance of the distribution of paging load among the cells.

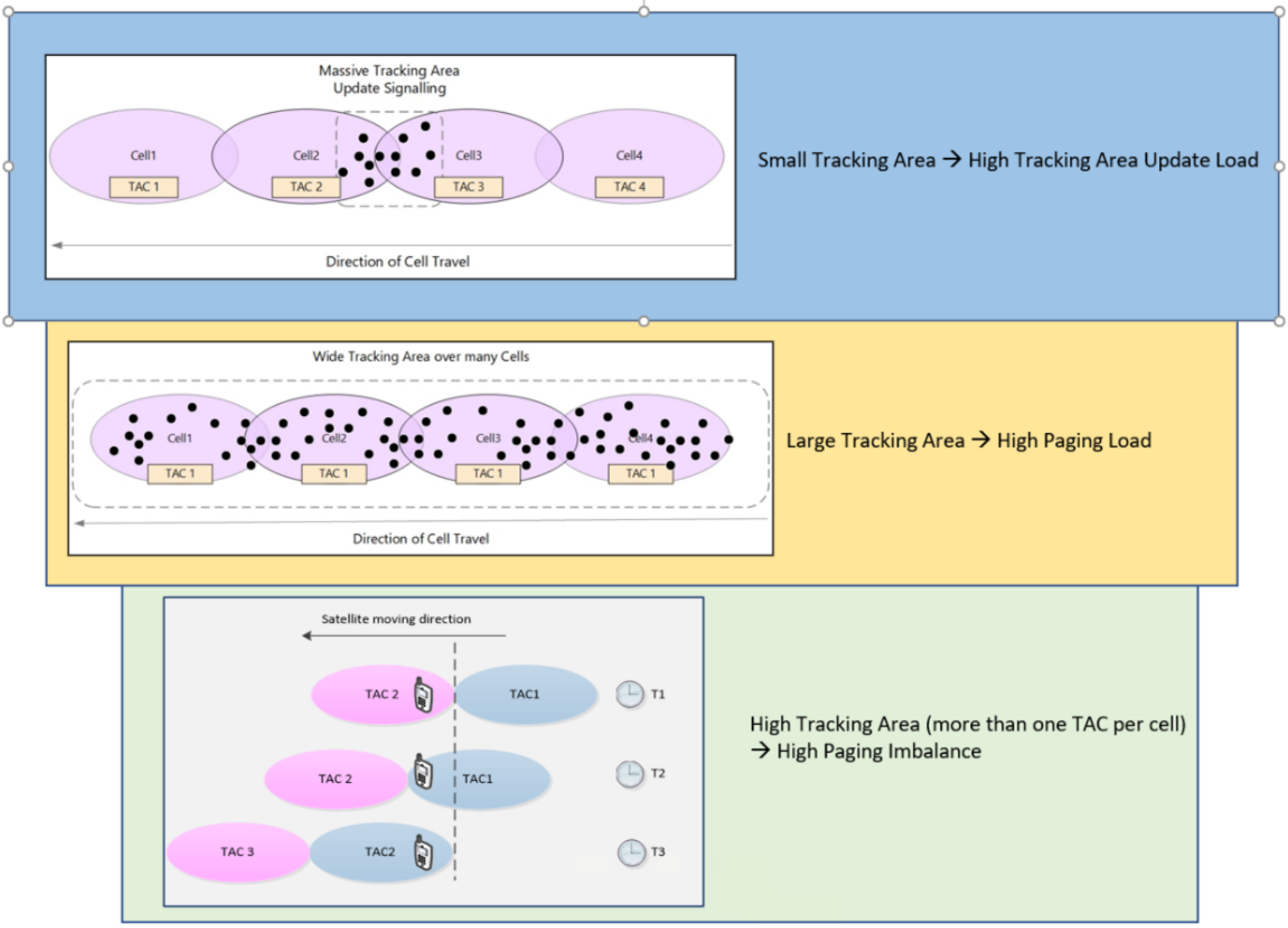
The figure below illustrates the trade-off to be considered when networks based on these solutions are deployed: The number of registration updates from the UE, the number of pages needed to reach a given UE, and the paging load variation from cell to cell.

6.3 Mobility Management in Connected Mode

While the UE is in connected mode, mobility is handled by handovers. In terrestrial networks, handovers are triggered by the network based on measurements reported from the UE about the current cell and neighbor cell signal quality. The handover procedure is illustrated in the figure below. The service interruption time is defined as the time between when the UE stops transmission/reception with the source gNB and the time when target gNB resumes transmission/reception.

The interruption time is different in the uplink and in the downlink. For the downlink, the interruption time can be defined as the time from network sending RRC Reconfiguration with sync (Step 3) until the target gNB receives the RRC Reconfiguration Complete (Step 6). Since the gNB cannot send more data after step 3, and it can continue after it receives

Figure 6.1-1 Tracking Area Update vs. Paging Load Tradeoffs



RRC Reconfiguration Complete. For the uplink, the UE can potentially continue sending data to the source gNB until RRC Reconfiguration with sync is received, the interruption time can be defined as the time from UE receiving RRC Reconfiguration with sync (Step 3) until the target gNB receives the RRC Reconfiguration Complete (Step 6).

Propagation delay in satellite-based NTN is orders of magnitude higher than terrestrial systems, introducing additional latency to mobility signalling such as measurement reporting, reception of the HO command, and HO request/ACK (if the target cell originates from a different satellite).

GEO scenarios are characterized by much larger propagation delay than LEO, however the latter requires consideration of satellite movement. To avoid extended service interruption, latency associated with mobility signalling should be addressed for both cases.

Adding Other Handover Triggers

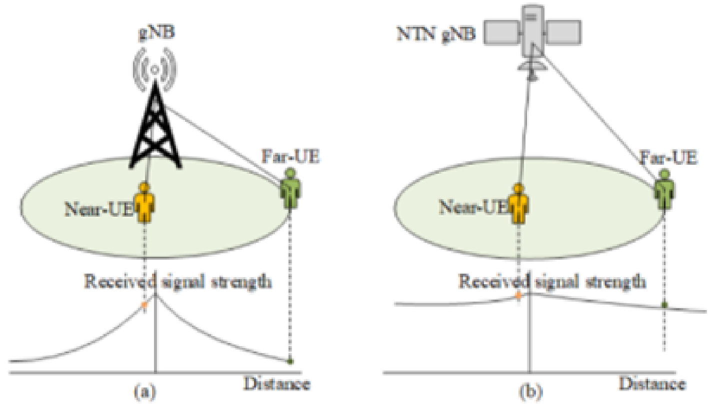
Besides measurement triggered handovers, other triggers can be considered for handover decisions, as follows:

- *Triggering based on location of the UE and the satellite: Location triggering condition may be expressed as distance between the UE and the satellite.*
- *Timer-based triggering: Triggering conditions based on the time a region is served can be considered. Time-based conditional HO in LEO scenarios should consider deterministic satellite movement.*
- *Timing advance based triggering: Triggering based on the timing advance value to the target cell.*
- *Elevation angles of source and target cells-based triggering: additional triggering conditions based on elevation angles of source and target cells can be considered in satellite-based NTN.*
- *These triggering conditions may be considered independently or jointly.*

Conditional Handover

The deterministic satellite movement can also be considered in the handover decision. Configurations

Figure 6.2 a) Terrestrial Network b) Satellite-Based Non-Terrestrial Network



related to the target gNB can be provided to the UE in advance, as the satellite orbit is known. This solution is referred to as conditional handover: The handover configuration (i.e., configuration in the new cell) is provided in advance, together with a condition that will trigger such handover before the radio conditions get too poor. The UE monitors the condition and performs the handover when the condition is met.

Conditional handover in satellite-based NTNs can be based on time and UE location (which corresponds to elevation angles). Also, the remaining time until the satellite will stop serving a cell can be broadcasted by the satellite.

Another benefit of knowing the satellite ephemeris is that if the UE knows its own location. In this case, it can estimate the required Timing Advance value of the target gNB. The UE then can perform pre-compensation of delay and Doppler shift for all UL transmissions using that information.

In non-GEO deployments satellites constantly move with respect to a fixed point on earth. Such movement may have several implications to the UE, such as how long a candidate cell will remain valid.

Given the deterministic movement of satellites in LEO, the network may be able to compensate for the changing cell set via existing Rel-15 mechanisms, possibly with the aid of UE location.

As GEO satellites are relatively static, dynamic neighbor cell set is not anticipated to be a challenge.

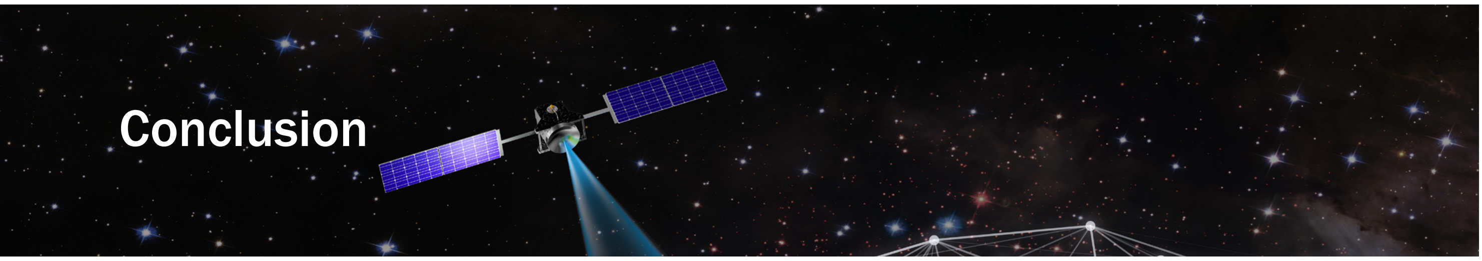
Configuration Considerations

It is important to note that the received signal strength in a satellite cell does not vary much throughout the cell, as it is illustrated in the figure below. Therefore, the difference of the signal strength measured at the center of the cell versus the edge of the cell is small, and this should be taken into consideration when configuring the measurement triggering and measurement reporting thresholds.

Measurement Optimizations

There are some optimizations that can be done to optimize the UE measurement performance by taking advantage of the fact that the UE is being serviced by a satellite with known orbit.

- *Conditional triggering of measurement reporting: The triggering of measurement reporting can be based on UE location.*
- *Inclusion of location information in the measurement report: Location information may be piggy backed onto the measurement report to provide the network additional information when determining whether to HO.*
- *Network compensation of propagation delay difference between satellites: The network can compensate for propagation delay differences in the UE measurement window, e.g., via system information, or in a UE specific manner via dedicated signaling.*



Conclusion

5G continues to make progress in standards and deployments throughout the world. The advancements for integrating the non-terrestrial networks (NTN) continue at as fast pace as well. There are multiple new NTN being proposed and launched that could complement the 5G services through integrated reliable coverage across different geographies. 5G will offer new business models and use cases with NTN providing additional coverage possibilities to extend these use cases to new areas.

There is much more work to be done regarding NTN in future releases at 3GPP. 3GPP Release 17 will introduce new network topologies into the 3GPP specs that include high-altitude platforms and Low Earth Orbit and geosynchronous orbit satellites.

New constellations of satellite deployments and work at 3GPP has provided a possible pathway for closer integration of Terrestrial and Non-Terrestrial Networks. Overall, there is increased activities in the various industry groups, standards organizations and commercial companies to work toward solutions for consumers and enterprises that integrate both types of networks. This paper focused on the multiple aspects of 5G satellite-based networks from architecture, standards to deployments.

Acronyms

A-GNSS: Assisted GNSS

AMF: Access and Mobility Management Function

ATG: Air to Ground

CPRI: Common Public Radio Interface

CQI: Channel Quality Indication

e-MTC: enhanced Machine Type Communication

FDD: Frequency Division Duplex

FR1: Frequency Range 1

FR2: Frequency Range 2

GEO: Geostationary Earth Orbit

GNSS: Global Navigation Satellite System

gNB: GNodeB

GSMA: GSM Association

HAPS: High Altitude Platform System

IMT: International Mobile Telecommunications

IoT: Internet of Things

ISL: Inter Satellite Links

ITU: International Telecommunication Union

LCS: Location Services

LEO: Low Earth Orbit

MCS: Modulation and Coding Scheme

MEO: Medium Earth Orbit

MNO: Mobile Network Operator

MOCN: Multi-Operator Core Network

MORAN: Multiple Operator RAN

MTC: machine type communication

NB-IoT: Narrow Band IoT

NG-RAN: Next Generation Radio Access Network

NGSO: Non-Geostationary Satellite Orbit

NSA: Non-Standalone

NTN: Non-Terrestrial Network

PDCP: Packet Data Convergence Protocol

PLMN: Public Land Mobile Network

QoS: Quality of Service

RLC: Radio Link Control

RTT: Round Trip Time

SA: Stand Alone

SLA: Service Level Agreement

SMF: Session Management Function

SNO: Satellite Network Operator

SRI: Satellite Radio Interface

TAC: Tracking Area Code

TAI: Tracking Area Identifier

TN: Terrestrial Network

TR: Technical Report

VPLMN: Visiting Public Land Mobile Network

WCRTT: Worst Cast Round Trip Time

Acknowledgments

5G Americas' Mission Statement: 5G Americas facilitates and advocates for the advancement and transformation of LTE, 5G and beyond throughout the Americas.

5G Americas' Board of Governors members include Airspan Networks, Antel, AT&T, Ciena, Cisco, Crown Castle, Ericsson, Intel, Liberty Latin America, Mavenir, Nokia, Qualcomm Incorporated, Samsung, Shaw Communications Inc., T-Mobile USA, Inc., Telefónica, VMware and WOM.

5G Americas would like to recognize the significant project leadership and important contributions of group leaders Sridhar Rajagopal, Mavenir and Rahul Pal, T-Mobile along with many representatives from member companies on 5G Americas' Board of Governors who participated in the development of this white paper.

Endnotes

[1]RP-171450

[2]RP-190710

[3]RP-211784

[4]TR 22.822

[5]TS 22.261

[6]SP-181253

[7]TR 23.737

[8]SP-191335

[9]SP-190138

[10]TR 28.808

[11]CP-203235

[12]TR 24.821

[13][RP-193235]

[14]TR 36.763

[15]X. Lin, S. Rommer, S. Euler, E. A. Yavuz, and R. S. Karlsson, “5G from space: An overview of 3GPP non-terrestrial networks,” arXiv preprint arXiv:2103.09156, March 2021.

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[17]TR 38.821

[18]TR 38.821

[19]TR 38.821

[20]TR 38.821

[21]3GPP R4-2115640

[22]3GPP Study Report 23.737

[23]TR 38.821

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[26]https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.1036-6-201910-I!!PDF-E.pdf

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[28]3GPP standard (23.122 and 31.102)

[29]3GPP 23.737

[30]Time the UE Remains in a Cell for a Moving-Beam Scenario [TR 38.821]