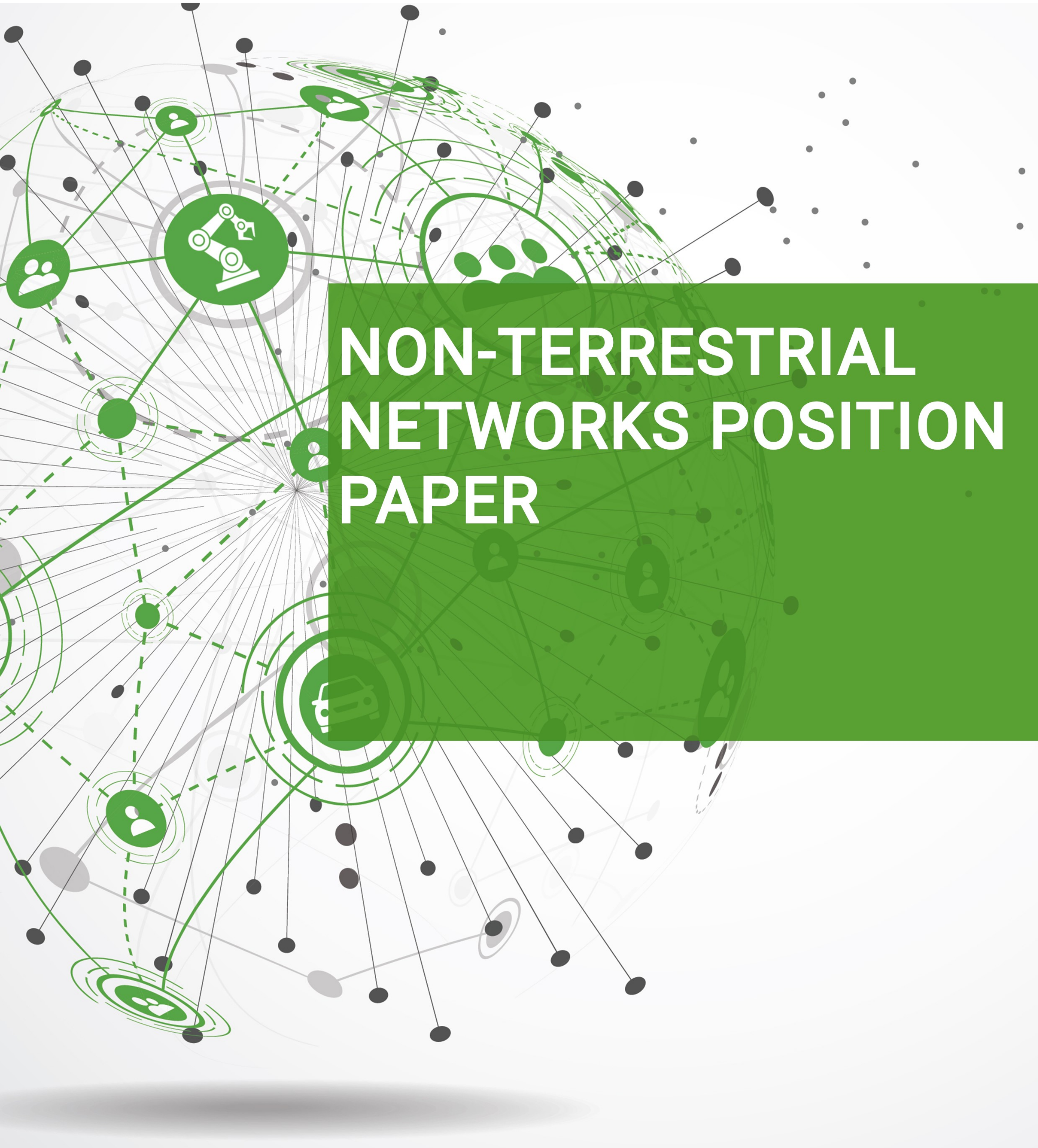
NON-TERRESTRIAL NETWORKS POSITION PAPER



Non-Terrestrial Networks Position Paper

by NGMN Alliance

Version: **Date:** **Document Type:** **Confidentiality Class:** **Authorised Recipients:** (for CR documents only)	**V0.8** **27-November-2019** **Final Deliverable (approved)** **P - Public**

Project:	**Extreme Long-Range Communications for Deep Rural Coverage**
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Executive Summary

NGMN's Extreme Long-Range Communications for Deep Rural Coverage project presented in [1] paves the way for the study of cellular coverage for sparsely populated areas. In this study, a number of Mobile and Satellite Technologies that could provide coverage to remote areas have been analysed and studied.
The present paper elaborates on that recommendation, providing an overview and analysis of non-terrestrial cellular technologies that can provide coverage to remote areas.
The purpose of this project, undertaken by NGMN, is to explore technologies that could provide internet and mobile broadband services, similar to a conventional cellular network, to the following areas:

- Rural area away from ground based cellular coverage
- Sparsely populated areas such as deserts, mountainous areas, forests, coastlines etc.
- Seas and Oceans
- Connectivity to airborne vehicles

The new Satellite based services could also be utilised to serve the following vertical markets where the conventional cellular coverage is absent. These vertical markets are:

- Rural broadband
- IoT based verticals (farming, sensing, fleet/asset tracking, oil & gas)
- Connected Cars
- Aeronautical
- Cruise ship/vessels
- Public Safety
- Smart city, smart village

5G direct satellite access to conventional smartphones was highlighted as a promising solution [1] to provide ubiquitous coverage to users in deep rural areas without having to deploy traditional ground-based RAN Equipment.

Aware of the value non-terrestrial networks (NTNs) can provide to mobile network operators (MNOs) in extending the reach of their services, NGMN entered into collaboration with the EMEA (Europe, Middle-East and Africa) Satellite Operators Association (ESOA[1]) to promote complementarity between terrestrial and non-terrestrial networks and encourage the development of coverage-extending solutions. ESOA members have been lead contributors to this document through this cooperation.

Non-Terrestrial Networks (NTN) refers to networks providing connectivity through space-borne vehicles or an airborne platform. These vehicles provide radio connectivity between the User Equipment (UE) on the ground and the vehicle. Furthermore, in order to pass the call to other networks and to provide connectivity to Core Networks, these vehicles provide radio connections, to one or more Ground Based Gateways. A number of options are available to provide radio connectivity from space or from the air down to UEs on the ground:

1. Stationary Satellites are space-borne vehicles employing either an amplified non-regenerative payload or a regenerative payload, placed into Geostationary Earth orbit (GEO),
2. Non-Stationary Satellites: Like GEO but with the satellites positioned in Medium-Earth Orbit (MEO), or Low-Earth Orbit (LEO), in relative motion with the Earth
3. High Altitude Platforms (HAPS): High Altitude Platforms (HAPS) are airborne vehicles, i.e., planes or balloons, watching over Earth from the stratosphere. Operating like satellites but closer to Earth, typically at 20 km altitude, they float above conventional aircraft flight altitudes and can offer continuous coverage of the territory below.

[1] ESOA is the world's only CEO-driven satellite association and leads a coordinated and impactful response to the global challenges and opportunities the commercial satellite communications sector faces (https://www.esoa.net)

3GPP studies on 5G integration of Non-Terrestrial Network solutions providing backhaul service as well as direct access to 3GPP "Class 3" UE began in March 2017, involving both cellular and satellite stakeholders. With the successful conclusion of the Study Phase, the Normative Phase of the standardisation may commence in January 2020, as part of the 3GPP Release 17 work package upon decision of 3GPP RAN#86 plenary meeting.

At the time of writing this report, NTN work item is a candidate for Release 17 work package. The NTN work in Release 17 would focus on features enabling 3GPP-defined NTN solutions to contribute to provision of eMBB/MBB services based on NR (5G). Furthermore, other NTN scenarios providing massive Machine Type Communication (mMTC) services based on LTE NB-IoT/LTE-M Technologies would be considered as part of study activity.

Targeted end-users include typical public users as well as the new emerging verticals, such as public safety, agriculture, utilities, mining, broadcasters, transportation (maritime, aeronautics, trains, buses, trucks or even cars) and logistics not to name others. Hence, both mass market devices such as smart phones as well as specific devices such as VSAT (fixed or mobile) with or without phase array antennas are in scope.

MNOs defined their requirements for space-based systems to guarantee smooth integration and complementarity with existing terrestrial networks especially in regions that are not easily accessible by conventional deployments. Mutual non-interference, mobility management between systems including roaming and sharing capabilities as well as requirements on handsets power consumption are listed.

To satisfy those requirements and meet some scenario characteristics, a number of important adaptations and enhancements of the 5G system standard may be required, including: timing relationship, UL time and frequency synchronisation, random access, timing advance, HARQ, RLC/PDCP sequence number extension, triggers for cell selection/reselection and hand-over procedures to cope with effects of motion of the space/aerial vehicles, altitude, cell ground footprint and propagation. Among these required adaptations, physical layer related areas are being carefully looked at since they may impact the design of the chipset. Nevertheless, the on-going study shows that the complexity of the needed modifications to support NTN is confirmed not to impact the 5G chipset design at UE level with the appropriate NTN infrastructure configurations.

The uniqueness of this document lies on the provision of link budget assessment for the feasibility of service transmission of 3GPP Class 3 UE by NTN platforms GEO, NGSO (LEO, MEO) or HAPS. In addition, several use cases including GEO fixed IoT direct connectivity, NGSO cellular backhaul, GEO maritime and connected cars with VSAT in Ku/Ka bands are addressed.

Those use cases link budget results yet not completely harmonized, provide good insights into future NTN performance and their ability to complement existing terrestrial networks in unserved and underserved areas for various end users and vertical markets.

The study of the Non-Terrestrial Networks Release 16 was completed during the 3GPP November 2019 meeting with the Technical Reports TR 38.821 and TR 23.737 finalised. 3GPP will reach a major milestone during the RAN Plenary #86 meeting (9-12th December 2019) by endorsing the content of the forthcoming Release 17 work package. As of writing this report, NTN has been selected as a candidate topic for 3GPP Release 17. Pending decision of RAN#86, the normative work may commence as part of 3GPP Release 17 package beginning January 2020.

Document History

Date	Version	Author	Changes
01/11/2019	V 0.1	ESOA	Section 2 & 4
08/11/2019	V 0.2	Orange	Section 3 + comments
08/11/2019	V0.3	Orange	Exec Summary
13/11/2019	V0.4	Vodafone	Executive summary, body of the text, conclusion
14/11/2019	V0.5	ESOA Members	Section 1 + Responses to comments
22/11/2019	V0.6	ESOA Members	Section 4.9, conclusion, edits to executive summary and responses to comments
26/11/2019	V0.7	ESOA Members	Review of executive summary, section 4.9 and conclusion
27/11/2019	V0.8	NGMN	Add contribution of Telus Review of conclusion.

Contents

1 INTRODUCTION

The purpose of this paper is to highlight the complementarity between terrestrial networks and space-based networks and to address the challenges faced by MNOs. Encouraging the integration of spaced-based networks with greatly expanded reach can help MNOs provide improved levels of service across their territories. The focus of this effort is to address line-of-sight connectivity for open spaces.

Phase1, which is presented in this document, addresses the generic high-level link performance utilizing input assumptions referenced in TR 38.821 for different NTN platforms and verticals. Phase 2 which will be delivered at a later date, will follow up with detail analysis planned to address specific NGMN requirements such as throughput capacity per beam, user density distribution and user experience performance.

1.1 Context and Rationale for Position Paper

Recent studies[2] estimate that about 4 billion people still lack access to internet and communication. With the increasing demand for rural, remote coverage, the cost of purely terrestrial coverage will become significant. Under these challenging conditions, terrestrial infrastructure could be complemented by spaced-based segments as envisaged for future 5G communication systems. Satellites will also support machine-type communications, paving the way for new applications ranging from smart agriculture to environmental protection, transportation, animal tracking, etc. It is commonly assumed that 5G systems must address multiple challenges including higher capacity, higher data rate, lower end-to-end latency, massive device connectivity, reduced cost, and consistent Quality of Experience (QoE) provisioning.

1.2 Approach

This paper has been developed in the frame of a joint project letter between ESOA and NGMN which purpose is to facilitate the rapid and efficient development of next generation mobile broadband networks in deep rural areas. It leverages the 3GPP Rel-16 “FS_NR_NTN_solutions” study item. Section 2 begins with an introduction of non-terrestrial system characteristics and prospects for their application as promising solutions to MNO in underserved and unserved areas. Section 3 describes the framework under which NTN could efficiently and seamlessly interacts with MNO networks in a 5G context. Section 4 describes the vision for NTN and the effort in 3GPP to be part of the 5G ecosystem. The effort includes studying the impact on NR in many aspects including physical layer, architecture, mobility and performance aspects. Additionally, section 4 offers several use case scenarios addressing the various verticals.

The last section concludes with observations and motivations for NGMN and MNO to support NTN in 3GPP Rel-17 and beyond.

2 NON-TERRESTRIAL NETWORKS PRESENTATION

2.1 Operators Requirement for Rural Environments

Coverage has historically been the main challenge for rural markets for its coverage and usability. The geography of rural access is far more varied than urban geography, with fjords, mountains, islands, ice, deserts, weather extremes and vast distances posing unique challenges to radio coverage, backhaul and power availability, and site construction and maintenance. In some areas, mountains are so high or distances so vast that wide area coverage is only likely to be possible from aerial or satellite platforms. Though the technological solutions are still emerging, there are compelling reasons for which operators would like to provide wide area coverage even where population densities are low and geography is challenging:

- Wide area connectivity provides a public safety benefit
- Wide coverage expands the addressable market for services

[2] https://www.internetworldstats.com/stats.htm

- Wide coverage technologies can allow an operator to divert other infrastructure spend away from achieving coverage and towards meeting capacity demand

Regardless of countries, rural markets are everywhere, and every MNO are facing this challenge. Operators in low ARPU emerging markets mainly in Africa, Latin America and Asia will have some specific requirements. Operators in higher ARPU markets (e.g. North American) will also have their own specificities.

2.2 Non-Terrestrial Networks (NTN)

Non-terrestrial networks (NTN) refers to networks based on spaceborne vehicles or an airborne platform for radio transmission. Satellites are spaceborne vehicles employing either a transparent bent pipe payload or a regenerative payload, placed into Geostationary Earth orbit (GEO), Medium-Earth Orbit (MEO), or Low-Earth Orbit (LEO):

Geostationary Earth orbit satellites: Circular orbit at 35,786 kilometres above the Earth's equator and following the direction of the Earth's rotation. An object in this orbit has an orbital period equal to the Earth's rotational period and thus appears motionless at a fixed position in the sky to ground observers.

Non-Geostationary Satellites: Satellites (LEO and MEO) orbiting around the Earth and moving across the sky. Medium-Earth Orbit (MEO) typically orbit at an altitude between 7,000 to 25,000 km and LEO typically at an altitude between 500 km to 2,000 km. A constellation of multiple Non-Geostationary satellites is necessary to carry service as they move over the horizon, requiring handover management to ensure service continuity.

High Altitude Platforms (HAPS): HAPS are airborne vehicles, i.e., planes or balloons, watching over Earth from the stratosphere. Operating like satellites but closer to Earth, typically at 20 km altitude, they float above conventional aircraft and can offer continuous coverage of the territory below.

Propagation contributes to the round-trip delay for transparent satellites which impacts the latency. However, latency decreases with altitude, from GEO to MEO down to LEO and HAPS. Maximum propagation delay contribution to the Round Trip Delay for transparent satellites is decreasing with altitude from 541.46 ms for GEO at 35786 km, 93.45 ms for MEO at 10000 km down to 25.77 ms for LEO at 600 km. HAPS latency is less than 10ms.

2.3 NTN integration in 5G system – 3GPP Context

In a few years everyone and everything will need to be connected: from any geographic location and including every application from consumer broadband to mobile gaming; connected cars to global business networks; ships, airplanes, and first responders; to connected farms and far more. Universal connectivity is a challenge that today's telecommunication infrastructure cannot address on their own. Fortunately, the 5G world promises a network architecture able to support a variety of access technologies. 3GPP has defined the specific requirements for provisioning 5G services with satellite in TS 22.261, "Service requirements for next generation new services and markets." The substantial value added of satellite as part of the access technologies mix for 5G is now becoming clear, especially for mission critical and other applications where ubiquitous coverage is crucial.

3GPP studies on 5G integration of non-terrestrial network solutions providing backhaul service as well as direct access to 3GPP Class 3 UE began in March 2017, involving both cellular and satellite stakeholders. At the time of writing this report, NTN work item is a candidate for Release 17 normative phase. Pending decision of 3GPP RAN#86 plenary in December, the normative phase may start as part of the 3GPP Release 17, beginning in January 2020.The NTN work in Release 17 will focus on an initial set of essential features supporting the most relevant use cases, enabling 3GPP-defined NTN solutions to contribute to provision of eMBB/MBB services based on 5G NR, and potentially eMTC services based on 4G NB-IoT/LTE-M.

2.4 NTN identified as promising solution

A major advantage of NTN integration into the 5G ecosystem will be to broaden service delivery, especially to unserved or underserved areas, by complementing and extending terrestrial networks. Space-based access networks in 5G will be vital to reliably serve passengers onboard moving platforms; populations in rural areas;

support flexible and fast network restoration, e.g., in the context of public protection and disaster relief; and sustaining audience access to content via efficient broadcast/multicast capabilities combined with edge-caching techniques thereby reducing core server and network loads.

These and other technological advances in space-based platforms will provide significant yet cost effective performance enhancements, in addition to improved capacity/coverage flexibility. Full integration of NTN within the 5G standard will open the door for creating new service capabilities critical for service continuity, reliability and widespread access to various verticals. It is envisioned that non-terrestrial networks based on GEO, MEO, LEO, and HAPS platforms will be seamlessly integrated within the 5G system and contributing to mobile network operator and verticals' success in meeting the challenge of ensuring reachability, reliability and system resiliency.

For MNOs, NTN applications offer a two-fold solution: Non-Terrestrial Networks (NTN), where GEO, MEO or LEO Satellites provide direct coverage to users without having to deploy traditional ground-based RAN Equipment; and utilizing satellite backhaul which are currently available today.

3 DEPLOYMENT SCENARIO DEFINITION

In rural or deep rural contexts, MNOs currently face economic sustainability problem to deploy traditional terrestrial coverage solutions. This was extensively studied in [NGMN Rural 1]. Non-Terrestrial Networks will likely be part of 3GPP Rel.17 and future releases and might be a promising alternative to conventional terrestrial coverage solutions. The inherent global coverage capabilities of satellites make them a good candidate for underserved areas coverage. On the other hand, from MNOs perspective NTN should complement existing MNOs networks especially on regions that are not easily accessible by conventional deployment and should not come into frontal competition in MNOs core business.

This section intends to describe the framework under which NTN could efficiently and smoothly interact with MNOs networks in a NR context.

- First space-based systems and mobile networks shouldn't interfere each other and satellite system shall manage and limit interference with existing terrestrial networks (UL & DL). Interference mitigation mechanisms and thresholds should be defined for systems where NTNs and terrestrial systems are co-channel, in adjacent channels, or in separated spectrum.
- Satellite system should be able provide distinct coverage cells along the border with ground based Cellular systems, such not to interfere with Terrestrial Cells.
- Practical Link RF Budget in the DL (Satellite to Ground) and in particular in the UL (Ground to Satellite) direction, based on a standard UE category with no enhancements nor modifications.
- Then satellite system shall enable direct communication to mass market smartphones. In contrast to a backhaul model, direct spatial communication should not require a relay link between the handset and satellite / aerial platform. LEO constellations and HAPS are seen as the most straightforward NTN technology to achieve direct access to smartphones from a link budget perspective. Direct access to MEO or GEO would certainly necessitate high power UEs to cope with high altitude propagation. Ground stations would be required to aggregate and disaggregate traffic to and from the satellite and to connect with local PLMN or PSTNs. Depending on the regulatory environment, one Ground Station per country/territory would be required. Direct communication to NTNs should be enabled by interoperable 3GPP standards, be possible to mass-market smartphones, and should not significantly impact smartphone production cost.
- To guarantee smooth integration between access networks mobility between terrestrial and satellite networks is critical. There should be smooth mobility solutions for UEs to be handed-out to the Satellites coverage area and handed-in to Cellular coverage area. Signalling in both terrestrial and non-terrestrial Systems must be developed to cater for smooth handover between systems. Multi connectivity support, either for transparent or regenerative NTN-based NG-RAN, and in combination or not with terrestrial-based NG-RAN would ease smooth integration between access networks by supporting simultaneously more than one radio access. Multi connectivity would help addressing high-speed trains and motorways use cases.

- Non-Terrestrial satellite networks should be able to support for multi-band and multi frequency operation to cater for regional and regulatory spectrum variations such as sub 1GHz to sub 6GHz bands. One essential component would be to have flexible and tuneable antenna banks to efficiently tune from e.g. 700 MHz to 3.5 GHz.
- The Feeder Link Capacity, between the Space Segment and the Ground Based Equipment should have sufficient capacity not to choke the transmission from the UEs in the NTN cells and Cellular Networks Cells.
- NTNs can be shared between MNOs. Ground coverage of NTNs can be used by several MNOs with appropriate RAN sharing and hosting mechanisms. Roaming should be allowed on NTNs.
- Solutions for Lawful Intercept must be developed to provide regional Regulatory requirements
- As Space and Ground Segment Equipment capacity is related to the number of subscribers that is served by the satellite system, a number of generic Traffic Models are to be developed to illustrate expected traffic combinations for the following:
  - Voice and Text service
  - Mobile broadband service
  - Narrow Band IoT applications
  - Regional variations e.g. Rural Africa, Dense European Urban etc.
- A Flexible / tuneable Satellite Footprint on the ground to focus the beam from small to large radii coverage From a Green perspective in coverage of satellite system, mobile handsets battery consumption should remain comparable as when in terrestrial network coverage. Signaling load is expected to be comparable under satellite coverage stationary cells. Signaling load is expected to increase with Moving Satellite Cells, however new enhancements should be introduced to limit unnecessary overhead signaling.

Table 3-1: MNOs generic requirements toward space-based systems

MNOs generic requirements
Satellite system shall manage and limit interference with existing terrestrial networks (UL & DL)
Satellite system shall enable direct communication to mass market smartphones
Mobility between terrestrial and satellite networks is required
Roaming is allowed on NTNs
NTNs can be shared between MNOs
In coverage of satellite system, mobile handsets battery consumption should remain comparable as when in terrestrial network coverage
Ability to Lawful interception in the country

4 DEPLOYMENT SCENARIO ASSESSMENT

4.1 Vision for NTN

3GPP studies on 5G integration of non-terrestrial network solutions providing backhaul service as well as direct access to 3GPP Class 3 UE began in March 2017, involving both cellular and satellite stakeholders. The subsequent normative phase is expected to start as part of the 3GPP Release 17, beginning in January 2020. The vision is to deploy non-terrestrial networks as part of 5G by 2025 in order to meet the challenges of mobile network operators and verticals in terms of reachability, availability and resiliency. This encompasses all deployment options like GEO, MEO, LEO, as well as HAPS.

To achieve this goal, NTN is currently being studied by 3GPP in Release-16, with the intention of including non-terrestrial access and/or transport network support in the Release-17 specifications.

It has been identified that NTN solutions for direct access introduce potentially new constraints compared to typical cellular deployments due to moving cell patterns, larger Doppler shifts and variation, larger and varying propagation delays, larger cell sizes, the highly frequency selective propagation channel, the power limited link budget and due to feeder link handover.

4.2 Approach to Standards

The integration of non-terrestrial networks (satellite and HAPS based) in the 3GPP 5G eco-system aims at complementing the coverage and availability of cellular networks. Targeted end-users are the typical public end users as well as the new emerging verticals, such as transport & logistics, public safety, agriculture, utilities, mining, broadcasters, transportation (maritime, aeronautics, trains, buses, trucks or even cars) and logistics not to name others. Hence, both mass market devices such as smart phones as well as specific devices such as VSAT (fixed or mobile) with or without phase array antennas are in scope.

The following performances for mass market devices are have been assumed: 3GPP Class 3: 0 dBi gain antenna (linear polarization), maximum 200 mW transmit power (23 dBm) and 7 dB of Noise figure.
The cellular and satellite industry stakeholders have studied and defined over the past 24 months enabling features for 5G systems to support non-terrestrial networks (i.e. satellite and HAPS). This pre-standardisation work is reflected in the table below:

Table 4-1: List of Non-Terrestrial Network related documents developed by 3GPP

Item reference	Lead WG	Title	3GPP doc	Completion date
SI ”FS_NR_nonterr_nw on NR”	RAN	Study on New Radio (NR) to support Non Terrestrial Networks (Release 15)	TR 38.811	June 2018
SI ”FS_NR_NTN_solutions”	RAN3	Solutions for NR to support non-terrestrial networks (NTN) (Release 16)	TR 38.821	Dec 2019
SI ”FS_5GSAT”	SA1	Study on using Satellite Access in 5G; Stage 1 (Release 16)	TR 22.822	June 2018
WI ”5GSAT”	SA1	CR’s to Service requirements for the 5G system; Stage 1 (Release 16)	TS 22.261	Dec 2018
WI ”FS_5GSAT_ARCH”	SA2	Study on architecture aspects for using satellite access in 5G (Release 16)	TR 23.737	Nov. 2019
WI ”FS_5G_SAT_MO”	SA5	Study on management and orchestration aspects of integrated satellite components in a 5G network	TR 28.808	Dec 2019

There are several effects creating impacts on 5G standards to support “NTN”. They are listed in the table below and depend on the NTN reference scenario considered (See 3GPP TR 38.811 table 8.3-2).

Table 4-2: NR impacts to support the reference scenarios of Non-Terrestrial Networks

Effects		HAPS	LEO	MEO	GEO	HEO
Motion of the space/aerial vehicles	Moving cell pattern	*Yes if beams are moving on earth*	*Yes if beams are moving on Earth (hence high speed)*[3]	*Yes if beams are moving on Earth (hence high speed)*	*No*	*Yes if beams are moving on Earth (hence high speed)*
		No if beams are fixed on Earth	*No if beams are fixed on Earth*	*No if beams are fixed on Earth*		*No if beams are fixed on Earth*
	Delay variation	*No*	*High (Note 3)*	*Medium (Note 3)*	*No*	*Low (Note 3)*
	Doppler	*TBD*	*High (Note 3)*	*Medium (Note 3)*	*Negligible*	*Low (Note 3)*
Altitude	Latency	*Negligible*	*Low*	*Medium*	*High*	*High*
Cell size	Differential delay	*Small*	*Typically relatively medium*	*Typically relatively medium*	*Possibly relatively high*	*Possibly relatively high*
Propagation channel	Frequency selectiveness impairments	*Note 4*	*Note 4*	*Note 4*	*No*	*No*
	Delay spread impairments	*Note 4*	*Note 4*	*Note 4*	*No*	*No*
Duplex scheme	Regulatory constraints	*FDD and Possibly TDD*	*FDD and Possibly TDD*	*Only FDD*	*Only FDD*	*Only FDD*
Note 3: Doppler and Delay variation can be pre-compensated at beam centre. In such case residual Doppler and Delay variation can be accommodated by the UE						
Note 4: Some delay spread and frequency selective effect can be experienced in case of omni-directional antenna device especially at low elevation angle						

Some additional scenario characteristics will also impact the 5G system standard:

- Max cell size especially for LEO and GEO based access
- Transparent or regenerative payload options
- earth fixed or mobile cells especially for HAPS and LEO based access scenarios
- UE with location determination capability (e.g. GNSS) or not especially for LEO and GEO based access scenarios

[3] Assuming fixed relation between beams and cells

- targeted usage scenarios (See table B.2-1: Non-Terrestrial network target performances per usage scenarios in TR 38.821 and in the annex of this document).
- UE type (3GPP Class 3 or other)

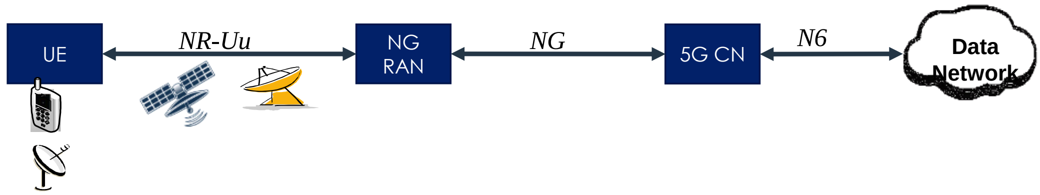

Figure 4-1: Transparent payload based Non-Terrestrial network integration in 5G system architecture

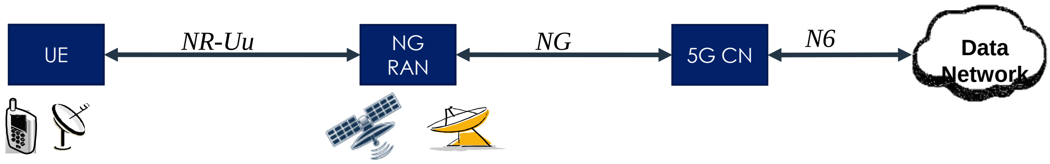

Figure 4-2: Regenerative payload (gNB on board) based Non-Terrestrial network integration in 5G system architecture

For Earth fixed cells, the cells are fixated to a certain location on earth from the time where the satellite (these cells belongs to), is at a certain elevation angle over the horizon until the same satellite has reached the same elevation angle at the opposite horizon. At that point in time, another satellite takes over and all Connected UEs are handed over to a new cell at the new satellite. Only UEs in cells at the satellite coverage border are subject to the handover.

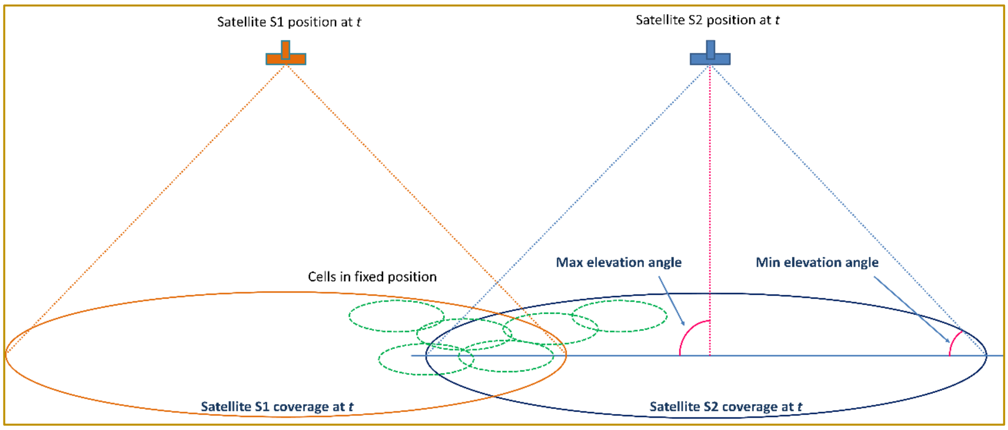

Figure 4-3: Earth fixed cells

For Earth moving cells, the cells follow the satellite coverage, and move with the speed of the satellite, i.e. 7.5 km/s. cells the UEs in the satellite coverage have to be handed over gradually as the coverage area of the cells moves.

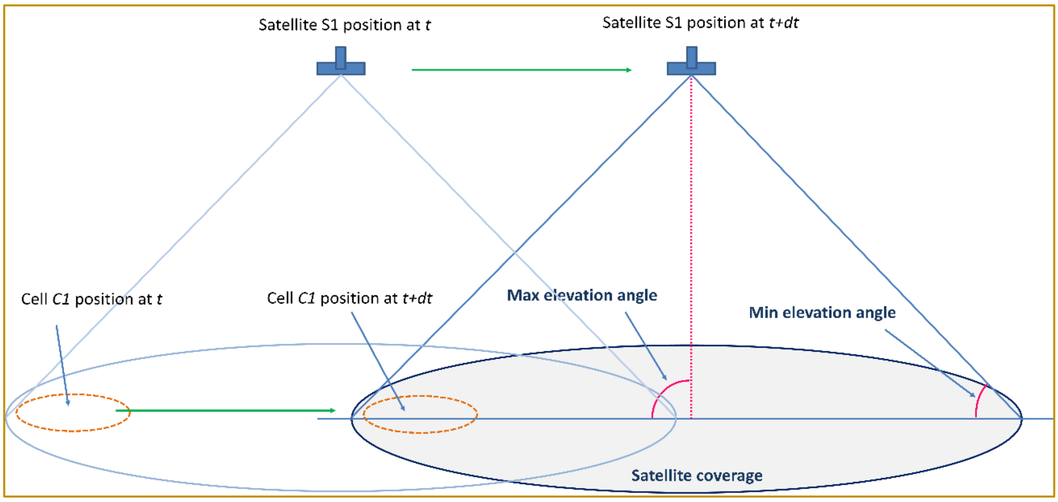

Figure 4-4: Earth moving cells

The preference from the Operators is to have an NTN solution based on 3GPP Standards to enable inter-operability and integration with Terrestrial Systems, in particular the inter-operability between multi-vendor Satellite and Ground Based Equipment suppliers.

4.3 Impacts on the 5G Standards

Depending on the considered NTN scenario (orbit, device, frequency band), the following 3GPP NR/NG-RAN features may need to be enhanced: timing relationship, UL time and frequency synchronisation, random access, timing advance, HARQ, RLC/PDCP sequence number extension, triggers for cell selection/reselection and hand-over procedures, feeder link handover over procedure, radio resource management, and multi-connectivity/mobility management across cellular/NTN access.

Among these required adaptations, physical layer related features should be carefully looked at since they may impact the design of the chipset. Nevertheless, the 3GPP REl-16 study has demonstrated that the level of complexity of the necessary modifications, is confirmed not to impact the 5G chipset design at UE level with the appropriate NTN infrastructure configurations.

4.4 Network architecture design choices

The studies for NR to support Non-Terrestrial Networks considered different reference scenarios:

Table 4-3: Reference scenarios as defined in TR 38.821

	Transparent satellite	Regenerative satellite
GEO based non-terrestrial access network	Scenario A	Scenario B
LEO based non-terrestrial access network: steerable beams	Scenario C1	Scenario D1
LEO based non-terrestrial access network: the beams move with the satellite	Scenario C2	Scenario D2

For transparent satellite, the payload implements frequency conversion and a Radio Frequency amplifier in both up link and down link direction. It corresponds to an analogue RF repeater whereby the satellite repeats the NR radio interface from the feeder link (between the 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 NTN 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.A critical issue to note here for Transparent Satellite system is the feeder link capacity, from the space down to the ground segment. The feeder Link must be sufficient not to choke or limit the traffic from the UEs.

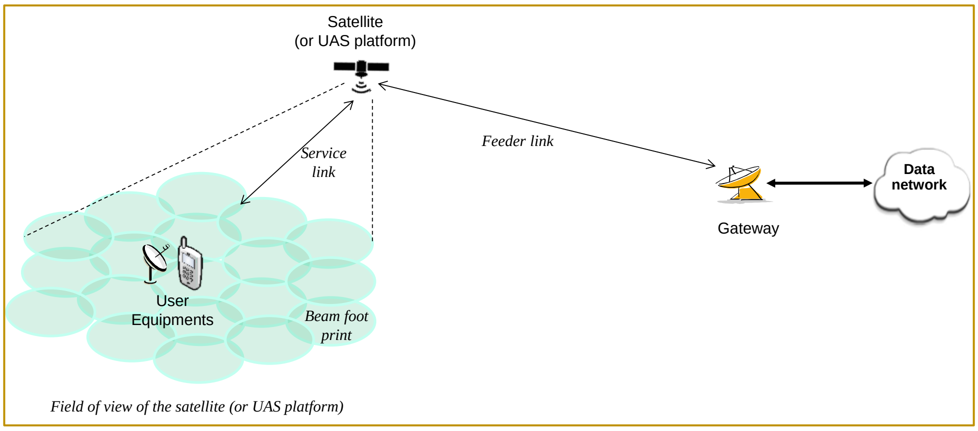

Figure 4-5: Non-terrestrial network typical scenario based on transparent payload

For Regenerative satellite-based NG-RAN architectures, the NG-RAN logical architecture as described in TS 38.401 is used as baseline for NTN scenarios. The satellite payload implements regeneration of the signals received from Earth. NR-Uu radio interface is on the service link between the UE and the satellite and the satellite Radio Interface (SRI) is on the feeder link between the NTN gateway and the satellite.

MEO scenarios feature characteristics which are less challenging than GEO scenarios in terms of latency and similar or less than LEO scenarios for the other effects (e.g. Doppler). Hence, if the normative work considers LEO scenarios, the 5G system will also be able to support MEO scenarios. HEO scenarios have been postponed to future releases given their very specific use case.

4.5 NR Spectrum and Radio Resource Management

New Radio (5G NR) is an evolution of the 4G radio interface developed for 5G to support the wide variety of services, devices and deployments across diverse frequency bands. 3GPP had identified two frequency ranges for 5G NR, FR1 below 6GHz and FR2 above 6GHz.

Satellite operators use radio frequencies based on ITU-allocated frequency bands for satellite communications, as shown in *Appendix 6A*. The designation of band classes allocated to satellite services within 5G NR will allow for deployment of future 5G NR services and applications via NTN. Satellite intends to bring its own frequency bands based on ITU-allocated for NTN NR. For direct communications to mass market devices, operation of the satellite service link in FR1 frequency range will be more suitable to allow maximum commonality in the RF front end of the devices.

Introduction of any new bands that will have to consider interference to other services sharing the same band and services in adjacent bands. To illustrate when LTE Band 65 (2.1 GHz) was introduced, a thorough interference analysis was conducted to ensure protection of adjacent services operating within the same frequency range. This involved identification of mitigation techniques and appropriate measures. Harmonization effort was done by modifying existing ETSI EN 302 574-1 and ETSI EN 302 574-2 which provided the legal framework for RF conformance testing against identified frequencies. For the UE, this work was subsequently incorporated in 3GPP TS 36.521-1.

There is on-going work in 3GPP TR 38.819 lead by RAN4 to standardize MSS band as part LTE Band 65 for NR (n65). In essence, NTN can operate in FR1 or FR2 ranges. Defining NR bands for NTN should be included as part of dedicated Rel-17 RAN4 led work items including an analysis of regulations in spectrum considered, which bands 3GPP should specify, as well as potential co-existence between NR terrestrial and satellite.

4.6 Mobility management impact: seamless mobility between terrestrial and satellite

To guarantee smooth integration between access networks mobility between terrestrial and satellite networks is required. The mobility management procedures require adaptation to accommodate large propagation delays, between satellite and UE. 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 will be addressed with high priority in both cases.

4.6.1 Service Continuity

In 3GPP TS 22.261 (Clause 6.2.3 Service continuity requirements), for a 5G system with satellite access, the following requirements apply:

- The 5G system shall support service continuity between 5G terrestrial access network and 5G satellite access networks owned by the same operator or owned by 2 different operators having an agreement.

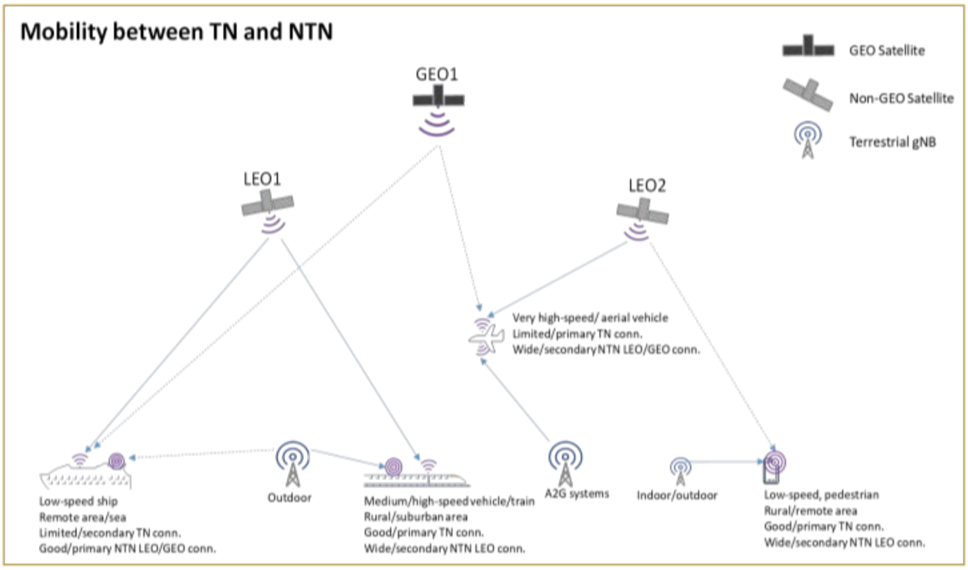

Figure 4.6: Typical example of NTN-TN interworking

The focus of the studies carried out in the 3GPP Standardisation forums is to develop a practical and efficient solution for mobility scenario for the following cases:

- NTN to TN – A hand in scenario
- TN to NTN – A hand-out scenario

For the NTN-TN service continuity and mobility studies, most companies agree to use a simple outdoor scenario where outdoor handheld (pedestrian) UEs or VSAT (vehicular relay) UEs are capable of TN and NTN connectivity (for NTN UE use Table 6.1.1-3 in TR 38.821 v0.9.0). Further assessment will be done to determine if the baseline NTN-TN service continuity and mobility mechanism solutions rely only on the detection of TN coverage edge using RSRP/RSRQ threshold and/or PLMN indication.

In the case of idle/inactive mode UE procedures in NTN, the NR mechanism in TN system is regarded as the baseline. For adaptation of existing procedures, several issues were considered to minimize too frequent update and not to cause signalling burden; one scenario to note is the frequent Traffic Area Update for moving LEO cells, which potentially could add substantial signalling load on the network. Implementation and deployment techniques can also resolve some of the issues caused by low power transmission from the UE. One example to resolve poor uplink RF link budget is to have highly tuned and sensitive antennas on board the Satellites.

4.6.2 Roaming

The proposed NTN system is intended to provide overlay to terrestrial networks. NTN is specifically targeted at providing services in underserved and unserved areas, when out of coverage of the terrestrial home network. Thus, satellite and terrestrial interoperability is a key issue to provide subscribers the quality and diversity of service offered by terrestrial systems plus the broad coverage offered by satellite systems.
This will affect the following:

- identification method of cells,
- the design of tracking and location areas,
- the roaming between Terrestrial and Non-Terrestrial networks
- billing procedures and
- location-based services.

The above issues are expected to be resolved by network planning between Cellular Operators in conjunction with Satellite Service providers. The issue on regulatory and commercial requirements for super-national cell coverage areas is being discussed in the SA2 working group.

In TR 22.822 the following PR had been identified and approved:

- [PR 5.1.5-002] A 5G system with satellite access, shall enable roaming between 5G satellite access networks and 5G terrestrial access networks.
- [PR 5.1.5-003] A 5G system with satellite access shall support network reselection based on home operator policy, even when a UE is still in coverage of its current network.
- [PR 5.1.6-002] A 5G system with satellite access shall enable roaming between 5G satellite access networks and 5G terrestrial access networks.

4.7 Potential deployment synergies between terrestrial 5G network and NTN ground segment

Any satellite network deployment relies on a rich ground infrastructure in order to deliver traffic at an optimal point of presence for the Mobile Operator network (from the legacy BSC, RNC to the Core Network or instances of Core network functionality). At an architecture level, a collaboration between the satellite service providers/infrastructure providers and the Mobile Network Operators (MNO) can take advantage of the extensive fibre infrastructure and data centres already used for content, core and access delivery and therefore reduce the Total Cost of Ownership of the overall 5G network architecture by integrating backhaul and service delivery methods for the benefit of the 5G subscribers.

This cooperation could take several forms: from the simple sharing of fibre links, the hosting or sharing of network peering points environments (Data Centres) to the hosting of the satellites operators gateways earth stations (Teleports) on a Mobile Operator' owned property taking advantage of shared resources such as redundant fiber routes and better integration with core network access. Hub hosting or Gateway hosting could further improve the delivery of high availability connectivity, better integrate with the MNO's network management system and reduce latency and jitter in the overall quality of the traffic delivery. In addition, the use of satellite as a non-terrestrial overlay allows for an independent, ubiquitous and redundant connectivity for all terrestrial network nodes, increasing the resiliency of the overall 5G network fabric.

4.8 Corollary: specific needs for resource optimization and orchestration of network functions close to the edge

Satellite can efficiently deliver rich multimedia and other content across multiple sites simultaneously using broadcast and multicast streams with information centric network and content caching for local distribution.

In the EC project SaT5G a review of possible use cases was identified in the deliverable D2.1[4] (not public); the first use case was called "Trunking and Head-end Feed". This Use Case addresses high-speed trunking of video, IoT and other data to a central site, with the potential of further terrestrial distribution to local cell sites, for instance neighbouring villages.

The satellite link is used as an overlay to leverage its inherent multicast capabilities and efficiencies, and its ability to reach every point across the satellite coverage. The project has identified a potential design and architecture that are summarised in the *Appendix* C:

4.9 Performance assessment: can space-based system meet MNO's service requirements and link budget

This section presents the link analysis of total 8 use cases that are based on GEO, LEO and HAP space-based platforms, covering FR1 and FR2 bands and utilizing future satellite payload architecture technology. Reports targets a total 6 verticals addressing 3GPP "Class 3", "VSAT type" and IoT UE.

4.9.1 Satellite Technology view

Future Satellite and payload architectures that are considered in some of the use cases are shown below:

- Steerable and overlapping capacity
- Large number of beams (hundred to thousands) utilizing the BFN (Beam Forming Network)
- Polarization diversity (dual-pol UE) double the link capacity over the same spectrum
- BFN optimised beam-to-beam isolation and interference to increase link capacity/throughput
- Better aggregate capacity due to dynamic channelization and BFN
- Tracking mobile devices – similar to MU-MIMO
- Digital payloads allow to manage gain and performance on a per channel basis.
- Large antenna size providing high transmit EIRP density and high receive antenna gain

4.9.2 Use cases

8 use cases have been considered as NTN candidates are presented in the following table. Some use cases and scenarios are considered for link assessments against the NGMN requirements, by considering the following segmentation:

1. Direct access to "Class 3" UE: use cases # 1, 2, 3, 4
2. Direct access to "VSAT type" UE for cruise ship, connected cars and community WiFi: use case # 6, 7,8
3. Direct access to IoT devices: use case # 3
4. Backhaul for cellular or WiFi access networks: use case # 5

[4] https://www.sat5g-project.eu

Table 4-4: Use cases

Use case	Scenario	Frequency band	Vertical	UE Class	UE Location	Service Type	Contributor
1	LEO (NGSO)	S Band	Land-mobile (pedestrian)	"Class 3"	North America	MBB services	Thales Alenia Space
2	HAPs	1.8 GHz	Land-mobile (pedestrian)	"Class 3"	Nigeria	MBB services	Intelsat
3	GEO	L Band	Fixed IoT	"Class 3" IoT device	Algeria	IoT services	Inmarsat
4	GEO	S Band	Land-mobile	"Class 3"	Rural America and Africa	MBB services	EchoStar
5	LEO (NGSO)	Ku Band	Community WiFi/ Cellular Backhaul (2G, 3G, 4G or 5G)	Flat Panel Antenna	Central Africa	Cellular backhaul services	Oneweb
6	GEO HTS	Ku Band	Maritime	"VSAT type" (panel)	Mediterranean Sea	Vertical (maritime)	Intelsat
7	GEO HTS	Ka Band	Connected car	"VSAT type" (panel)	Western Europe or North America	Vertical (connected car)	Avanti
8	GEO	S Band	Community WiFi	"VSAT type"	Rural America and Africa	Fixed & mobile services	EchoStar

Detail assumptions for each use case are presented in "Appendix B: Performance assessment".

The methodology has been defined in the 3GPP reference document TR 38.821 v1.0.0 (chapter 6.1.3.1: Link Budget Calculation). A reference link budget was conducted to assess the feasibility of service transmission of 3GPP Class 3 UE by NTN space-based GEO and NGSO (LEO, MEO and HAPS). The performance requirements provided for different traffic profiles was assessed for different space-based platforms. The analysis was conducted assuming parameters defined in TR 38.821 (unless otherwise stated).

4.9.3 Use cases comparison

Table 4-5: Use case comparison

Use case	Space segment & frequency bands	Type of terminals	Radio interface/ access	Added value for 5G	Spectral efficiency in bps/Hz (DL/UL)	Example throughput assuming 10 MHz channel (Mbps DL/UL)[(1)]	Service Type
1	NGSO/S Band	Handset (0.2 W Tx power class, Gain 0 dBi, NF 7 dB)	3GPP defined NR	Service Continuity	1.35 / 1 [(2)]	13.5 / 10	MBB services

2	HAPS/L Band	Handset (0.2 W Tx power, Gain 0 dBi, NF 7 dB)	3GPP defined NR	Service Continuity	5.5 / 5.5	55 / 55	MBB services
3	GEO/L Band	IoT device (0.2 W Tx power, Gain 0 dBi, NF 5 dB)	3GPP defined NB-IoT	Service Continuity	1.7 / 0.7	17 / 7	IoT services
4	GEO/S Band	Handset (0.2 W Tx power, Gain 0 dBi, NF 7 dB)	Non 3GPP defined radio interface	Service ubiquity	1.2 / 1 (2)	12 / 10	MBB service
5	LEO/Ku Band	Flat Panel Antenna (2 W Tw power, Gain 18 dBi, NF 3dB)	Non 3GPP defined radio interface	Service Scalability	3.3 / 3.5	33 / 35	Cellular backhaul services
6	GEO/Ku Band	VSAT (8 W Tx power, Gain 27 dBi, NF 2.5 dB)	Non 3GPP defined radio interface	Service Scalability	1 / 1.9	10 / 19	Vertical (maritime)
7	GEO / Ka Band	VSAT (car mounted)	Non 3GPP defined radio interface	Service Scalability	0.9 / 1.3	9 / 13	Vertical (connected car)
8	GEO/S Band	VSAT (2 W Tx power, Gain 39.7 dBi, NF 5 dB)	Non 3GPP defined radio interface	Service Scalability	4.0 / 2.5 (2)	40 / 25	Fixed & mobile services

Notes
(1) 10 MHz carrier is for illustration and comparison purpose only. This does not mean a particular use case will deploy 10 MHz in both directions. For example, use case #3 (NB-IoT) would deploy 200 kHz carrier in the forward and will not deploy 10 MHz carrier. Ku and Ka Band may use higher than 10 MHz channel bandwidths.
(2) at 30-degree elevation

4.10 Identification of new enablers and new capabilities brought by space-based system (that would come in addition to support of direct access to smartphones)

5G networks will need to operate in a highly heterogeneous environment characterized by the existence of multiple types of access technologies. Multiple access technologies already included in 3GPP TS 22.261 V15.5.0(2018-07) section 6.3.

4.10.1 Vertical Markets

For space-based systems, TR 22.822 included 12 use cases that have been identified as to address various Vertical markets. Three main service categories have been identified, Service Continuity, Service Ubiquity and Service Scalability.

Service Continuity

- Roaming between terrestrial & satellite (section 5.1)
- Satellite transborder service continuity (section 5.6)
- Indirect connection through a 5G satellite access network (section 5.8)
- 5G fixed backhaul between NR and the 5G core (section 5.9)

Service Ubiquity

- Internet of Things with a satellite network (section 5.3)
- Temporary use of a satellite component (section 5.4)
- Optimal routing or steering over a satellite (section 5.5)
- Global satellite Overlay (section 5.7)
- Satellite connection of remote service centre to off-shore wind farm (section 5.12)

Service Scalability

- Broadcast & multicast with a satellite overlay (section 5.2)
- 5G moving platform backhaul (section 5.10)
- 5G to premises (section 5.11)

Additionally, Connected Car is a new Vertical market with high potential Use Cases that includes capabilities as following:

Service Continuity

Vehicle telematics or mobile service for passengers continue to be provided when outside of mobile coverage area

Service Ubiquity

- Connectivity between Mobile Core network and base station serving IoT devices in a cell or a group of cells.
- Provide extension of coverage for mMTC

Service Scalability

- Broadcast/multicast same content or data to millions of vehicles simultaneously
- Automotive industry to provide Firmware / Software

5 CONCLUSIONS

Non-Terrestrial network solutions can contribute to the deployment of 5G services for the provision of coverage, capacity, reliability and availability as a complement to cellular networks. Satellite can be particularly valuable in extending 5G services to rural and extremely rural areas. This added value will be maximized via seamless integration of satellite networks within 5G, enabled by the development of 3GPP standards supporting satellite access & backhaul solutions as part of Rel-17 and beyond.

In this Phase 1 report, several use cases with distinct verticals are presented, representing various space-based systems access technologies and addressing Service Continuity, Ubiquity and Scalability.

It has been demonstrated through the various use cases that space and high altitude-based platforms can provide direct mobile broadband access to Class 3 UE, VSAT UE and IoT devices:

- With Class 3 UE, LEO (using 3GPP air interface) and GEO (using non-3GPP) can provide mobile broadband services. Furthermore, HAPs (using 3GPP air interface) can also provide mobile broadband services.
- With VSAT UEs, both GEO and LEO can provide home broadband, broadband connectivity to connected cars, airborne vehicles and cruise ship/vessels
- With Class 3 UE, GEO (using 3GPP air interface) can also provide global IoT services

It can also be summarized:

- Due to the lower orbits LEO and HAPS provided benefits of lower RTT and high throughput
- GEO with advance phased array and beamforming results in higher transmit power and high throughput

- Propagation contributes to the round-trip delay for transparent satellites which impacts the latency. However, latency decreases with altitude, from GEO to MEO down to LEO and HAPS.

Following table summarises outcomes of the use cases study:

Use case category	UE Class	Space platform	Frequency band	Example throughput assuming 10 MHz channel (Mbps DL/UL)(1)	Added value for 5G
Land-mobile (pedestrian)	3GPP Class 3	LEO (NGSO)	S Band	13.5 / 10	MBB Service Continuity (outdoor)
	3GPP Class 3	HAPs	1.8 GHz	55 / 55	
	3GPP Class 3	GEO	S Band	12 / 10	
IoT	3GPP Class 3(2)	GEO	L Band	17 / 7	IoT Service continuity (outdoor)
Direct VSAT access for Verticals (Maritime, Connected car, community WiFi)	VSAT	GEO	S Band	40 / 25	Fixed & mobile services in unserved areas
	VSAT Flat Panel Antenna	GEO HTS	Ku Band	10 / 19	Vertical (maritime)
	VSAT Flat Panel Antenna	GEO HTS	Ka Band	9 / 13	Vertical (connected car)
Backhaul Support for Community WiFi or/and Cellular 2G, 3G, 4G or 5G	Flat Panel Antenna	LEO (NGSO)	Ku Band	33 / 35	Cellular backhaul in unserved & underserved areas

Notes:

(1) 10 MHz carrier is for illustration and comparison purpose only. This does not mean a particular use case will deploy 10 MHz in both directions. For example, use case #3 (NB-IoT) would deploy 200 kHz carrier in the forward and will not deploy 10 MHz carrier. Ku and Ka Band may use higher than 10 MHz channel bandwidths.

(2) NF = 5 dB

Phase 2 of the ESOA-NGMN joint efforts will assess how the specific MNO requirement and user traffic profiles can best be addressed for tailored systems with technical feasibility analysis based on 3GPP NTN radio interface.

LIST OF ACRONYMS

ARPU	Average Revenue Per User
CDN	Content Delivery Networks
eMBB	enhanced Mobile Broadband
GEO	Geostationary Orbit
HAPS	High Altitude Platforms
LEO	Low Earth Orbit
MCL	Maximum Coupling Loss
MEO	Medium Earth Orbit
mMTC	massive Machine Type Communication
MNO	Mobile Network Operator
NGSO	Non-Geostationary Orbit
NTN	Non-Terrestrial Networks
UE	User Equipment
VoD	Video on Demand
VSAT	Very Small Aperture Terminal

BIBLIOGRAPHY

[1] Extreme Long Range Communications for Deep Rural Coverage (incl. airborne solutions) by NGMN Alliance; 17th May 2019 – https://www.ngmn.org/wp-content/uploads/Publications/2019/190606_NGMN_5G_Ext_Long_Range_D1_v1.7.pdf

6 APPENDIX A: ITU ALLOCATION

6.1 ITU-Allocated Frequency Bands for satellite communications

The information on ITU-Allocated Frequency Bands for satellite communications, was derived from the ITU document: Section IV – Table of Frequency Allocations of Radio Regulations Articles, Edition of 2016:

Satellite Band	Downlink	Uplink
L band (GEO)	1518 – 1559 MHz	1626.5 – 1660.5 and 1668 – 1675 MHz
L band (Non-GEO)	1613.8 – 1626.5 MHz	1610.0 – 1626.5 MHz
C band	3400 - 4200 MHz and 4500 - 4800 MHz	5725 - 7025 MHz
S Band	2160 -2200 and 2483.5 - 2500 MHz	1980 - 2025 MHz
Ku band	10.7 - 12.75 GHz	12.75 - 13.25 GHz and 13.75 - 14.5 GHz
Ka band (GEO)	17.3 – 20.2 GHz	27.0 – 30.0 GHz
Ka band (Non-GEO)	17.7 – 20.2 GHz	27.0 – 29.1 GHz and 29.5 – 30.0 GHz
Q/V band	37.5 – 42.5 GHz, 47.5 - 47.9 GHz, 48.2 - 48.54 GHz, 49.44 - 50.2 GHz	42.5 – 43.5 GHz, 47.2 – 50.2 GHz, 50.4 – 51.4 GHz

7 APPENDIX B: PERFORMANCE ASSESSMENT

7.1 NTN use cases description

7.1.1 Use case 1: NGSO direct access

Use case #	Scenario	Frequency band	Vertical	UE Class	UE Location	Contributor
1	LEO (NGSO)	S-band	Land-mobile (pedestrian)	Class 3	North America	Thales Alenia Space

7.1.1.1 Rationale:

Already some mobile satellite systems provide the capability to serve directly handset terminals from a space infrastructure whether GSO or Non GSO. However, this requires specific handset with either specific antenna/radio front-end and/or a specific radio interface protocol.

In the context of Rel-16, the ongoing study item “NR support non-terrestrial networks” investigate the feasibility of serving directly 3GPP Class 3 UE from a space infrastructure. Such terminal corresponds to the vast majority of smartphones or even IoT devices on the cellular market whether for 4G or 5G systems. This would provide capability for any smartphones or IoT devices to benefit from a satellite coverage in complement from the cellular coverage hence fulfilling the ATAWAD (Any Time, Any Where, Any Devices) requirements for the benefit of both consumer and vertical markets.

NTN direct access to 3GPP Class 3 UE is expected to complement and extend cellular networks with provision of outdoor eMBB services with satellites line of sight situations. Note that NTN direct access is not designed to provide indoor and dense urban environment coverage.

7.1.1.2 Assumptions and methodology

The assumptions can be found in table 6.1.1-1 “Set-1 satellite parameters for system level simulator calibration” in TR 38.821 v0.9.0:

- Satellite parameters
  - Satellite orbit: circular
  - Satellite altitude: 600Km
  - Transparent payload
  - Equivalent satellite antenna aperture: 2 m (circular polarised)
  - Satellite EIRP density: 34 dBW/MHz
  - Satellite G/T: 1.1 dB K^{-1}
- User Equipment
  - 3GPP Class 3 UE
  - Antenna gain: 0 dBi, linear polarised (+/-45°X-pol)
  - Noise figure: 7 dB
  - Tx power: 200 mW (23 dBm)
- Service link
  - Frequency band for the service link: 2 GHz (downlink) – 2 GHz (uplink)
  - Propagation model: See 3GPP TR 38.811 (Parameters defined in Clause 6 of 3GPP TR 38.821)

7.1.1.3 Methodology

Link analysis performed using link budget calculation defined in clause 6.1.3.1 of TR 38.821.

- Feeder link is assumed to be dimensioned in a way that doesn't degrade the service link (satellite – UE) performance.
- Target elevation angle: 30°.
- Frequency reuse: 3

This corresponds to case 10 of the simulation cases.

7.1.1.4 Conclusions

Using the assumption highlighted above and the described methodology, the following results are achieved:

Table 7-1: Link budget summary for NGSO providing direct access to 3GPP class 3 UE

	Downlink	Uplink
CNR	~6.5 dB	~2.5 dB
C/I	~12 dB	~15 dB
CINR	~5.5 dB	~2.5 dB
Spectral efficiency	~1.35 bps/Hz	~1 bps/Hz
Channel bandwidth	10 MHz	360 kHz
Experienced data rate (average)	~13.5 Mbps	~300 kbps

Note 1: yet to be consolidated at 3GPP RAN1#99 meeting in Reno
Note 2: Higher performances can be expected for UE with better RF characteristics (e.g. car mounted devices)

Please note that this is to be compared with the performance targets considered for evaluation purposes (see table B.2-1 of TR 38.821) for the pedestrian usage scenario:

Usage scenarios	Experience data rate		Max UE speed	Environment	UE categories
	DL	UL			
Pedestrian	2 Mbps	60 kbps	3 km/h	Extreme coverage	Handheld

7.1.2 Use case 2: Land mobile via HAPS

Use case #	Scenario	Frequency band	Vertical	UE class	Comments	Responsible
2	HAPS	1.8 GHz	Land-mobile (pedestrian)	Class 3	Nigeria Deep Rural cases	Intelsat

7.1.2.1 Rationale

High Altitude Platform Station (HAPS) are unmanned air vehicles that fly at nominal altitude of 20km +/- 2 km at a fixed-point position relative to Earth. Compared to LEO, MEO, and GEO satellites, HAPS are at much lower altitude which enables them to provide fiber-like latency to application on the ground. HAPS can conservatively cover an area of 50km radius.

The use case for HAPS is to support direct access to handset (Class 3 UE), mobility (channel model classification is land-mobile but outdoor limited) using 1.8 GHz frequency band (FR1). Nigeria, as shown in Figure 7-1, is close to the Equator and has favourable wind and solar characteristics which makes it good candidate for HAPS technology. This document is focused on the user link portion of the HAPS payload for both downlink and uplink.

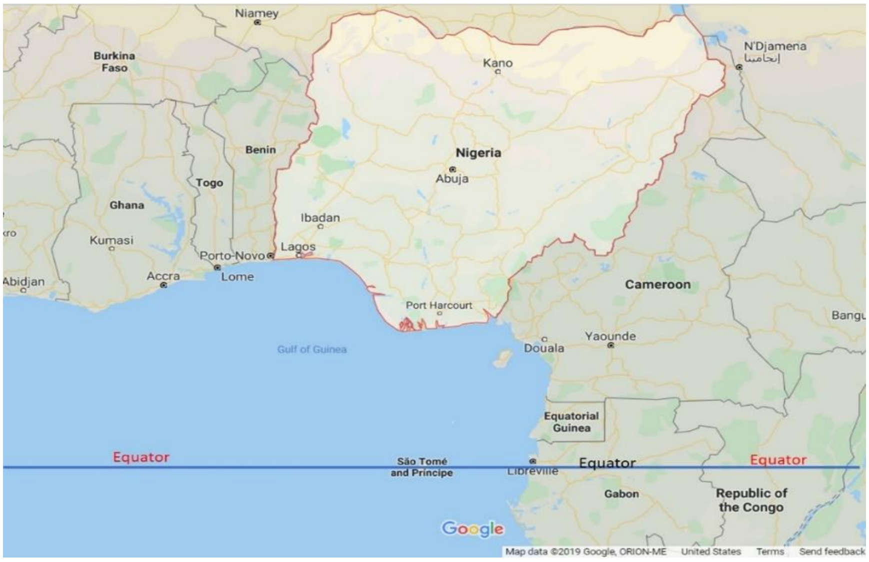

Figure 7-1: Nigeria

7.1.2.2 Assumptions, methodology and input

Table 7-2**Fehler! Verweisquelle konnte nicht gefunden werden.** summarizes the key end user parameters for the Deep Rural scenarios in Nigeria. The services are broadband, voice, and SMS. The experienced user data rate is the minimum data rate required to achieve a sufficient quality experience. The area traffic capacity is the total traffic throughput served per geographic area.

Table 7-2: HAPS Scenario Data

Services: Basic Broadband + Voice & SMS			Deep Rural Scenario	
			Min	Max
Experience User Data Rate		DL [Mbps]	2	
		UL [Mbps]	0.25	
Mean		[User/Km2]	2	100
End-to-end latency		[msec]	50	
Activity Factor		[%]	1.5	
Ave. User Busy Hr Usage Rate		[Kbps]	30	
Area Trafic capacity		[Mbps/Km2]	0.06	

Table 7-3 summarizes the user device parameters.

Table 7-3: User Device Parameters

Services: Basic Broadband + Voice & SMS		Deep Rural Scenario	
		Min	Max
Max UE speed	[Km/Hr]	3	
Antenna Gain	[dBi]	0	
Noise figure	[dB]	9	
Maximum Up-link EIRP	[dBm]	23	

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Table 7-4 shows the HAPS coverage and payload assumptions (3GPP TR38.821 V.9).

Table 7-4: HAPS Coverage and Payload Assumptions

HAPS Coverage:				
	Radio of coverage	[Km]	50	
HAPS antenna serving Users:				
	Type	Electronicaly Steering Flat Panel Array w/multi-beamforming		
	Shape		Square	
	Side Size	[m]	0.5	
	N Beams Forming		16	
	Frequency	[GHz]	1.8	
	Receiver G/T	[dB/K]	-6.6	At boreside
	Transmit Gain	[dBi]	18	At boreside
	Maximum RF Tx power	[Watts]	25	Per beam
	Minimum C/I	[dB]	13	
	Min.Distance btw beams	[Km]	11.4	to keep C/I isolation

7.1.2.3 Use case summary result

Table 7-5 summarizes the throughput assumption for Deep Rural scenario. The total downlink and uplink required capacity is 419Mbps and 52Mbps respectively for Deep Rural scenario. Table 7-6**Fehler! Verweisquelle konnte nicht gefunden werden.** summarizes the average spectral efficiencies for the downlink and uplink. These spectral efficiencies assume Line-of-sight connectivity and clear sky conditions. The link margin is 4 dB for rain fade.

Table 7-5: Throughput assumptions

Services: Basic Broadband + Voice & SMS		Deep Rural Scenario	
		Min	Max
Total trafic demand	[Mbps]	4.5	225
Over- subscription	[Mbps]	75	3750
Number total of subscrivers		15700	785000
Total trafic through HAPS	[Mbps]	471	471
Simultaneous active users		209	209
Total Dw-link Required Capacity	[Mbps]	419	419
Total Up-link Required Capacity	[Mbps]	52	52
Total trafic through HAPS (Verification)	[Mbps]	471	471

Table 7-6: Average Spectral Efficiencies

User Links Average Spectral Efficiencies Achieved:				
	Ave. D/L Spectral Efficiency	[bps/Hz]	2.2	Line of sight, Clear Sky
	Ave. U/L Spectral Efficiency	[bps/Hz]	2.4	Line of sight, Clear Sky

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Table 7-7 summarizes the C/N and user spectral efficiencies for the service downlink and uplink at beam peak and beam edge. The number of beams formed per HAPS is 16. The bandwidth assumption for the service side is 13 MHz for the downlink and 13 MHz for the uplink. In summary, HAPS operating in 1.8 GHz spectrum in Nigeria can support the land-mobile (pedestrian) verticals with Class 3 UE on the ground as defined in TR38.821. The Deep Rural scenario use case results in acceptable HAPS payload requirement.

Table 7-7: Forward and Return Link C/N and Spectral Efficiency (HAPS)

Direction	Beam Peak/Edge	C/N (dB)	Spectral Efficiency (bps/Hz)
Forward Link (downlink) HAPS/UE	Beam Peak	21.6	5.555
	Beam Edge	7.9	1.477
Return Link (uplink) UE/HAPS	Beam Peak	21.6	5.555
	Beam Edge	2	0.877

7.1.3 Use case 3: GEO IoT

Use case #	Scenario	Frequency band	Vertical	UE Class	UE Location	Contributor
3	GEO	L	IoT	Class 3 IoT device	Algeria	Inmarsat

7.1.3.1 Rationale:

The use case is around providing low data rates services for fixed IoT devices that utilise GEO stationary satellites for direct access services using NB-IoT standard.

7.1.3.2 Assumptions and methodology

Fundamental assumptions

- Frequency band – L-band (~1.5 GHz)
- Transparent GEO payload
- EIRP downlink (service link) = 44 dBW/200 kHz
- Satellite G/T return (service link) = 11 dB/K
- UE location = Algeria
- UE elevation with respect to satellite = 30°
- Atmospheric + random losses = 0.5 dB
- UE antenna profile = Omni
- UE antenna gain = 0 dBi
- UE equivalent noise temperature (Ta) = 290K
- UE TX EIRP = 23 dBm

Additional notes/commentary:

1. Feeder link is assumed to be stable
2. No impact/degradation due to OFDM PAPR is considered
3. No gain from HARQ mechanism is considered

7.1.3.3 Methodology

Link analysis performed using link budget on the service link (downlink and uplink).

7.1.3.4 Conclusions

Forward link (downlink)	Return link (uplink)
➢ NF 5 dB (G/T=: -29.6 dB/K) ○ Example congif=200 kHz ○ 0.67 b/s/Hz ○ ~ 112 kbps	➢ 15 kHz: ○ 0.67 b/s/Hz ○ ~ 9.33 kbps
➢ NF 3 dB (G/T=: -26.6 dB/K) ○ Example congif=200 kHz ○ G/T = -26.6 dB/K ○ 1.33 b/s/Hz ○ ~ 224 kbps	➢ 3.75 kHz: ○ 1.60 b/s/Hz ○ ~ 5.6 kbps

Note:

(1) NF > Noise Figure

(2) G/T: As 0 omni antenna is considered, it 'sees' hot earth and atmosphere which is assumed to be at 290K. Therefore, from G/T perspective this is worst case scenario and actual G/T may be better. 3GPP TR 38.811 V15.2.0 (2019-09) sec 4.4 is used a reference for computing G/T from NF and antenna gain.

7.1.4 Use case 4 and 8: GEO S Band direct access

Use case #	Scenario	Frequency band	Vertical	UE Class	UE Location	Contributor
4	GEO	S Band	Land-mobile	Class 3	Rural America and Africa	EchoStar
8	GEO	S Band	Community WiFi	Direct VSAT	Rural America and Africa	EchoStar

7.1.4.1 Rationale

In the context of 3GPP Rel-16, the study item to investigates the feasibility of S Band (as part of FR1) satellite serving VSAT, Class 3 UE and IoT devices from a GEO space infrastructure. Such scenarios may support many users in the rural and extreme rural areas worldwide. A service like this would provide opportunity for connecting the unconnected benefiting from GEO satellite coverage hence fulfilling the ATAWAD (Any Time, Any Where, Any Devices) requirements for the benefit of both consumer and vertical markets. NTN direct access to VSAT and handheld devices is expected to complement and extend cellular networks with provision of outdoor mobile broadband services (MBB) with satellites line of sight situations.

The satellite payload will utilise antenna array and beamforming technologies.

7.1.4.2 DVB-S2 and SCMA Waveform

In this scenario we use DVB-S2 waveform for the downlink and Scrambled Code Multiple Access (SCMA) for the uplink. DVB-S2 is a widely used standard developed in 2003 on digital data transmission via satellite. Its performance is close to theoretical limits on a wide range of throughputs. It supports adaptive coded modulation that allows a suitable code rate/modulation pair based on the link quality. It is ideally suited for forward link, but it can also be used non-short message return link. SCMA technology has been deployed for 2 years, operating in the Hughes Jupiter 2 network both in the US and Brazil. Currently it is being used for encrypted interactive traffic to reduce the latency for consumer customers. It is ideal for IoT application and can also be used to eliminate “request-grant” time for satellite access of short messages. Modulation used is QPSK or Offset QPSK.

7.1.4.3 Assumptions and methodology

The methodology for link analysis performed follow link budget calculation defined in clause 6.1.3.1 of TR 38.821.

- Feeder link is assumed to be dimensioned in a way that doesn’t degrade the service link performance.
- Target elevation angle: 30 deg
- Frequency reuse: 3
- Using DVB-S2 (DL) and SCMA (UL) waveforms as described above.

The assumptions used for satellite and UE can be found in table 6.1.1-1 “Set-1 satellite parameters for system level simulator calibration” in TR 38.821 v0.9.0:

- Satellite parameters:
  - Satellite scenario: GEO, transparent payload
  - Equivalent satellite antenna aperture: 22 m (circular polarized)
  - Satellite EIRP density: 59 dBW/MHz
  - Satellite G/T: 19 dB K^{-1}
  - Satellite receive antenna gain = 51 dBi

- Service link
  - Frequency band for the service link: 2 GHz (downlink) – 2 GHz (uplink)
  - Propagation model: See 3GPP TR 38.811 (Parameters defined in Clause 6 of 3GPP TR 38.821)

- Class 3 User Equipment
  - 3GPP Class 3 UE
  - Antenna gain: 0 dBi, linear polarized (+/-45°X-pol)
  - Noise figure: 7 dB
  - Tx power: 200 mW (23 dBm)
- VSAT User Equipment
  - Antenna gain: 12 dBi, circular
  - Noise figure: 5 dB
  - Tx power: 2 W (33 dBm)

7.1.4.4 Observation

Using the assumptions highlighted above and the described methodology, the following results are achieved:

	Downlink		Uplink	
	VSAT	**Handheld**	**VSAT**	**Handheld**
CNR (dB)	17.8	3.1	11.8	0.8
C/I (dB)	19.0	19.0	19.0	19.0

CINR (dB)	15.4	3.0	11.0	0.7
Spectral efficiency (bps/Hz)	4.0	1.2	2.5	1.0

The results meet the requirement for VSAT and handheld direct access performance targets. For land mobile it is sufficient to say that the rate can support a 3G/4G experience. With satellite advances, this can be further improved to meet the NTN performance target for land mobile.

7.1.5 Use case 5: LEO Cellular support

Use case #	Scenario	Frequency band	Vertical	UE Class	UE Location	Contributor
5	LEO (NGSO)	Ku	Community WiFi/ Cellular Backhaul (2G, 3G, 4G or 5G)	Flat Panel Antenna	Central Africa	Oneweb

7.1.5.1 Rationale:

This Use Case assumes the utilization of flat panel antennas mounted on public or private infrastructures and interfaces with the ground network, with the aim of serving remote communities. The main objective is to offer a support service to terrestrial network. This would allow to connect remote locations thanks to the ubiquitous advantage of satellite networks or to offload datastreams from terrestrial network.
OneWeb mission is to offer connectivity to remote locations and adapting it to a 5G world would allow to overcome the proprietary system interface which is one of the bigger limitations of today satellite communication systems.

7.1.5.2 Assumptions and methodology

Fundamental assumptions

- Orbit altitude 1200Km
- Flat panel antenna
- Frequency band for the service link: 11.7 GHz (downlink) – 14.5 GHz (uplink)
- Regenerative LEO payload
- EIRP downlink (service link - average) = 32 dBW
- Satellite G/T return (service link - average) = 6 dB/K
- UE location = South Africa
- Minimum UE elevation with respect to satellite = 30º
- Atmospheric losses (average) = 2 dB
- UE antenna profile = Steerable Flat panel /directional
- UE antenna gain (average) = 18 dBi [elevation dependent]
- UE TX EIRP (average) = 33 dBW

Additional notes/commentary *(examples below):*

- Feeder link is assumed to be stable.
- Being a LEO constellation, the User Terminal elevation is not constant.
- The LEO Constellation offer truly global coverage with fixed beams on Earth.

7.1.5.3 Methodology

Link analysis performed using link budget. For the analysis, a best case and a worst case was considered, assuming performance at peak and the edge of the beam, with different UT elevations and for different frequency channels, both for forward and return link. The link budget assumes clear sky condition.

Conclusions

Using the assumption highlighted above and the described methodology, the following results are achieved:

- In the forward link we can achieve a data rate ranging between 140 Mbps and 830 Mbps per beam, depending on the assumptions made.
- In the return link we can achieve a data rate ranging between 140 Mbps and 880 Mbps per beam depending on the assumptions made.

Forward link (downlink)	Return link (uplink)
➢ Best case scenario ○ G/T= 9 dB/K ○ Data rate = 830 Mbps	➢ Best case scenario: ○ 880 Mbps
➢ Worst case scenario: ○ G/T= 7 dB/K ○ 140 Mbps	➢ Worst case scenario: ○ 140 Mbps

7.1.6 Use case 6: Ku band maritime GEO HTS

Use case #	Scenario	Frequency band	Vertical	UE class	Comments	Responsible
6	GEO HTS	Ku	Maritime	VSAT (panel)	Mediterranean Sea	Intelsat

7.1.6.1 Rationale

The GEO high throughput satellite (HTS) scenario operates in Ku band (FR2) to support Maritime services using flat panel VSAT terminal over the Mediterranean Sea. **Fehler! Verweisquelle konnte nicht gefunden w erden.**shows the single GEO beam over the Mediterranean Sea. The peak of the beam is at 42.4N degree latitude and 9.8E degrees longitude. This document is focused on the user link portion of the payload (downlink and uplink).

Figure 7-2: Mediterranean Sea

The GEO HTS can provide the following satellite flexibilities including:

1. Steerable and overlapping capacity
2. Large number of beams (hundred to thousands) utilizing the BFN (Beam Forming Network)
3. Polarisation diversity (dual-pol UE) double the link capacity over the same spectrum
4. BFN optimised beam-to-beam isolation and interference to increase link capacity/throughput
5. Better aggregate capacity due to dynamic channelization and BFN
6. Tracking mobile devices – similar to MU-MIMO
7. Digital payloads allow to manage gain and performance on a per channel basis.

7.1.6.2 Assumptions & methodology:

Table 7-8**Fehler! Verweisquelle konnte nicht gefunden werden.** summarizes the key satellite parameters. The satellite orbital location is 60 degrees E longitude and operates in Ku band frequency (FR2).

Table 7-8: Satellite Characteristics

Considered Satellite Characteristics

Satellite Orbital Location	[Deg E]	60	
User Beam Size	[deg]	1.0	
Beam Pointing Lat/Long	[degN, degE]	42.4° , 9.8°	On Mediterranean Sea
User Beam Size (diameter on ground)	[Km]	~ 1000	
Minimum G/T at beam Edge	[dB/K]	13.7	
Minimum EIRP denisty at Beam Edge	[dBW/Hz]	-27	
Maximum EIRP density at Beam Peak	[dBW/Hz]	-22	
Max. CoCh C/I at Beam Edge (Tx & Rx)	[dB]	15	

Peak Terminal Locations Lat/Long	[degN, degE]	42.4°, 9.8°	On Mediterranean Sea
Peak Terminal Elevation angle =	[Deg]	20	
Peak Terminal Skew Angle =	[Deg]	40	
Edge Terminal Locations Lat/Long	[degN, degE]	40.0°, 15.2°	On Mediterranean Sea
Edge Terminal Elevation angle =	[Deg]	25	
Edge Terminal Skew Angle =	[Deg]	40	

The terminal antenna on the ground is flat panel VSAT with 0.7m diameter. The flat panel VSAT is capable of active beamforming terminal on receive and transmit side; and adjacent satellite interference management. The G/T is 3.5 dB/K. The transmit antenna gain (peak) is 27 dBi. The transmit power of the terminal is 8 watts. Table 7-9**Fehler! Verweisquelle konnte nicht gefunden werden.** shows the link budget assumptions for the downlink and uplink.

Table 7-9: Downlink and Uplink Link Budget Assumptions

Direction	Assumptions
Downlink	Modem DVB-S2X/RCS2 mod-cods are assumed in clear sky
	Adjacent Satellite Interference (ASI) -30 dBw/Hz
	Ku-band
Uplink	Modem DVB-S2X/RCS2 mod-cods are assumed in clear sky
	Maximum FCC allowable uplink PSD considering antenna off-axis exceedance is considered.
	Ku-band

7.1.6.3 Use case summary result

Table 7-10**Fehler! Verweisquelle konnte nicht gefunden werden.** shows the downlink and uplink C/N and spectral efficiency thresholds for beam peak. In summary, GEO HTS operating in Ku band in Mediterranean Sea can support the Maritime service with VSAT (flat panel) UE class.

Table 7-10: Forward and Return Link C/N and Spectral Efficiency (SAT)

Direction	Beam Peak/Edge	C/N (dB)	Spectral Efficiency (bps/Hz)
Forward Link (downlink) SAT/VSAT	Beam Peak	1.9	1
	Beam Edge	0.5	0.6
Return Link (uplink) SAT/VSAT	Beam Peak	9.2	1.9
	Beam Edge	6.5	1.6

7.1.7 Use case 7: GEO High Throughput Satellite (HTS)

Use case #	Scenario	Frequency band	Vertical	UE class	Comments	Responsible
7	GEO HTS	Ka	Connected car	VSAT (panel)	Western Europe or North America	Avanti

This assumes a vehicle mounted 3GPP UE that (a) uses external antenna and (b) can relay to consumer UE in vehicle. Antenna may be dual mode (terrestrial and satellite). Calculations made for general purpose broadband high throughput satellites (HTS).

7.1.7.1 Rationale

Many higher end cars already offer a 4G based wi-fi hotspot system that may also provide support for ICE (in car entertainment) updates and tracking.
This use case takes this concept and adapts for a 5G world adding satellite for ubiquitous coverage

7.1.7.2 Assumptions

Antenna performance

- “Car” antenna performance based on data from an ESA project for a 43cm x 23cm antenna rather than that introduced in TR38.821
    - A larger size also being considered for commercial vehicles
- Performance at 40° from antenna boresite
    - On boresite performance significantly better due to simple geometry
- EIRP is limited by off-axis power density(satellite terminals need to meet an off-axis power density mask to minimise interference towards other satellites in the GEO arc),:
    - $EIRP_{max}$ = 28.4dBW per 1MHz of carrier
    - Note that this is higher than a typical class 3 UE as this antenna is tailored for this role
- G/T = 7.4dB/K

GEO Satellite performance

- Link budget performance based on generalised Avanti HTS (branded as HYLAS) capacity in a southern European location (62dBW and 19dB/K)
    - This is “bent pipe” so no signal processing on board
    - Location chosen as Lisbon in Portugal
    - Used as baseline in this section rather than TR38.821 data
- Then extended for a future broadband vHTS performance based on an online FCC filing for ViaSat 3 (66dBW and 22dB/K)
    - Performance assumed to be AWGN limited not limited by adjacent footprint interference

- Again assumed to be "bent pipe" with no signal processing on board
  - All other parameters assumed to be the same as HYLAS
- A vHTS optimised for this use case can be envisaged but this is out of scope for this initial analysis
- Other points
  - Feeder link is assumed to be stable
  - No impact/degradation due to OFDM PAPR is considered and this may be significant

7.1.7.3 Analysis methodology

- Tool used is SatMaster Pro V9.1
  - Will minimise link power to close link
  - This is a a GEO link budget tool well-known in the industry and regularly used as a tool for sharing data between organisations rather than using their own specialist tools
  - This tool is based on standard satellite waveforms
- Analysis made to calculate the C/(N+I) for satcom standard carrier
  - Used a BPSK ½ rate FEC 8.33Mbaud, 20% roll-off
  - Chosen to identify minimum performance
  - Modcod then increased to calculate peak symbol efficiency
- Terminology
  - Forward link – from core towards car, known in terrestrial industry as Downlink
  - Return link – from car towards core, known in terrestrial industry as Uplink

7.1.7.4 Findings

	Forward Link (Downlink)	**Return Link (Uplink)**
$C/(N+I)_{clear\ sky}$	2.3dB	4.4dB
Faded margin	2.5dB	4.6dB
Peak symbol efficiency (using faded margin)	0.9b/Hz	1.3b/Hz

7.1.7.5 Context

A suite of larger antennas is being considered in the same project targeted at commercial vehicles. These offer about 4dB better rf performance which would translate in to 4dB better link performance - the link noise being dominated by the small antenna on the user terminal (downlink in forward direction and uplink in the return).

8 APPENDIX C:

8.1 Corollary: specific needs in terms of resource optimization and orchestration of network functions close to the edge

As stated in the main text, satellite can efficiently deliver rich multimedia and other content across multiple sites simultaneously using broadcast and multicast streams with information centric network and content caching for local distribution.
the EC project SaT5G a review of possible use cases was identified in the deliverable D2.1[5] (not public); the first use case was called "Trunking and Head-end Feed". This Use Case addresses high speed trunking of video, IoT and other data to a central site, with the potential of further terrestrial distribution to local cell sites, for instance neighbouring villages, as shown in the figure below.

8.1.1 Concept

In today's networks, video content assets (live and video-on-demand – VoD[6]) are served to mobile devices on-the-go from centralised CDNs, usually located on Points of Presence (POPs) owned and controlled by the network operator. It is always a few given POPs that are elected to stream all the content to mobile users. The concept of distributed CDN, where most popular video contents are cached in the edge and streamed from a location closer to end-users, has so far not been used for video content delivery to mobile devices.

There are multiple reasons for that, like:

- the challenge to find physical locations and the cost to deploy and maintain this edge infrastructure
- the overcapacity of aggregation and backbone networks
- the lack of latency-sensitive video applications
- the concentration of the congestion issues at the radio cell level
- the need to distribute mobile core user plane functions at the edge (S/P-GW in 4G, UPF in 5G)

As the video-over-cellular traffic is increasing every year, very soon further boosted by 5G, composed of bandwidth-intensive and latency-sensitive immersive video applications, the central CDNs will not be sufficient anymore.

Leveraging new hosting locations such as base stations or transmission aggregation point would lead to a higher granularity of POPs and the possibility of streaming content from a location closer to end-users. These POPs need to be provisioned with the stream content, with a certain level of elasticity to cache in each location only the most popular ones. This provides an opportunity to integrate in to 5G networks and leverage its traditional strength of the efficient broadcast and multicast of content.

8.1.2 Offline multicast and caching potential design

SaT5G focused on the delivery of video content asset. The solution envisioned could be easily extended to other types of assets (Webpages, VNF software update repository…). The project has proposed a generic architecture reusing satellite multicast capabilities to cache popular (or expected to be) assets to the edge (also detailed in SaT5G deliverable D3.2):

5 https://www.sat5g-project.eu/

6 This may also be virtual/augmented reality, large game content and/or other major software.

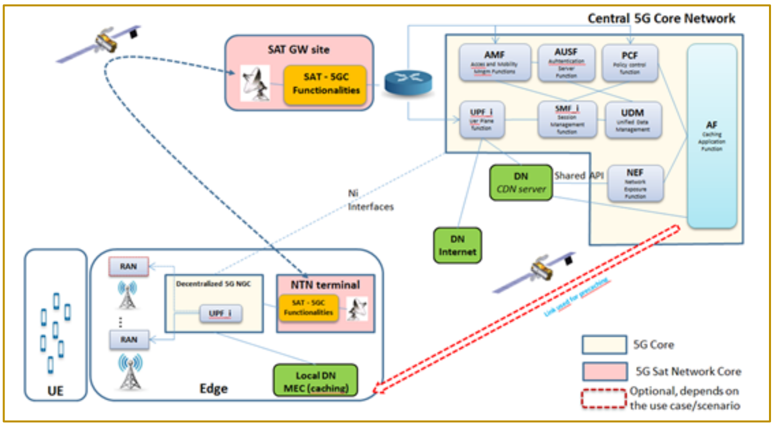

Figure 8-1: Offline caching

Within the Core Network, a dedicated AF for caching is deployed. The AF is in charge of steering traffic to the Edge Network so that it is served locally from the cache server (located in Local DN). This AF is also in charge of orchestrating the caching by multicasting to the edge the popular assets in a carousel. The Local cache joins this multicast and stores locally the assets chunks. The asset popularity is computed on the fly by an analytics server. For more dynamicity, another solution based on prefetching of segments was also studied in the project.

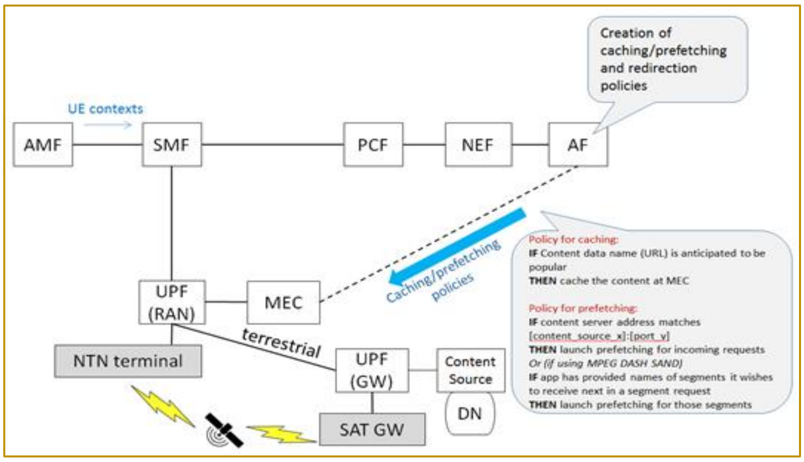

Figure 8-2: Dynamic prefetching

The traffic is rerouted to the UPF (RAN), which is connected to a local cache (symbolized here by MEC). This local cache serves the UE directly from its cache and fetches the next segments from the content source before they are even requested by the UE.

8.1.3 Potential design for multicast live streaming

Secondly, SaT5G has also investigated how to optimize the delivery of OTT video live channels. As a basis, they reused the work done for the Multicast ABR (mABR). The basic concept behind mABR, is to send in multicast the live traffic over the backbone transmission network (the satellite backhaul in our case) and then convert it back to unicast at the edge of the network. The architecture is very similar to what has been presented for Caching.

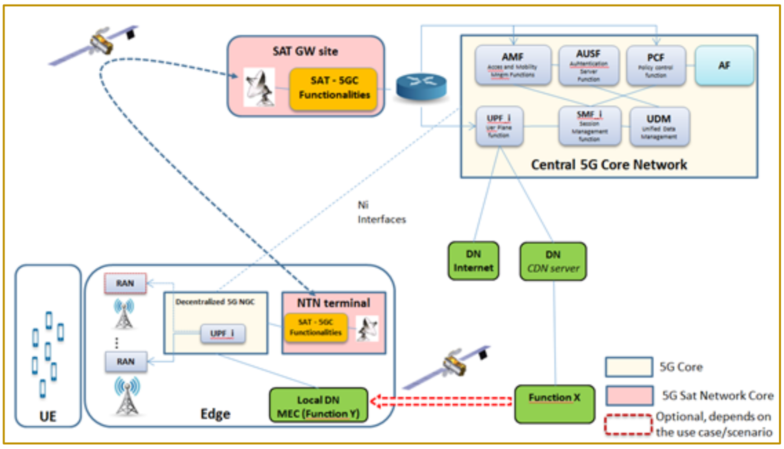

Figure 8-3: Live channel delivery

Compared to the generic architecture presented in SaT5G 2018 deliverable D3.1 (Integrated SaT5G General Network Architecture), the following new elements are added:

- A dedicated AF in charge of redirecting the requests to the UPF connected to Function Y;
- A Function X managed which converts live from unicast to multicast;
- A Local DN acting as function Y (in mABR terminology), this function has joined the multicast to receive the live. The Function Y receives the multicast and sends it on as unicast to the UE.

When a UE requests a session on a popular live, this UE is redirected to a decentralized UPF connected to a Local DN. This Local DN receives the popular lives in Multicast from the 5GC and converts them back in Unicast for the UE. The satellite link is used for its inherent Multicast capabilities and efficiencies, and its ability to reach every point across the satellite coverage.