D2.1: Scenarios, use cases, and services

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Abstract	This document describes the use cases and services for a flexible full 5G heterogeneous network integrating terrestrial and non-terrestrial networks with multi-connectivity concepts. Then, the user requirements and consolidated KPIs are derived from these use cases. Finally, the priority for the PoC and the relation with other work packages are defined.
Keywords	5G, NTN, use case, on board, requirements, KPIs, Proof-of-Concept

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DATA: Data sets, microdata, etc.

DMP: Data management plan

ETHICS: Deliverables related to ethics issues.

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EXECUTIVE SUMMARY

Deliverable D2.1 provides an analysis of the scenarios and use cases that will be deployed during 5G-STARDUST project, their main requirements and Key Performance Indicators (KPIs), and the selection of the scenarios that will be tested during the Proof-of-Concept (PoC), where the focus will be on the 5G network and the integration between Terrestrial Networks (TNs) and Non-Terrestrial Networks (NTNs). This deliverable also includes the scenarios and use cases studied among different organizations like 3GPP and GSOA.

5G-STARDUST scenarios focus on two different topics:

- Dual connectivity: scenarios of hybrid networks between NTNs and TNs indicating a unified radio interface, which will provide enhanced Mobile Broadband (eMBB) services to the final users working with multi-orbital satellites.

- Architecture and Service Distribution: definition of architectures and systems for different use cases implementing regenerative payloads, eMBB, and distributed systems. This scenario will provide different use cases with multi-orbital satellites and hybrid networks scenarios.

The following use cases have been studied during this task, providing the first definitions and concepts that will be thoroughly analysed and developed during the next tasks and work packages:

- Airway neutral-host cell: Airway Geostationary Earth Orbit (GEO) and Non-Geosynchronous Satellite Orbit (NGSO) complementing the terrestrial coverage when airplanes leave the airport. 5G broadband services for passengers with terrestrial and satellite, providing a homogeneous and transparent experience for users.

- Residential broadband: Direct Access/Low Earth Orbit (LEO) Integrated Access and Backhaul (IAB), helping to fast deploy networks to accelerate terrestrial 5G rural deployments or temporal gap filler. Fixed Wireless Access (FWA) from LEO/GEO with dual connectivity and common Operation and Management (O&M) with terrestrial and satellite, providing a homogeneous and transparent experience for users and a common management for the Mobile Network Operators (MNOs).

- Vehicle connected: Vehicle-to-Network (V2N) communications to enhance 3 different services like Software over the air updates, High Definition (HD) maps updates and NG eCall service to provide rapid assist in serious accident; using TN and LEO satellites to extent V2N coverage for underserved areas.

- Public Protection and Disaster Relief (PPDR): communications in case the TN infrastructure is damaged during/after a disaster event. NTN will provide temporarily coverage to the first responders. In addition, extended coverage in case of uncovered areas for first responder agencies is considered. Direct and backhauled access of LEO satellites.

- Global Private Network: distributed 5G systems for private networks. LEO with on-board User Plane Function (UPF), ensuring shorter global data paths, data retention, and potentially with ultra-secure and ultra-reliable signalingg centralized in the satellite environment.

The studied scenarios are justified and analyzed including the pre-conditions, service flows, the post-conditions, service requirements, and existing features partly or fully covering the use case functionality. This deliverable includes the KPIs and requirements consolidation. Additionally, it has also been explained which KVIs are the main ones for each scenario. In the end, a set of use cases have been selected and prioritized for the PoC phase. The purpose is to detail expected functional results and monitored KPIs so that test plans, procedures and validation can be performed.

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ABBREVIATIONS

3GPP	3rd Generation Partnership Project
5G-A	Advanced 5G
5G-STARDUST	5G-Satellite and Terrestrial Access for Distributed, Ubiquitous, and Smart Telecommunications
AI	Artificial intelligence
AI/ML	Artificial Intelligence/Machine Learning
ATAWAD	Anytime, Anywhere, and Any Device
C2C	Command & Control
CN	Core Network
CU	Central Unit
DA2GC	Direct Air to Ground Communications
DL	DownLink
DU	Distributed Unit
E2E	End to End
eMBB	enhanced Mobile Broadband
eMTC	Enhanced Machine-Type communication
eNTN	evolved Non-Terrestrial Network
ESIM	Earth Station in Motion
FDD	Frequency Division Duplex
FR	Frequency Range
FWA	Fixed Wireless Access
GEO	Geosynchronous Earth Orbit
gNB	next Generation Node B
GSOA	Global Satellite Operator's Association
HAPS	High Altitude Platform Station
HD	High Definition
IAB	Integrated Access Backhaul
IMS	Ip Multimedia Subsystem
IoT	Internet of Things
IP	Internet Protocol
KPI	Key Performance Indicator
KVI	Key Value Indicator
LEO	Low Earth Orbit
MC	Mission Critical
MCS	Mission Critical services
MCX	Mission Critical Communication
MEC	Multi-access edge computing
MEO	Medium Earth Orbit
MIMO	Multiple Input Multiple Output
mMTC	massive Machine Type Communications
NR	New Radio
NTN	Non-Terrestrial Networks
O-RAN	Open-RAN
PLMN	Public Land Mobile Network
PoC	Proof of Concept

PPDR	Public Protection & Disaster Relief
PPT	Push-to-talk
PSAP	Public Safety Answering Point
RAN	Radio Access Network
RAT	Radio Access Technology
Rel.	Release
RF	Radio Frequency
SA	Stand Alone
SIB	System Information Block
SNS	Smart Networks and Services
SOTA	Software Over The Air
TCP	Transmission Control Protocol
TN	Terrestrial Network
TRL	Technology Readiness Levels
UE	User Equipment
UL	UpLink
UPF	User Plane Function
URLLC	Ultra Reliable & Low Latency Communications
V2N	Vehicle to Network
V2X	Vehicle-to-everything
VSAT	Very Small Aperture Terminal
WP	Work Package

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1 INTRODUCTION

1.1 PROJECT SUMMARY

The objective of 5G-STARDUST is to achieve a seamless integration of 5G and NTN technologies to facilitate service deployment in low-density areas and regions with challenging economic coverage. The project aims to create a fully integrated 5G-NTN autonomous system, which will incorporate highly flexible multi-constellation architectures merged with the 5G terrestrial segment. Additionally, it will encompass full 5G compliant regenerative satellite communications capabilities, unified radio interfaces, data-driven AI-based techniques for multi-connectivity, and efficient radio resource management. Furthermore, the project will draw upon the 3GPP and Open Radio Access Network (O-RAN) architecture and concepts.

The progress achieved in the latest 3GPP releases highlights the critical importance of non-terrestrial networks in realizing the aspiration to contribute significantly to the European leadership in cultivating a sustainable and comprehensive digital economy.

1.1.1 Challenges

5G-STARDUST challenges will define and analyse some key points to ensure the co-existence between terrestrial and non-terrestrial networks to achieve the main target of provide an Anytime, Anywhere, and Any Device (ATAWAD) connectivity also in underserved European zones.

- To define an integrated terrestrial-satellite network building on 5G-compliant regenerative satellite payloads, enabling cost-effective connectivity in un(der)served areas.
- To ensure a more efficient user connectivity concept by providing geographic coverage according to user-centric approaches (*i.e.*, cell-free strategies).
- To define a self-organised end-to-end network architecture able to adapt to diverse verticals' requirements and to time-varying network operations (*e.g.*, data traffic loads and topology changes).
- To provide end-to-end network flexibility by means of data driven AI-based multi-connectivity and resource allocation strategies.
- To guarantee cost reduction and capability to scale up the integration of satellite with terrestrial infrastructures to efficiently manage the deployment and operation of massive capacity networks.

5G-STARDUST positions itself in the worldwide 5G/6G ecosystem timeline development, both from the global standardization and market perspective, 5G-STARDUST results are planned to support the inclusion of NTN in the overall standardization workplan towards 6G.

1.1.2 Project objectives

The main goal of 5G-STARDUST is to design, develop and demonstrate a deeper integration of TN and NTN. To realise its ambitious goal, the project will pursue the following specific objectives:

- To identify and analyse a comprehensive set of use cases enabled by the envisioned integrated TN-NTN architecture and derive system requirements.
- To define 5G/6G system architectures building on unified terrestrial and multi-layer NTN networks supporting cost-effective, ubiquitous, reliable, and scalable service provisioning for un(der)served areas.
- To study, design, and analyse a 5G-based satellite network, implementing onboard processing and storage capabilities towards effective networking and mobile computing in the sky.
- To define, design, and analyse a unified radio interface towards a cost-effective TN-NTN network integration.
- To define, design and analyse data-driven management system components, building on AI/ML-based solutions for resource allocation and service provision in highly dynamic integrated hybrid networks.
- To define advanced techniques for Cell-Free massive MIMO (CF-m-MIMO) communications in NTN aimed at effective and traffic-driven service coverage.
- To define, design, and analyse a full softwarisation of the E2E network architecture towards a cost-effective, scalable, and self-organised network architecture.
- To define, design, and analyse multi-connectivity models to ensure effective data distribution through terrestrial and non-terrestrial networks.
- To design, implement, and demonstrate (TRL 5) E2E services over a fully integrated TN-NTN advanced network architecture with regenerative space nodes.
- To contribute to the development of a European Research and Technology roadmap to ensure strategic positioning and global competitiveness of Europe in integrated TN-NTN communications, by engaging in standardisation activities, by ensuring exploitation in a longer-term perspective, and by injecting directly into the ambitious plans of the Smart Networks and Services (SNS) initiative.

1.2 DELIVERABLE OVERVIEW

Deliverable D2.1 provides an analysis of the use cases that have been imagined to build a realistic scenario to be deployed during the project, together with requirements and consolidated KPIs.

This deliverable first gives an overview of the technologies developed for the project, where the focus will be on the 5G network. To achieve a global overview of this technology, Section 2 discusses the status of NTN standardisation. Section 3 lists the scenarios indicated by different organizations like 3GPP or GSOA and put them in perspective with the use cases selected for 5G-STARDUST, additionally it describes the methodology considered for use case description and analysis of requirements and KPIs. The studied scenarios are justified in their respective sections: Section 4 for the Airways use case, Section 5 for residential broadband, Section 6 for Automotive, Section 7 for PPDR, and Section 8 for global private networks.

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In Section 9, the consolidated KPIs are deduced for user application, service continuity and service ubiquity.

Additionally, in Section 10 some Key Value Indicators (KVIs) have been defined for the 5G-STARDUST project, for each use case independently, always following the preliminary KVIs defined in 5G-STARDUST Grant Agreement.

Section 11 contains Task 2.3 information about the selection scenarios of the PoC.

Finally, section 12 closes the deliverable giving some conclusions about the work done in T2.1, T2.2, and T2.3.

1.3 RELATION WITH OTHER WORK PACKAGES

The relationship between different work packages is present in Figure 1.

The scenarios and use case definition (WP2), as it shows Figure 1, have a direct relation with the architecture design (WP3) and the Impact Creation (WP7). In other words, the work done in WP2 (Scenarios and Use Case Definition) serves as input and guidance for the work carried out in WP3 (Architecture Design). Likewise, the architecture designed in WP3 informs the strategies and solutions implemented in WP7 (Impact Creation).

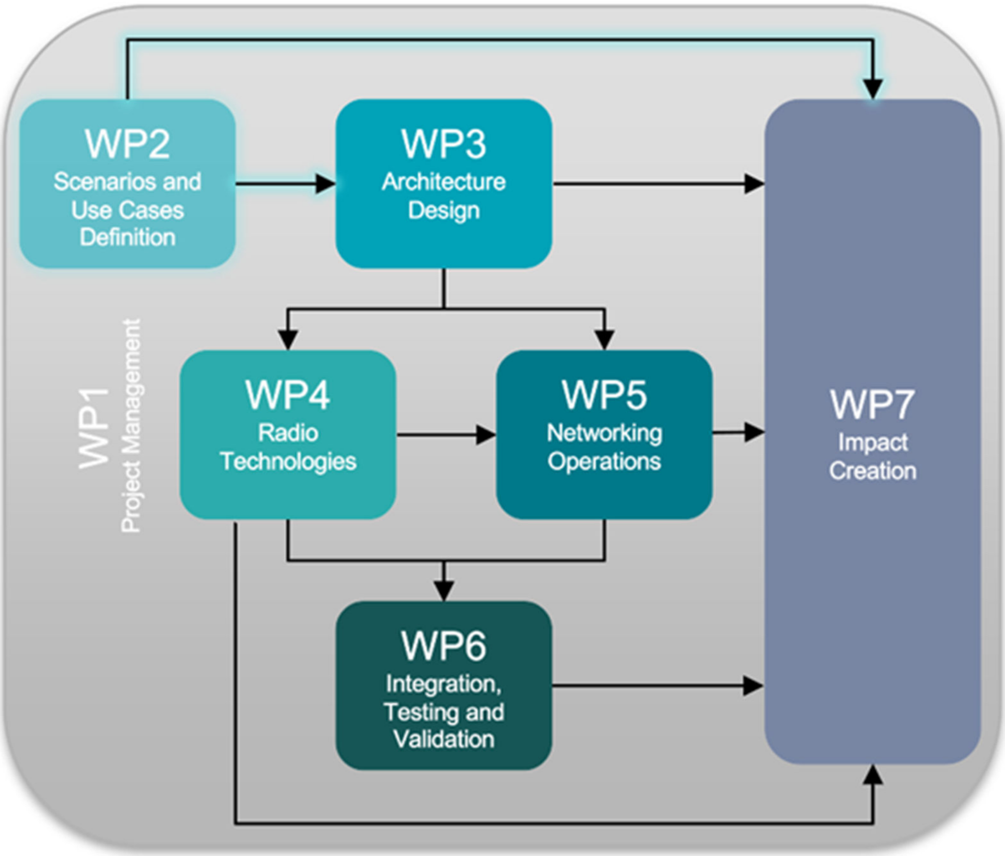

Figure 1: 5G-STARDUST WP flow chart

- Work Package 2 (WP2): Scenarios and Use Case Definition

WP2 deals with the identification and definition of various scenarios and use cases that the project aims to address. These scenarios represent different real-world situations or applications where the project's technologies and solutions could be applied.

- Work Package 3 (WP3): Architecture Design

WP3 is responsible for designing the architecture of the project. It involves planning and defining the overall framework and structure that will enable the project to address the identified scenarios and use cases effectively.

- Work Package 7 (WP7): Impact Creation

WP7 is focused on creating and maximizing the project's impact. It aims to ensure that the developed technologies and solutions have a meaningful effect on the intended domains, such as improving connectivity, enhancing services, or enabling new opportunities.

2 NTN STANDARDIZATION STATUS

The added value of the integration of a Non-Terrestrial (NT) segment in the New Radio (NR) architecture was recognized by 3GPP since Rel. 15, aiming at, [1]:

- complementing 5G services in under-/un-served areas and resolving the “0G” issue;
- improving the 5G service reliability and continuity for massive Machine Type Communications (mMTC), Internet of Things (IoT) devices, or for Mission Critical services;
- improving the 5G network scalability by means of efficient multicast/broadcast resources for data delivery.

In the timeframe 2017/2019, Rel.15 and Rel. 16 Study Items (SIs), *i.e.*, pre-normative work, under Technical Specification Group (TSG) Radio Access Network (RAN) and Service and system Aspects (SA) related to the use of satellite access in 5G and the support of NR for NTN, paved the way for the approval of the first dedicated NTN Work Item (WI) in December 2019. [2] This represented a turning-point for the definition of a truly integrated NT component in the terrestrial 5G system, starting from Rel. 17 frozen in 2022.

The NTN standard is the result of a joint effort between stakeholders of both the mobile and satellite industries, leading to a two-fold benefit:

- the possibility to truly achieve global service continuity and resiliency, for 3GPP.
- the access to the unified and global 3GPP ecosystem and the possibility to reduce the costs through economy of scale, for the satellite industries.

Moreover, before NTN, there was not interoperable standard in SatCom; thus, the inclusion of a non-terrestrial component in 3GPP based systems can also lead to huge benefits for the SatCom industry as ground systems exploiting equipment coming from different providers are now available.

This standard is also supported by vertical stakeholders (Public Safety, transportation, automotive, etc.) calling for:

- the seamless combination of satellite and mobile systems; and
- the support of all 5G features across the access technologies.

Figure 2 depicts the foreseen roadmap of future 3GPP released as of today focusing on NTN.

5G-STARDUST is dedicated to 5G Advanced releases:

- On-going Rel. 18 is working on several enhancements, including verified UE locations and the introduction of the NTN component in Frequency Range 2 (FR2), i.e., above 10 GHz, for Very Small Aperture Terminals (VSAT).
- The package for Rel. 19 is being defined, with a first discussion held during a workshop in June 2023. While the actual content of Rel. 19 will be finalised at the end of 2023, it is already commonly recognised that regenerative payloads will be part of it. In this context, where 5G-STARDUST is ambitioning to play a key role in the definition of these architectures.

- Rel. 20 is planned for further enhancements and may of interest for 5G-STARDUST to push some additional elements. Rel. 20 will initiate the activities during the final year of the Project; as such, outcomes of 5G-STARDUST might support the definition of the Release package and the related first assessments.

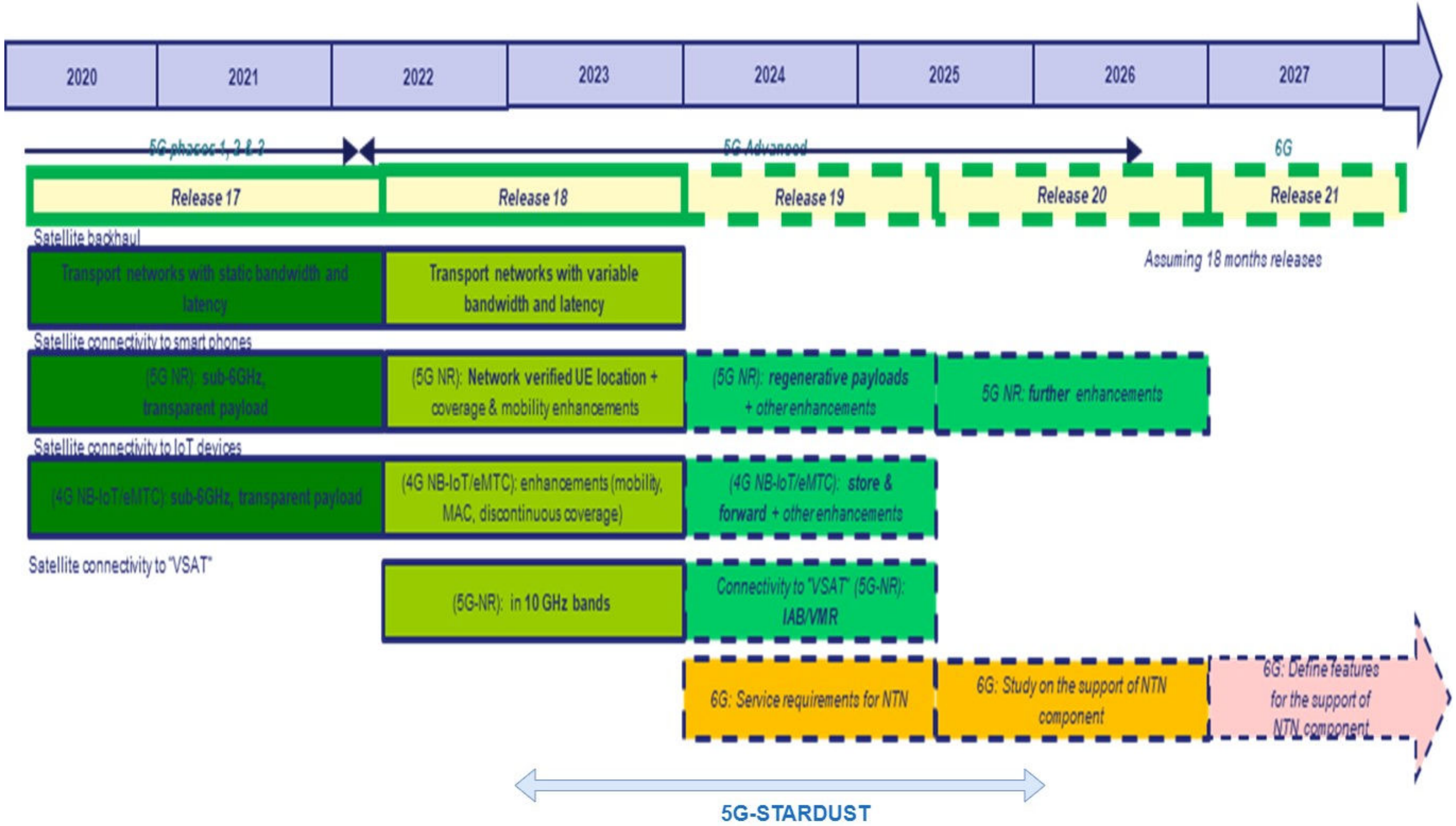

Figure 2: 3GPP roadmap

The NTN standard aims at supporting three general reference scenarios, which differ from each other in terms of targeted terminal types, operating band, service, and orbit. We can distinguish between: [3]

- with Rel. 17 and upward, satellite access networks operating in Frequency Range 1 (FR1), which provide direct wideband and narrowband connectivity to, respectively:
    - outdoor handheld terminals and/or car/drone mounted devices, via the 5G NR standard; an
    - outdoor IoT devices, via the 4G NBIoT/eMTC standard.
- with Rel. 18 and upward, satellite access networks operating in FR2, providing broadband connectivity to local access networks via VSATs installed on building rooftops or Earth Station in Motion (ESIM) terminals on moving platforms (vehicle, train, vessel, or airplane).

During the 5G-STARDUST project, the standardization activities and the impact in the standard will be carried out during task 7.3 "Standardization and open source".

Therefore, the study performed in this section will be introductory to the T7.3, which will be developed during the whole project timeframe.

3 SCENARIOS AND USE CASES

3.1 3GPP SCENARIOS

3GPP is an entity responsible for the definition of new technologies reported in Technical Specifications and Technical Reports for mobile broadband standards. Such specifications indicate which are the next steps to standardisation for the different technologies, like NTN in our case.

In this section, different releases will be studied, and the use cases proposed by 3GPP are discussed. They are presented in chronological order and as such start by TR documents as the NTN introduction started by a Study Item in release 16 before its introduction in release 17 through a dedicated Work Item.

3.1.1 TR 22.891

3.1.1.1 Use Case n°72 from 3GPP TR 22.891

The study described the following Use Cases specifically thought for the 5G satellite connectivity, [4]:

- Areas where it is not possible to deploy terrestrial towers, *e.g.*, maritime services, coverage on lakes, islands, mountains, or other recreational areas that can only be covered by the satellites.
- Disaster relief: during natural disasters or other unforeseen events that entirely disable the terrestrial network, satellites are the only option to provide connectivity.
- Emergency response: besides wide scale natural disasters, there are specific emergency situations in areas where there is no terrestrial coverage. For example, a public safety uses case of an accident in a power plant.
- Secondary/backup connection (limited in capability) in the event of the primary connection failure or for connected cars.
- Connectivity in rural areas that are hard to cover using terrestrial networks.
- Connectivity for remotely deployed sensors, *e.g.*, farms, substations, gas pipelines, digital signage, remote road alerts, etc.
- Low bit-rate broadcast services: Satellites can broadcast wide area emergency messages at a more efficient rate than terrestrial networks.

3.1.1.2 Other Use Cases from 3GPP TR 22.891

Other Use Cases from this TR could actually find some application and/or have specific interest for satellite (see Table 1). For the sake of synthesis, their description cannot be provided here.

Note that many other use cases could also be supported by satellite, but with a lower interest for their study, [4].

Table 1: Use cases TR 22.891 [4]

Use Case Number	Topic
Use Case 3	Lifeline communications / natural disaster
Use Case 6	Mobile broadband for hotspots scenario
Use Case 10	Mobile broadband services with seamless wide-area coverage
Use Case 28	Multiple RAT connectivity and RAT selection
Use Case 29	Higher User Mobility
Use Case 30	Connectivity Everywhere
Use Case 31	Temporary Service for Users of Other Operators in Emergency Case
Use Case 34	Mobility on demand
Use Case 48	Provision of essential services for very low-ARPU areas
Use Case 52	Wireless Self-Backhauling[1]
Use Case 53	Vehicular Internet & Infotainment
Use Case 56	Broadcasting Support
Use Case 57	Ad-Hoc Broadcasting
Use Case 64	User Multi-Connectivity across operators
Use Case 66	Broadband Direct Air to Ground Communications (DA2GC)
Use Case 70	Broadcast/Multicast Services using a Dedicated Radio Carrier

[1] Self-Backhauling refers to concept of coverage extension by interconnecting a base Station to another Base station through the 5G radio system

One of the key requirements across various industry white papers is ensuring high availability and service reliability via ubiquitous coverage. The role associated with the satellite is crucial to ensure a 100% geographic coverage requirement case, because satellites are ideal to deployment 5G in underserved or difficult zones.

Service Category	Deployment Scenario/Services	3GPP SA Use Case (TR 22.891-200)
Multimedia delivery	Mobile Broadcast	5.53 Vehicular Internet & Infotainment 5.56 Broadcasting Support 5.64 User Multi-Connectivity across operators
	Content Caching	5.36 In-network and device caching
	Broadcast to home	5.56 Broadcasting Support
Broadband	Mobile Broadband to users and Vehicles	5.28 Multiple RAT connectivity and RAT selection 5.29 Higher User Mobility 5.53 Vehicular Internet & Infotainment
	Fixed Broadband to homes and enterprises	5.41 Domestic Home Monitoring
	Ubiquitous coverage- Remote areas services	5.30 Connectivity Everywhere 5.10 Mobile broadband services with seamless wide-area coverage
	Backhaul Connectivity	5.30 Connectivity Everywhere 5.10 Mobile broadband services with seamless wide-area coverage
	Broadband to moving platforms- flights, ships etc.	5.30 Connectivity Everywhere 5.12 Connectivity for drones 5.29 Higher User Mobility
Machine Type Communication	Fleet Tracking	5.43 Materials and inventory management and location tracking
	Asset Management	5.43 Materials and inventory management and location tracking
	Wide area sensor management	5.42 Low mobility devices 5.73 Delivery Assurance for High Latency Tolerant Services
Critical Communication	Disaster Management	5.3 Lifeline communications / natural disaster 5.31 Temporary Service for Users of Other Operators in Emergency Case
	Air Traffic Management	
	Reliable Communication	5.73 Delivery Assurance for High Latency Tolerant Services
Vehicular Communication	Traffic Updates and Software Upgrades	5.33 Connected Vehicles
	eCalls and Emergency Notifications	5.3 Lifeline communications / natural disaster 5.31 Temporary Service for Users of Other Operators in Emergency Case

Figure 3: 3GPP 5G Services

3.1.2 TS 22.261

In the section of TS 22.261 [1] dedicated to NTN, all GEO, Medium Earth Orbit (MEO), or LEO are recognized as candidates for a “generic” satellite-based access.

Table 2: Review of TS 22.261 [1] high data rate scenarios and their performance requirements when applied to satellite access.

#	Scenario	Experienced data rate (DL)	Experienced data rate (UL)	Area traffic capacity (DL)	Area traffic capacity (UL)	Overall user density	Activity factor	UE speed	Coverage
S1	Rural macro – P	10 Mbps	1 Mbps	20 Mbps/km^2	2 Mbps/km^2	10/km^2	20%	Pedestrian	Outdoor/open area (note 1)
S2	Rural macro – V	50 Mbps	25 Mbps	100 Mbps/km^2	50 Mbps/km^2	10/km^2	20%	Users in vehicles (up to 120 km/h	In car (note 2)
S3	Indoor hotspot in rural area	200 Mbps	100 Mbps	400 Mbps/km^2	200 Mbps/km^2	10/km^2	20%	Pedestrians	Office and residential (note 3)
S4	Broadcast-like services – P	Maximum 10 Mbps	N/A or modest (e.g., 10 kbps per user)	N/A	N/A	TV channels of [10 Mbps] on one carrier	N/A	Stationary users, pedestrians	Outdoor/open area
S5	Broadcast-like services - V	Maximum 50 Mbps (per TV channel)	N/A or modest (e.g., 50 kbps per user)	N/A	N/A	TV channels of [10 Mbps] on one carrier	N/A	users in vehicles (up to 500 km/h)	In car (note 2)
S6	High-speed train	50 Mbps	25 Mbps	200 Mbps/train	100 Mbps/train	10/train	30%	Users in trains (up to 500 km/h)	In train (note 2)
S7	Airplanes connectivity	15 Mbps	7.5 Mbps	1,2 Gbps/plane	600 Mbps/plane	400/plane	20%	Users in airplanes (up to 1 000 km/h)	In plane (note 2)
NOTE 1: Performance equivalent to cellular network at cell edge NOTE 2: For users in vehicles, the UE can be connected to the network via an on-board moving base station. NOTE 3: For users in building, the UE can be connected to the network via a repeater. NOTE 4: All the values in this table are targeted values and not strict requirements.									

Satellite access can typically provide:

- A communication service availability of up to 99.9%
- A reliability of up to 99.9%
- An end-to-end latency down to 25 ms (assuming LEO systems)

NOTE: Communication service availability relates to the service interfaces, reliability relates to a given system entity. One or more retransmissions of network layer packets may take place in order to satisfy the reliability requirement.

3.1.2.1 Delay and other requirements

Delay and other performance requirements were also identified (already published in TS 22.261).

Delay requirements:

- A 5G system providing service with satellite access shall be able to support GEO based satellite access with up to 285 ms end-to-end latency.
  - NOTE 1: 5 ms network latency is assumed and added to satellite one way delay.
- A 5G system providing service with satellite access shall be able to support MEO based satellite access with up to 95 ms end-to-end latency.
  - NOTE 2: 5 ms network latency is assumed and added to satellite one way delay.
- A 5G system providing service with satellite access shall be able to support LEO based satellite access with up to 35 ms end-to-end latency.
  - NOTE 3: 5 ms network latency is assumed and added to satellite one way delay.

Other requirements:

- The 5G system with satellite access shall support high uplink data rates for 5G satellite UEs.
- The 5G system with satellite access shall support high downlink data rates for 5G satellite UEs.
- The 5G system with satellite access shall support communication service availabilities of at least 99.99%.

3.1.2.2 Functional requirements

- A 5G system shall support negotiation on quality of service taking into account latency penalty to optimise the QoE for UE.

3.1.3 TR 22.822

This work may be viewed as an extension of work done in TR 22.891 [4].

It classifies potential satellite access use cases (without no specific system configuration).

- “Service Continuity” Category

- "Service Ubiquity" Category
- "Service Scalability" Category

A list of 12 use cases is provided, as shown below. [5]

Table 3: 3GPP TR 22.822 [5] Use Cases

Use cases
Roaming between terrestrial and satellite networks
Broadcast and multicast with a satellite overlay
Internet of Things with a satellite network
Temporary use of a satellite component
Optimal routing or steering over a satellite
Satellite transborder service continuity
Global satellite overlay
Indirect connection through a 5G satellite access network
5G Fixed Backhaul between NR and the 5G Core
5G Moving Platform Backhaul
5G to Premises
Satellite connection of remote service centre to off-shore wind farm

For each Use Case are expressed high-level descriptions of:

- Generic description
- Pre-conditions
- Service Flows
- Some Post-conditions
- Potential Impacts or Interactions with Existing Services/Features
- Potential Requirements

The document concludes on a list of overall potential functional requirements related on various aspects: connectivity, roaming, Quality of Service (QoS), UE-related requirements, security and regulatory constraints.

Co-funded by the European Union

3.1.4 TR 38.913

This document aims at identifying, for Next Generation (NG) access (*i.e.*, NR), the typical deployment scenarios associated with attributes such as carrier frequency, inter-site distance, and requirements.

Starting from the deployment's scenarios proposed in TS 22.261, [1], a new category was introduced referred to as "Satellite extension to Terrestrial". The purpose was to introduce the usage of satellite mainly as a geographical extension of the terrestrial service. Initial satellite deployment was proposed as examples.

Table 4: Examples for Satellite Deployment (from TR 38.913) [6]

Attributes	Deployment-1	Deployment-2	Deployment-3
Carrier Frequency NOTE1	Around 1.5 or 2 GHz for both DL and UL	Around 20 GHz for DL Around 30 GHz for UL	Around 40 or 50 GHz
Duplexing	FDD	FDD	FDD
Satellite architecture	Bent-pipe NOTE2	Bent-pipe, On-Board Processing	Bent-pipe, On-Board Processing
Typical satellite system positioning in the 5G architecture	Access network	Backhaul network	Backhaul network
System Bandwidth (DL + UL)	Up to 2*10 MHz	Up to 2*250 MHz	Up to 2 * 1000 MHz
Satellite Orbit	GEO, LEO	LEO, MEO, GEO	LEO, MEO, GEO
UE Distribution	100% Outdoors	100% Outdoors	100% Outdoors
UE Mobility	Fixed, Portable, Mobile NOTE3	Fixed, Portable, Mobile	Fixed, Portable, Mobile

NOTE1: The options noted here are for evaluation purpose, and do not mandate the deployment of these options or preclude the study of other spectrum options. A range of bands from 450MHz – 960MHz identified for WRC-15 are currently being considered and around 700MHz is chosen as a proxy for this range. A range of bands from 1427 – 2690MHz identified for WRC-15 are currently being considered and around 2GHz is chosen as a proxy for this range. A range of bands from 3300 – 4990MHz identified for WRC-15 are currently being considered and around 4GHz is chosen as a proxy for this range.

NOTE2: The aggregated system bandwidth is the total bandwidth typically assumed to derive the values for some KPIs such as area traffic capacity and user experienced data rate. It is allowed to simulate a smaller bandwidth than the aggregated system bandwidth and transform the results to a larger bandwidth. The transformation method should then be described, including the modelling of power limitations.

NOTE3: Consider larger aggregated system bandwidth if 20MHz cannot meet requirement.

NOTE4: The maximum number of antenna elements is a working assumption. 3GPP needs to strive to meet the target with typical antenna configurations.

3.1.5 TR 23.737

TR 23.737 (Release 16) [7] reports on-going study on the *architecture aspects* for using satellite access in 5G. The scope is as follows:

- The identification of impact areas of satellite integration in the 5GS, when considering TR 22.822 [5] use cases.
- The identification of solutions to adjust the 5G system for the impact impacts areas for the reference use cases:
- Roaming between terrestrial and satellite networks.
- 5G Fixed Backhaul between Satellite Enabled NR-RAN and the 5G Core (5GC).
- The resolution of RAN & CN inter-related issues.

At the time being, the document is still in early phase.

3.1.6 TR 38.811

This document probably reflects the most advanced works towards a future expression of specifications. It specifically targets the support of NR over satellite (HAPS also).

The “Non-Terrestrial Networks” (NTN) terminology was introduced for that purpose.

Identified Satellite Use Cases are presented in the next table. [8]

Table 5: Satcom 5G Use cases in TR 38.811 [8]

5G Service enabler	5G Use case	5G Use case description	Satellite service	3GPP References
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 50 Mbps+. 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.	TR 22.864, §5.5: Backhauling TR 22.863, §5.6: Fixed Mobile Convergence TR 22.863, §5.7: Femto cell TR 22.863, §5.4: Higher user mobility TS 22.261 (related to §6.3)
eMBB	**Fixed cell connectivity**	Users in isolated villages or industry premises (Mining, offshore platform) access 5G services and benefit from 50 Mbps+.	Broadband connectivity between the core network and the cells in un-served areas (isolated areas).	TR 22.863, §5.3: Deployment and coverage
eMBB	**Mobile cell connectivity**	Passengers on board vessels or aircrafts access 5G services and benefit from 50 Mbps+.	Broadband connectivity between the core network and the cells on board a moving platform (e.g. aircraft or vessels).	TR 22.863, §5.3: Deployment and coverage TS 22.261 (related to §7.1)
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).	TR 22.862, §5.5: Higher availability TS 22.261 (related to §6.3)
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.	TR 22.863, §5.3: Deployment and coverage

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.	TR 22.864, §5.4: Efficient content delivery TS 22.261 (related to §6.6)
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 combined with terrestrial cellular access to connect a cell/group of cells or relay node(s) on board moving platforms.	TR 22.863, §5.3: Deployment and coverage TR 22.862, §5.5: Higher availability TS 22.261 (related to §7.1)
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.	TR 22.864, §5.4: Efficient content delivery TS 22.261 (related to §6.6)
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 optimisation, Vehicle software updates, automotive diagnostic reporting, user base insurance information (e.g. speed limit, driving behaviour), safety status reporting (e.g. air-bag deployment reporting), advertising-based revenue, Context awareness information (e.g. neighbouring 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.	TR 22.861, §5.2: connectivity aspects TR 22.864, §5.6: Access TR 22.862, §5.1: Higher reliability and lower latency TS 22.261 (related to §6.2.3 Service continuity acriss different access technologies)

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 located 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.	TR 22.863, §5.3: Deployment and coverage TS 22.261 (related to §7.1)
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.	TR 22.864, §5.4: Efficient content delivery TR 22.862, §5.6: Mission critical services TS 22.261 (related to)
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).	TR 22.862, §5.6: Mission critical services TS 22.261 (related to)
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 centre.	Broadband connectivity between the core network and the tactical cells.	TR 22.862, §5.6: Mission critical services TS 22.261 (related to)

The Deployment scenarios identified in TR 38.913 [6] are refined with in addition a link to supported services, and to architecture elements detailed in the frame of an ETSI study (cf. section 3.1.3.6).

Table 6: Deployment scenarios identified in TR 38.811 [8]

Main attributes	Deployment-D1	Deployment-D2	Deployment-D3	Deployment-D4	Deployment-D5
Platform orbit and altitude	GEO at 35 786 km	GEO at 35 786 km	Non-GEO down to 600 km	Non-GEO down to 600 km	UAS between 8 km and 50 km including HAPS
Carrier Frequency on the link between Air / space-borne platform and UE	Around 20 GHz for DL Around 30 GHz for UL (Ka band)	Around 2 GHz for both DL and UL (S band)	Around 2 GHz for both DL and UL (S band)	Around 20 GHz for DL Around 30 GHz for UL (Ka band)	Below and above 6 GHz
Beam pattern	Earth fixed beams	Earth fixed beams	Moving beams	Earth fixed beams	Earth fixed beams
Duplexing	FDD	FDD	FDD	FDD	FDD
Channel Bandwidth (DL + UL)	Up to 2 * 800 MHz	Up to 2 * 20 MHz	Up to 2 * 20MHz	Up to 2 * 800 MHz	Up to 2 * 80 MHz in mobile use and 2 * 1800 MHz in fixed use
NTN architecture options [2]	A3	A1	A2	A4	A2
NTN Terminal type	Very Small Aperture Terminal (fixed or mounted on Moving	Up to 3GPP class 3 UE	Up to 3GPP class 3 UE	Very Small Aperture Terminal (fixed or mounted on Moving	Up to 3GPP class 3 UE

[2] A1: access network serving UEs via bent pipe satellite/aerial

A2: access network serving UEs with gNB on board satellite/aerial

A3: access network serving Relay Nodes via bent pipe satellite/aerial

A4: access network serving Relay Nodes with gNB on board satellite/aerial

	Platforms) implementing a relay node			Platforms) implementing a Relay node	Also Very Small Aperture Terminal
NTN terminal Distribution	100% Outdoors	100% Outdoors	100% Outdoors	100% Outdoors	Indoor and Outdoor
NTN terminal Speed	up to 1000 km/h (e.g. aircraft)	up to 1000 km/h (e.g. aircraft)	up to 1000 km/h (e.g. aircraft)	up to 1000 km/h (e.g. aircraft)	up to 500 km/h (e.g. high speed trains)
Main rationales	GEO based indirect access via relay node	GEO based direct access	Non-GEO based direct access	Non-GEO based indirect access via relay node	Support of low latency services for 3GPP mobile UEs, both indoors and outdoors
Supported Uses cases	1/eMBB: multi-connectivity, fixed cell connectivity, mobile cell connectivity, network resilience, Trunking, edge network delivery, Mobile cell hybrid connectivity, Direct To Node multicast/ broadcast	1/eMBB: Regional area public safety, Wide area public safety, Direct to mobile broadcast, Wide area IoT service	1/eMBB: Regional area public safety, Wide area public safety, Wide area IoT service	1/ eMBB: multi-homing, fixed cell connectivity, mobile cell connectivity, network resilience, Trunking, Mobile cell hybrid connectivity	1/ eMBB: Hot spot on demand

3.1.7 TR 38.821

As a continuation of the TR 38.811 [8], TR 38.821 [9] addresses the case of NR over the satellite and HAPS link.

Four reference scenarios are also considered in higher priority. They are characterized as follows.

Table 7: Reference scenario A – B – C – D in TR 38.821 [7]

Scenarios	GEO based non-terrestrial access network (Scenario A and B)	LEO based non-terrestrial access network (Scenario C & D)
Orbit type	notional station keeping position fixed in terms of elevation/azimuth with respect to a given earth point	circular orbiting around the earth
Altitude	35,786 km	600 km; 1,200 km
Spectrum (service link)	<6 GHz (e.g. 2 GHz) >6 GHz (e.g. DL 20 GHz, UL 30 GHz)	
Max channel bandwidth (service link)	30 MHz for band < 6 GHz 400 MHz for band > 6 GHz	
Payload	Scenario A: Transparent (including radio frequency function only) Scenario B: regenerative (including all or part of RAN functions)	Scenario C: Transparent (including radio frequency function only) Scenario D: Regenerative (including all or part of RAN functions)
Inter-Satellite link	No	Scenario C: No; Scenario D: Yes
Earth-fixed beams	Yes	Scenario C: No (the beams move with the satellite) Scenario D, option 1: Yes (steering beams), see note 1 Scenario D, option 2: No (the beams move with the satellite)
Max beam foot print diameter at nadir	500 km	200 km
Min Elevation angle for both sat-gateway and user equipment	10°	10°
Max distance between satellite and user equipment at min elevation angle	40,586 km	1,932 km (600 km altitude) 3,131 km (1,200 km altitude)
Max Round Trip Delay (propagation delay only)	Scenario A: 562 ms (service and feeder links) Scenario B: 281ms	Scenario C: 25.76 ms (transparent payload: service and feeder links) Scenario D: 12.88 ms (regenerative payload: service link only)

Max delay variation within a beam (earth fixed user equipment)	16ms	4.44ms (600km) 6.44ms (1200km)
Max differential delay within a beam	1.6 ms	0.65 ms ([3])
Max Doppler shift (earth fixed user equipment)	0.93 ppm	24 ppm ([1])
Max Doppler shift variation (earth fixed user equipment)	0.000 045 ppm/s	0.27ppm/s ([1])
User equipment motion on the earth	1000 km/h (e.g. aircraft)	500 km/h (e.g. high speed train) Possibly 1000 km/h (e.g. aircraft)
User equipment antenna types	Omnidirectional antenna (linear polarisation), assuming 0 dBi Directive antenna (up to 60 cm equivalent aperture diameter in circular polarisation)	
User equipment Tx power	Omnidirectional antenna: UE power class 3 with up to 200 mW Directive antenna: up to 4 W	
User equipment Noise figure	Omnidirectional antenna: 7 dB Directive antenna: 1.2 dB	
Service link	3GPP defined New Radio	
Feeder link	3GPP or non-3GPP defined Radio interface	3GPP or non-3GPP defined Radio interface

[3] corresponds to altitude of 600 km

3.2 GSOA SCENARIOS

GSOA, as a global association of satellite operators, is a "market representation partner" for the satellite sector in the 3GPP standard. Thus, GSOA is an entity responsible to ensure the future of 5G-NTN.

In this point, the 5G technology promises a Hyper-connected society where the differences between the rural and urban zones are critical in terms of connectivity.

To solve it, the role associated with satellite communications is crucial to ensure the newest technologies in underserved zones or directly on zones where the terrestrial network has impossible its deployment, [10].

GSOA identifies different use cases in the 5G ecosystem, [11]:

- Communications on the move: This use case is about providing high-speed eMBB backhaul connectivity to individual satellite terminals in-motion on planes, road vehicles, trains, and vessels. Providing connectivity completing terrestrial networks, such as broadband and content multicast connectivity.
- Direct-to-Premises Connectivity ("hybrid multiplay"): This use case extends 5G network connectivity to homes, business, or governments. Completing terrestrial networks, distributing IP streaming services and extending the cloud services to all the zones.
- Direct Connectivity to End Devices: This use case extends 5G network to the end users, like vehicles, handheld, or ships, providing ubiquitous coverage to users in rural areas without having to deploy terrestrial base stations.
- Backhauling & Tower Feed (Cell Site Backhaul & Content Distribution): This use case provides that satellites can directly connect individual cell sites and base station, high capacity backhaul connectivity for individual 5G cell sites, and enabling efficient content distribution directly to these sites. 5G coverage in areas requiring new, standalone cell sites that cannot be connected to each other via terrestrial means due to geography or economics. Moreover, this use case provides of disaster relief, emergency response and the fast deployment of 5G networks.
- Trunking & Head-end Feed (Aggregated Mobile Backhaul & Content Distribution): This use case provides of high capacity of backhaul to one or multiple 5G cell sites. In a typical deployment, mobile traffic from multiple base stations is aggregated to a satellite terminal, which then carries the traffic to and from the network core. Head-end feed builds on satellite's inherent ability to efficiently transmit the same content to multiple locations simultaneously to enable the high-speed distribution of eMBB content such as videos or other common data closer to the network edge.

To continue the satellite deployment in the 5G networks is fundamental to ensure several key principles that regulators and policymakers globally must adhere to in adopting their policies and regulatory regimes.

- Technology Neutrality
- Cost-Efficiency

- Regulatory considerations
- Access to Spectrum resources

3.3 5G-STARDUST SCENARIOS

5G-STARDUST has the target to provide ubiquitous 5G coverage, specially focused on low density areas, with the deeper integration of TN and NTN. To provide coverage and services to a wide area economically, 5G-STARDUST will investigate the use of space borne components, namely satellite communication from LEO and GEO. Satellite systems can complement the 5G TN system to improve the value delivered to end-users.

The main benefit of NTN systems is the coverage provided by complementing existing TN systems, which will be an enabler for verticals and foster regions with a low density of population. NTN systems are also able to bring additionally resilience and reliability for a multitude of use cases, including disaster cases and mobile communication.

5G-STARTDUST will be an enabler for several verticals benefiting from this deeper integration and design an architecture which will support many different use cases.

Table 8: Scenarios 5G-STARDUST

Topics	Scenario	Description
Dual Connectivity	Scenario 1.1	Airway GEO and NGSO complementing terrestrial coverage when airplane leave the airport. 5G broadband services for passengers with terrestrial and satellite, providing a homogeneous and transparent experience for users.
	Scenario 1.2	Direct Access/LEO (IAB), helping to fast deploy networks to accelerate terrestrial 5G rural deployments or temporal gap filler. FWA from LEO/GEO with dual connectivity and common O&M with terrestrial and satellite, providing a homogeneous and transparent experience for users and a common management for the MNOs.
Architecture and Service Distribution	Scenario 2.1	V2N communications to enhance 3 different services like Software over the air updates, HD maps updates and NG eCall service to provide rapid assist in serious accident; using TN and LEO satellites to extent V2N coverage for underserved areas.
	Scenario 2.2	PPDR communication in case TN infrastructure is damaged during a disaster event. NTN will provide temporarily coverage for first responders. Also, extended coverage in case of uncovered areas for first responder

		agencies is considered. Direct and backhauled access of LEO satellites.
	Scenario 2.3	Distributed 5G Systems for private networks. LEO onboarded with UPF, ensuring shorter global data paths, data retention and potentially with ultra-secure and ultra-reliable signalling centralized in satellite environment.

To specify services, requirements, and KPIs, the structure of each use case description has been standardized to ensure coherency and ease-of-readability for the reader. A summary of the main aspects selected for UC description is provided in the following.

As previous stated, the five selected Use Cases (UCs) are analysed in Sections 4 to 8. A first high-level description is provided in Sub-section x.1: *Description*, including the pre-conditions, service flows, post-conditions, in a 3GPP-like format.

Then, more details are given in Sub-section x.2: *Service and user requirements specification* for the considered UC scenario. More precisely, such details target:

- **Service capabilities:** Details on the type of traffic involved in the UC (Data, Voice, Video, Real-time / Non-Real-time, Critical / non-critical, Downlink / uplink, etc)

- **Device characteristics:** Constraints with respect to installation (Access point / Smartphone / IoT / vehicle-mounted, potentially size, weight, and power consumption constraints), expected mobility pattern and Velocity, etc.

- **Network management aspects:** including remarks on device density, environment specificities (*e.g.*, open seas, mountains, altitude, under railway catenary wires, etc.), traffic heterogeneity and variability (for both short-term and long-term) and if relevant, applicable national regulation / cross-border and extra-territorial regulation.

Additionally, in section 9, the consolidated KPIs, extracted from the user requirements related to the considered use cases are analysed. In particular, three families of KPIs are proposed to assess user application capabilities, service continuity and service ubiquity.

Furthermore, in section 10, a KVI analysis has been performed for each scenario. Especially applying the KVIs as a method for deep understanding of novel technology-based solutions aimed at citizens' needs.

Finally, the chosen scenarios will provide inputs for the future Proof-of-Concept in section 11, which will showcase the integration of TN and NTN, and facilitate an analysis of the architectural aspects.

4 USE CASE 1.1 MARITIME, RAILWAY, AIRWAY NEUTRAL-HOST CELL

4.1 DESCRIPTION

Currently, telecommunication operators face challenges to provide continuous connectivity in underserved areas where terrestrial networks are difficult to deploy. A notable instance is found in remote oceanic or rural regions where the deployment cost of terrestrial networks is prohibitively high or simply not feasible.

To tackle this challenge, the coexistence of terrestrial and non-terrestrial networks has become a reality, allowing operators to leverage satellite communications technology to provide connectivity in previously underserved areas.

This solution enables rapid deployment in underserved areas, delivering the latest technologies anywhere, anytime, and on any device (ATAWAD). It represents an interesting solution for transportation purposes. For instance, a commuter who travels daily between two countries may experience a lack of full coverage due to limited infrastructure of terrestrial networks. As a result, they may face interruptions while streaming videos, working remotely, or playing online games. This is because the quality of connectivity is heavily dependent on proximity to the Base Transmission Station (BTS) located on the coast, station, or airport.

One of the objectives of this scenario is to ensure a hybrid network that guarantees comprehensive coverage, allowing users to enjoy services like remote working, thanks to the role associated to the satellite. In other words, the connectivity will be seamless for the end device, enabling passengers to stay connected while inside the means of transport. To backhaul the 5G cell, the means of transport will have diverse radio access technologies that will provide of connectivity to the passengers. This technology will work in the FR2 to ensure a nearly seamless mobile service all along the journey.

It will open new opportunities for the co-existence between TN & NTN as well as the transport communications, roadways for the autonomous car and accelerate the 5G/6G technologies deployment.

If we put the focus in the hybrid networks for means of transport, we will find different services that could be integrated in the 5G network:

- Maritime scenario (illustrated in Use case 1.1.a): nowadays the solution to the GMDSS (Global Maritime Distress and Safety Systems) has some limitations in terms of access to telecommunications services, including speech and broadband data transmission. There are satellite systems providing services like email or broadband with reduced capabilities. The 5G network allow the huge transmission rates and services necessaries to the vessel safety systems working with low latency. GMDSS would work on a 5G network, instead of a mix of different radio technologies, communication protocols, frequencies, Rescue Coordination Centres (RCC) are alerts via 5G in cases of distress at sea. To achieve it the vessel must be equipped with the necessaries 5G systems to ensure Safety Systems, [12].

- Railway scenario (illustrated in Use case 1.1.b): The integration of 5G hybrid networks for FRMCS (Future Railway Mobile Communication System) for trains will drive a new era of advanced services and high-quality connectivity. Hybrid networks will enable the implementation of a wide range of services on trains, including high-speed voice and data communications, real-time video streaming, remote equipment monitoring, real-time software updates and accurate location services. This will significantly improve the passenger experience, safety and operational efficiency of the rail system, positioning FRMCS over 5G NTN as a reference standard for rail transport of the future. It offers high capacity, performance, and reliability, along with support for massive MTC and IoT. With FRMCS based on 5G, you can support ultra-reliable, low-latency mission-critical communication, [13].

- Airway scenario (illustrated in Use case 1.1.c): 5G aircraft communication will enable exceptionally fast and reliable in-flight connectivity. This technology will use satellites and ground base stations to provide global coverage to the air traffic controllers and passengers. In this scenario, 5G networks bring high data rates and traffic providing evolved broadband for the passengers.

During this chapter, the airway scenario will be deeply analysed offering 5G eMBB (Enhanced Mobile Broadband) to passengers and the aircrew.

The airway scenario is selected hereafter as the reference for passenger transportation use-case since it englobes all other scenarios and the NTN terminal speed is high (1000 Km/h), higher than trains, ships and cars.

4.1.1 Scenario

As mentioned above, we focus on the Airway scenario for 5G services to passengers.

In this scenario, the idea is to provide 5G services to the passengers thanks to multi-orbital solutions using GEO and NGSO satellites. The plane must be equipped with the following elements:

- Antenna terminal connected to a GEO or NGSO satellites working on FR2 band.
- GEO or NGSO satellites working on FR2 band.
- Terrestrial networks working on FR1 band.
- gNodeB where the final users will connect to the 5G networks.
- Passenger’s UE with 5G capabilities

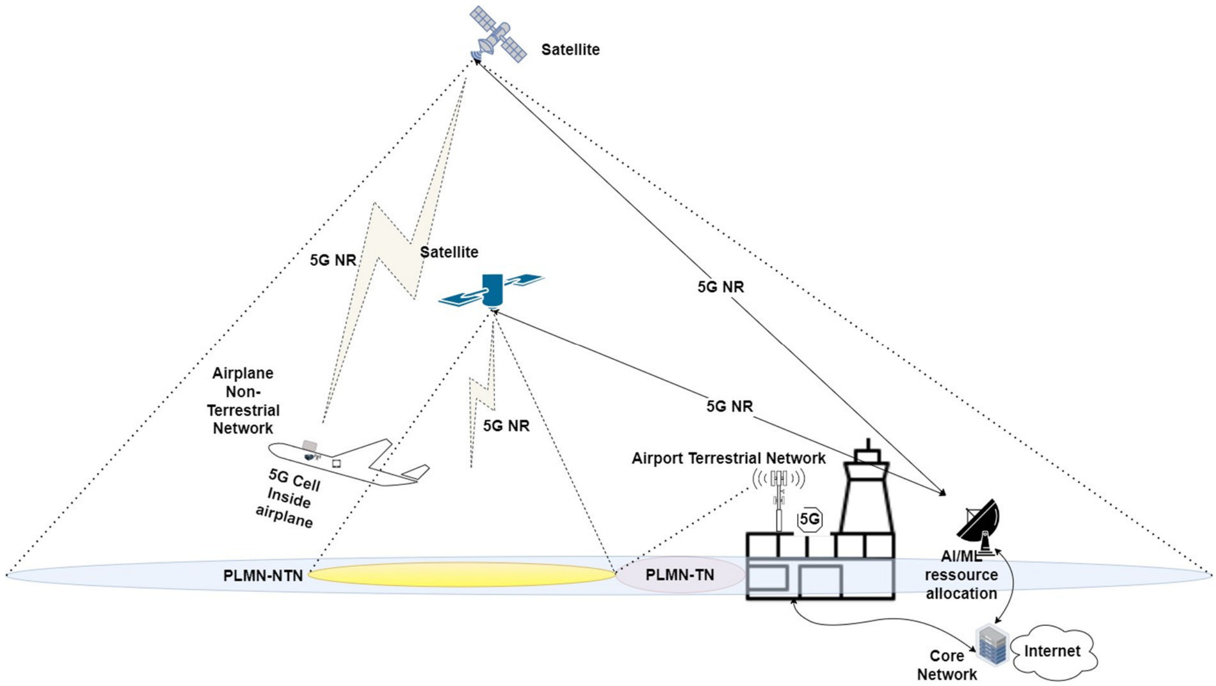

Figure 4: Airway 5G scenario

4.1.2 Pre-conditions

- Airway users have a subscription with terrestrial and non-terrestrial operators to provide 5G networks to their passengers. Different Public Land Mobile Networks (PLMNs) must be configured between terrestrial and non-terrestrial networks.
- The satellite and terrestrial connectivity provide 5G services where the backhaul is transparent for the final user.
- Plane are equipped with terminals which support satellite capabilities and allowed FR2 bands.
- Satellites GEO & NGSO have an allocated slot for this purpose.
- Neutral host cell onboard, connecting the passengers to the 5G network.
- 5G Core Network on ground to administrate the system.

4.1.3 Service Flows

- In the airport, two different types of networks connectivity are overlapped: (1) "Airport Terrestrial Network" destined to provide connectivity to users while on the ground, (2) "Airplane Non-Terrestrial Network" destined to provide access to users while on the aircraft whatever the airplane is on in the air or on the ground combining GEO and NGSO offering ubiquitous coverage across numerous geographies.
- At the initial stage, users located in the airport are experiencing Video Stream through Airport TN. Users experience good video QoS in the sense that the minimum Bit Error Rate (BER) requirement specified in the standard TS 23.501 [14] is met. NOTE: this part of the scenario is not to be considered as the main scope for current analysis. The rationale behind it is that this “on-the-ground part” of the use case is pure TN, and not

really related to TN/NTN switching; we do not anticipate this may drive any particular requirement for 5G-STARDUST. In the end, it is worth not focusing too much on this "international roaming" part of the Use Case as it calls for additional legal & contractual constraints that add a complexity that is not the main topic for the study.

- The connectivity switches from "(1) airport TN" to "(2) Airplane Company NTN". To achieve it, the 5G network must change the PLMN-ID between the terrestrial network to the non-terrestrial network. In this case, when the airplane is on air, the PLMN selected would not be home to any one national market, following the handover procedures.

- During the flight and until aircraft reaches final airport destination, connectivity is maintained through (2). The average 5G quality of service required for Video Stream Bit-Error-Rate is maintained. NOTE: this part of the scenario is not to be considered as the main scope for current analysis. The rationale behind it is that this "on-the-air part" of the use case is pure NTN, and not really related to TN/NTN switching; we do not anticipate this may drive any particular requirement for 5G-STARDUST. In the end, it is worth not focusing too much on this "international roaming" part of the Use Case as it calls for additional legal & contractual constraints a complexity that is not the main topic for the study.

- After Aircraft has landed and has reached airport terminal, users get out the plane. Connectivity switches from (2) "Airplane Company Non-Terrestrial Network" to (1) "Airport Terrestrial Network".

4.1.4 Post-conditions

The airway passengers enjoy the 5G services thanks to the hybrid networks and the dynamic resource management between the terrestrial and non-terrestrial networks. The Artificial Intelligence (AI) and resources allocation strategies are fundamental to achieve it.

4.1.5 Existing features partly or fully covering the use case functionality

The use case in question was proposed in the 3GPP Release 15 as a significant 5G use case. In the TR38.811, [8], document, the description outlines the "Mobile cell Hybrid connectivity" use case, which involves connecting passengers on board transport vehicles to a base station through a hybrid cellular/satellite connection. This hybrid approach allows for coverage continuity by leveraging the benefits of satellite technology.

The integrated 5G TN/NTN roaming agreement for the airway scenario was specified as a use case for the "Study on using Satellite Access in 5G" in TR 22.822, [5].Moreover, the requirements for the roaming procedure are specified in TR 23.122, [15] "Non-Access-Stratum (NAS) functions related to Mobile Station (MS) in idle mode."

In subsequent releases, non-terrestrial networks were introduced (in Release 17) to complement terrestrial networks by providing coverage in remote areas where terrestrial deployment was not feasible. Release 18 marked the start of 5G Advanced, which introduced improvements such as NTN-TN and NTN-NTN mobility and service continuity, as well as advancements in AI and Machine Learning (ML) with a focus on the unified radio interface.

4.2 SERVICE AND USER REQUIREMENTS SPECIFICATION

4.2.1 Detailed description of 5G and Satellite Services

Service capabilities

- Traffic type: 5G broadband services (enhanced mobile broadband).
- Traffic structure: Continuous traffic ensuring the seamless connectivity to the 5G network.
- The protocols and traffic type must be 3GPP 5G NR compatible.

Device characterization

Type of TN / NTN-enabled device: During the airplane connectivity use case, the users can be connected via an onboard base station to the network.

- Mobility pattern & Velocity: Airplanes up to 1000 km/h.
- Positioning and Timing Services: The 5G system shall support the combination of 3GPP and non-3GPP positioning technologies to achieve performances of the 5G positioning services better than those achieved using only 3GPP positioning technologies. Position Service availability shall be of at least 99%.
- Policies and regulatory constraints: the antenna terminal, on-board 5G cell, and the final UE terminal must be 3GPP compatible.

Network management aspects

- For the airway scenario, the network management aspects are specified in the TR 22.261 Table 7.1.1 - Performance requirements for high data rate and traffic density scenarios, [1], where it is stated that 400 users per plane shall be considered as the overall user density with 20% of activity factor, representing the percentage of simultaneous active UEs to the total number of UEs where active means the UEs are exchanging data with the network. The procedure to switch between TN/NTN as a cross-border procedure, where NTN operates where the TN are not reachable.

4.2.2 Detailed specification of Requirements

Use case 1.1.c description is expanded hereafter into requirements. The objective is to feed the subsequent architecture activities (e.g., system requirements definition, reported in D3.1). This may also give some inputs and contextualize to the Proof-of-concept related activities.

4.2.2.1 Mission Requirements

Table 9: Use case 1.1.c. Mission Requirements

REQ TYPE	REQ_ID	Priority	Justification	Related Components	REQ Description
MIS	UC1.1.C-MIS_1	Essential	Use Case; 3GPP	RAN	The mission of the Non-Terrestrial System shall consist in providing a space-based access to 5G networks

MIS	UC1.1.C-MIS_2	Optional	Use Case	RAN	The NTN RAN shall overlap the geographical coverage of TN RAN (*e.g.*, at airport)
MIS	UC1.1.C-MIS_3	Essential	Use Case	RAN	The NTN RAN shall provide an extension to the geographical coverage of TN RAN (e.g., during flight) Note: Even if essential requirement of the system, this part of the scenario is not to be considered as the main scope for current analysis. Rationale behind it: "on-the-air part" of the use case is pure TN, and not really related to TN/NTN switching.

4.2.2.2 User Requirements

Table 10: Use case 1.1.c. User Requirements

REQ TYPE	REQ_ID	Priority	Justification	Related Components	REQ Description
USR	UC1.1.C-USR_1	Essential	Use Case	UE	The NTN System shall provide direct access to airplane compatible type of terminal
USR	UC1.1.C-USR_2	Essential	Use Case	UE	The UE shall be able to connect with 5G to the airplane compatible type of terminal, for indirect access to NTN system.
USR	UC1.1.C-USR_3	Essential	Use Case	UE	At the airport, the UE shall be able to select the available network providing connectivity, i.e. either the usual TN or the airplane one, whichever is available.
USR	UC1.1.C-USR_4	Optional	Use Case	UE	Connecting to the airplane network may already be included within the regular UE subscription. The UE may have a subscription with a NTN provider.

5 USE CASE 1.2 RESIDENTIAL BROADBAND

5.1 DESCRIPTION

In large areas with low-user density, bridging the digital divide still represents a significant challenge when deploying additional terrestrial sites cannot prove economically viable. As a result, Mobile Network Operators (MNOs) are still chasing the unconnected users in rural and remote territories of emerging and more mature markets. Although the use of traditional satellite access (*i.e.*, with a dedicated terminal and rooftop antenna) may already represent a credible solution to serve these unconnected users, the distinct architecture of current-generation satellite network segments, in terms of user terminal or Customer Premises Equipment (CPE) makes it hard for MNOs to harmonize the way they serve their subscribers from both types of network segments.

In contrast, it is envisioned that a 5G-STARDUST compliant NTN network may support a harmonized operation of both TN and NTN networks, notably because supporting residential broadband from a LEO/GEO dual connectivity brings the opportunity of more homogeneous and transparent experience for users and a common management for the MNOs.

5.1.1 Scenario

This scenario focuses on residential broadband coverage and the ability for users in it to be served by a dual GEO/LEO connectivity. Here, a user is associated to a household and wishes to experience residential eMBB services to their fullest extent (*i.e.*, with a user experience comparable to that assuming a terrestrial FWA connectivity). In addition, this scenario assumes three possible types of residential terminals:

- **Type-1:** Terminal and antenna in FR2 band able to establish a dual connection to a GEO / LEO satellite. Moreover, this equipment may be used as an IAB Donor.
- **Type-2:** Supports type-1 features, plus the ability to connect to a terrestrial mobile site.
- **Type-3:** a terminal of simpler design, without antennas to directly connect to GEO / LEO satellite

Furthermore, UC1.2 requires that GEO / LEO satellites operate on FR2 band.

- 3 different sub-cases with separate objectives can be defined and are refined here-after:
    - Use Case 1.2.a illustrates LEO or GEO choice depending on QoS;
    - Use Case 1.2.b contextualizes IAB for residential broadband;
    - Use Case 1.2.c evaluate TN to NTN switching for energy saving purpose.

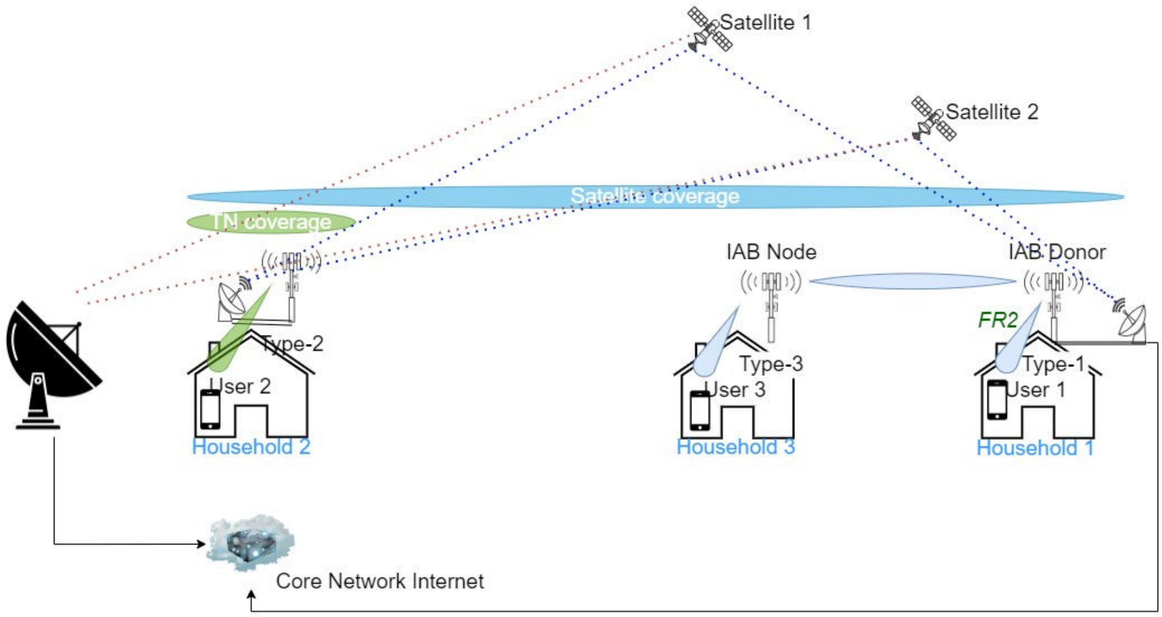

Figure 5. Residential Broadband high-level architecture

5.1.2 Pre-conditions

- Three (household, user) couples are considered. User 1 lives in household 1, which is equipped with type-1 terminal, user 2 in household 2 with type-2 terminal and user 3 in household 3 with type-3 terminal.
- All three residential users have a subscription with mobile network and satellite operators.
- In addition, user 1 and user 3 have a subscription with the same mobile network.
- Household 1 and household 3 are in close vicinity, outside the MNO's terrestrial coverage, and household 1 terminal is configured to be the IAB donor of household 3 terminal (which is configured as IAB node).
- Household 2 is inside the MNO terrestrial coverage, and household 2 terminal is configured by default to access the MNO's terrestrial cellular network.
- The MNO seeks to increase the energy efficiency of its terrestrial network, and as a result, the mobile site which serves household 2 is susceptible to be temporarily put into sleep mode, for instance at night, when the detected user traffic in the considered cell drops below a preconfigured threshold, or when satellite access is considered as more energy efficient (*e.g.*, most users are watching the same video live, such as Olympics games or soccer worldwide final), and the remaining user traffic, not related to such video live falls below the preconfigured threshold). However, before the user service flow starts, the considered cell is up and running.
- LEO and GEO satellites have an allocated slot for this purpose.
- TN can coexist with NTN on adjacent channels.

5.1.3 Service Flows

- Use Case 1.2a:

  - User 1 is located inside household 1 and wants to access online services, in particular a video streaming service, a light browsing session as well as a Visio conference session with friends and family.
  - Depending on the identifier (*e.g.*, an identifier referring to QoS characteristics such as 5G QoS Identifier (5QI)) associated with each considered service data flows, the terminal in household 1 uses the most adapted LEO/GEO link.
- Use Case 1.2b:
  - User 3 in household 3 subscribed to a remote security / health monitoring service, and the remote centre of this company wishes to check the household 3 automation system made of sensors (*e.g.*, a home camera with movement detection, intrusion detection sensor) and actuators (*e.g.*, a set of wireless smart plugs to remotely switch on/off equipment and a tele-operated automatic watering system).
  - The traffic to and from household 3 is always backhauled via the IAB connection connecting household 1 and household 3. The identifier associated to that traffic can also be used by household 1 terminal to transmit the corresponding service data flows with the most adapted LEO / GEO link.
- Use Case 1.2c:
  - User 2 is located inside household 2 and needs to access his FWA services at a time when the MNO's mobile site which serves household 2 terminal is put into sleep mode, for energy saving purposes. Household 2 terminal is then able to transparently switch to NTN LEO / GEO link, applicative sessions are not closed during the transition between TN and NTN, and user 2 is therefore able to continue experiencing his FWA services with a satisfying Quality of Experience (QoE).
  - When the terrestrial mobile site which serves household 2 terminal wakes up from sleep mode, household 2 terminal can transparently switch back to its regular attachment to this terrestrial mobile site.
  - The trigger to initiate TN / NTN switching remains one of the key aspects of such UC. The transparent and seamless transition depends on its technical implementation and on the role model sharing between the MNO and SNO.

5.1.4 Post-conditions (if required)

All three residential users: User 1, User 2, and User 3, respectively served by type-1, type-2, and type-3 terminals are able to experience broadband connectivity with a satisfying and homogeneous QoE.

5.1.5 Existing features partly or fully covering the use case functionality

This use case may be partly supported by the connectivity of non-NTN-compliant GEO satellites fleets or NGSO constellations, provided they can serve users in remote and rural areas with mobile broadband links, *e.g.*, in Ku or Ka-band. However, due to the lack of TN/NTN standardized interface, no seamless transition between either type of network segment can be easily envisioned with these solutions.

At 3GPP, TR 38.821, [9], pertains to NR over satellite and HAPS links and it makes assumptions about operating frequencies (> 6GHz) that align with the use case functionalities. TR 38.913, [6], explored the idea of "Satellite extension to Terrestrial," which relates to the overall use case goal of using satellite connectivity as an extension of terrestrial service. However, there is a need to identify dedicated NTN spectrum in FR2, and the aforementioned TRs do not address the mechanisms required to ensure a complex and highly dynamic system by intelligently switching from multiple LEO/GEO links, when there is link diversity available from the user terminal perspective.

5.2 SERVICE AND USER REQUIREMENTS SPECIFICATION

5.2.1 Detailed description of 5G and Satellite Services

Service capabilities

- Traffic type: 5G broadband and FWA services (enhanced mobile broadband).
- Traffic structure: Continuous traffic ensuring the seamless connectivity to the 5G network.
- The protocols and traffic type must be 3GPP 5G NR compatible.

Device characterization

- Type of TN / NTN-enabled device: Type-1 terminals must be compliant with 3GPP standards NTN connectivity, Type-2 terminals must be compliant with 3GPP standards TN and NTN connectivity, Type-1 and type-3 terminals must support 3GPP IAB standards. Type-1 terminal must be able to act as IAB donors, while type-3 terminals must be able to act as IAB nodes.
- Mobility pattern & Velocity: Static / almost static users are assumed.

Network management aspects

- While Use Cases 1.2a and 1.2b target only a few UEs to be moved from TN to NTN (or conversely) at the same time, the switch-off of a terrestrial base station in a remote rural area, in Use Case 1.2c, could disconnect several villages, scattered over a wide area. Several hundreds, to a few thousands, of people are expected to be simultaneously transitioned from TN to NTN.

5.2.2 Detailed specification of Requirements

5.2.2.1 Mission Requirements

Table 11: Use case 1.2. Mission Requirements

REQ TYPE	REQ_ID	Priority	Justification	Related Components	REQ Description
MIS	UC1.2-MIS_1	Essential	Use Case; 3GPP	RAN	The NTN System shall select or configure the most appropriate link depending on QoS requirements (e.g., latency, jitter, guaranteed data rate). The UE traffic shall be re-routed to the

					NTN system, depending on expected QoS. Note: For instance, in the case where both LEO and GEO links are available, delays sensitive applications may then be routed in priority to LEO.
MIS	UC1.2-MIS_2	Essential	Use Case	RAN	A few identified households in the network shall have direct access to NTN.
MIS	UC1.2-MIS_3	Essential	Use Case	RAN	UEs previously served by the MNO's mobile site that is switched-off shall be able to connect to the identified households that are granted with direct access to NTN, using the same subscription.
MIS	UC1.2-MIS_4	Essential	Use Case	RAN	The NTN RAN shall overlap the geographical coverage of TN RAN
MIS	UC1.2-MIS_5	Essential	Use Case	RAN CORE	The TN shall be able to communicate with the NTN to ensure all served UEs can be transitioned to NTN before switching-off a TN base station.
MIS	UC1.2-MIS_6	Essential	Use Case	RAN	The NTN shall support different forms of connectivity (FWA and IAB).

5.2.2.2 User Requirements

Table 12: Use case 1.2 User Requirements

REQ TYPE	REQ_ID	Priority	Justification	Related Components	REQ Description
USR	UC1.2-USR_1	Essential	Use Case	UE	The UE shall be seamlessly the UE shall seamlessly connect to either TN or NTN.
USR	UC1.2-USR_2	Essential	Use Case	UE	The UE shall not be impacted (QoS, but also service

					subscription) by a TN base station switch-off.
USR	UC1.2-USR_3	Essential	Use Case	RAN	Remote household automation services requirements shall include high availability requirements. Examples can be collected in TR 22.861, TR 22.864, TR 22.862, TS 22.261, and related documents.

6 USE CASE 2.1 VEHICLE CONNECTED

6.1 DESCRIPTION

V2N communications play a crucial role in enhancing vehicle safety and traffic efficiency. One of the key benefits of enabling vehicles to access the Internet using cellular networks is the provision of services such as

- Software over the air (SOTA) updates. The introduction of the SOTA updates offers the possibility to add new settings, configurations, or services to the in-vehicle systems, such as the infotainment and the navigation systems. The vehicle features are upgraded by means of the telematic control unit, which is in charge of downloading the updates.

- HD maps transmission. The use of HD maps emerges to support the driver on taking actions upon receiving the awareness information. HD maps reflect the actual environment conditions as they contain real-time traffic information. Receiving updated and reliable HD map information is essential to prevent accidents, avoid congestions and inform about closed roads or road repairs, which allows providing the optimal route.

- NG eCall service. In the event of a serious accident, the NG eCall system should guarantee a rapid assistance. In such a case, the in-vehicle sensors will automatically initiate an audio call with the public safety answering point (PSAP). At the same time, an emergency message with rescue details, e.g., position and sensor information, could be sent. Additional services such as a real-time video could also be provisioned. It is worth emphasizing that the eCall can also be triggered manually.

It is important to remark that there are still gaps in coverage for TNs, particularly in rural and remote regions. Consequently, V2N communications can only be realized in areas that are covered by terrestrial infrastructures. To provide the service to un- or underserved areas, NTN can be used. In order to ensure service continuity, NTN must be integrated into the terrestrial network infrastructure. Satellites are operated at different orbits, spanning from GSO to NGSO. LEO satellite communication systems are the most suitable option owing to the close proximity to Earth. This translates into lower latency, smaller antennas, lighter terminals and lower power consumption, which is a relevant aspect for vehicular communications.

6.1.1 Scenario

This use case focuses on vehicles that may need to share information from sensors, benefit from cloud services such as HD maps and software updates, establish audio channels or stream video. The vehicles are connected to a cellular network but along the route are expected to enter coverage gaps where the cellular connectivity is not available. The coverage gaps fall under the footprint of a LEO satellite, which can provide 5G connectivity at FR2. The LEO satellite is equipped with a regenerative payload that enables placing radio functionalities on-board. The vehicles can establish directional links with the visible satellite by using beam management mechanisms and electronically steerable antennas. To allow vehicles to access the network through LEO satellite or terrestrial links, a unified air interface is adopted in both segments. The unified air interface is exploited to perform fast handovers, between LEO satellites and from the LEO satellite to cellular network or vice versa, which guarantees service continuity. The LEO satellite could leverage on the edge computing capabilities to implement a call session control function to find the appropriate Public Safety Answering Point (PSAP) when the eCall is triggered.

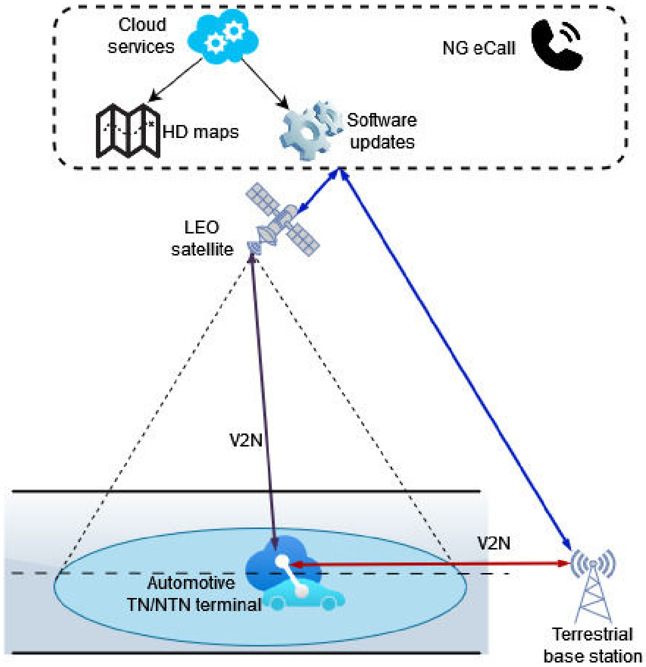

Figure 6: Vehicle connected scenario

6.1.2 Pre-conditions

- The vehicle has a subscription with mobile network and satellite operators.
- TN and NTN radio coverage is overlapping on the route.
- TN can coexist with NTN on adjacent channels.
- The vehicle is equipped with an electronic steerable antenna to establish directional links at FR2 with LEO satellites.
- The route of the vehicle is placed under the coverage of a LEO satellite that is equipped with a regenerative payload.

6.1.3 Service Flows

Use case 2.1.a:

- Cloud services can be delivered to vehicles.
- 5G connectivity is provided to a vehicle that travels at a moderate speed (max 250Km/h) via cellular network.
- The vehicle is approaching a mobile network operator coverage gap.
- Before moving out of coverage, the vehicle performs a search procedure to determine if it is under the coverage of a LEO satellite providing 5G connectivity.
- Upon detecting the cell that is associated to the LEO satellite, the vehicle does a hand-over to transfer the ongoing connection from the cellular network to the LEO satellite network.

- The vehicle makes use of the service link to receive HD maps or software updates from the LEO satellite without service interruption.

Use case 2.1.b:

- The vehicle is equipped with the NG eCall system.
- The vehicle is involved in a serious accident in a region where terrestrial cells are not available.
- Triggered by the in-vehicle sensors, the terminal performs the cell search procedure.
- The terminal is able to access the media either through TN or NTN links.
- Upon detecting a cell that is associated by the LEO satellite network, 5G connectivity is provided to the vehicle.
- The vehicle makes use of the service link to connect with the PSAP in an area that is not covered by terrestrial infrastructures.

6.1.4 Post-conditions

NTN access is used by vehicles to provide connectivity to delay tolerant applications in un-/underserved areas. Service continuity is achieved by seamless interaction between TN and NTN.

6.1.5 Existing features partly or fully covering the use case functionality

NTN have been included in the technical specifications of the 3GPP Release 17. The focus is on direct access and transparent payload architectures with FDD systems. The basic assumptions is that UE is equipped with Global Navigation Satellite System (GNSS) capabilities, as common in 5G and 5G-Advanced NTN. In the transparent mode, the satellite payload plainly forwards the radio protocol from the UE (via the service link) to the gNB, which is co-located to the satellite gateway, (via the feeder link) and vice-versa. The satellite payload may use different frequencies on the service and the feeder links. Remarkably, satellite cells can be fixed or moving on earth, depending on the beam steering capabilities. The normative work includes adaptations into the protocol and the RAN architecture that allow handling long delays, pre-compensating for the instantaneous Doppler frequency shift and supporting mobility between non-terrestrial and terrestrial networks. The new features rely on the satellite assistance information carried in the system information blocks, *e.g.*, the System Information Block 19 (SIB19). The information that is broadcasted includes a common timing advance, scheduling offsets, location of the satellite gateways, serving cell's satellite payload ephemeris and neighbouring cell's satellites payload ephemeris, to mention a few. These parameters are used at least for the random access, the uplink timing, frequency synchronization and mobility management purposes.

Within the scope of Rel. 18, RAN2 investigates NTN-TN mobility enhancements. The emphasis is given to the reduction of the UE power consumption during TN-NTN cell reselection. This enhancement is covered by the work item "NR NTN (Non-Terrestrial Networks) enhancements".

As part of the study item "Study on Support of Satellite Backhauling in 5GS " in Rel. 18, SA2 will investigate architecture enhancements for support of UPF deployed on GEO satellite with gNB on the ground.

6.2 SERVICE AND USER REQUIREMENTS SPECIFICATION

6.2.1 Detailed description of 5G and Satellite Services

Service capabilities

A. Software over the air / High-definition maps

- Traffic type: 5G broadband traffic
- HD maps transmission: Data traffic, 5G broadband traffic.
- Traffic structure: Continuous traffic ensuring the seamless connectivity to the 5G network.
- The protocols and traffic type must be 3GPP 5G NR compatible.

B. NG eCall

- Traffic type: NG eCall data communications (data rate mix of video streaming and 2 ways voice), voice over IMS.
- Traffic structure: Continuous traffic ensures seamless connectivity to the 5G network.
- The protocols and traffic type must be 3GPP 5G NR compatible. IMS eCall aligns with normal IMS emergency call procedures as specified in 3GPP TS 23.167 [16]

Device characterization

A. Software over the air / High-definition maps

- Type of TN / NTN-enabled device: NTN antenna connected (vehicle mounted). The UE can be connected to on board mobile base station too.
- Mobility pattern & Velocity: user in vehicle up to 250 Km/h, [1].
- Positioning and Timing Services: The 5G system shall support the combination of 3GPP and non-3GPP positioning technologies to achieve performances of the 5G positioning services better than those achieved using only 3GPP positioning technologies. Position Service availability 99%.
- Depending on regional radio regulations, the vehicle only needs to know in which region it is located.
- Policies and regulatory constraints: the antenna terminal, onboard 5G cell and the final UE terminal must be 3GPP compatible.
- Different OEMs may employ different providers of radio software. Radio regulations need to determine under which conditions a new release can be deployed.

A. NG eCall

- Type of TN / NTN-enabled device: NTN antenna connected (vehicle mounted). The UE can be connected to on board mobile base station too.

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- Mobility pattern & Velocity: user in vehicle up to 250 Km/h.
- Positioning and Timing Services: GPS based location

Network management aspects:

- For the vehicle scenario the network management aspects are specified in the TS 22.261 *Table 7.1.1 - Performance requirements for high data rate and traffic density scenarios.* [1] where indicates that the 5G network can support up to 4000 devices per Km2 as the overall user density with 50% of activity factor, that means the percentage value of the amount of simultaneous active UEs to the total number of UEs where active means the UEs are exchanging data with the network.

6.2.2 Detailed specification of Requirements

6.2.2.1 Mission Requirements

Table 13: Use case 2.1 Mission Requirements

REQ TYPE	REQ_ID	Priority	Justification	Related Components	REQ Description
MIS	UC2.1-MIS_1	Essential	Use Case	RAN	The NTN RAN shall overlap the geographical coverage of TN RAN
MIS	UC2.1-MIS_2	Essential	Use Case	RAN – CORE - UE	The NTN 5G system shall support NG eCall

6.2.2.2 User Requirements

Table 14: Use case 2.1 User Requirements

REQ TYPE	REQ_ID	Priority	Justification	Related Components	REQ Description
USR	UC2.1-USR_1	Essential	Use Case	UE	The UE shall seamlessly connect to either TN or NTN
USR	UC2.1-USR_2	Essential	Use Case	UE	The vehicle shall be equipped with a terminal that is compliant with 3GPP standards supporting TN and NTN connectivity.

USR	UC2.1-USR_3	Essential	Use Case	UE	UE shall have the capability to store one or more "In Case of Emergengy (ICE) information" on the SIM Card.

7 USE CASE 2.2 PPDR

7.1 DESCRIPTION

PPDR scenarios are typically characterised by the sudden unavailability of the terrestrial infrastructure (entirely or in partitions) for a limited period of time, whereby backup connectivity access has to be provided by means of satellite. As a matter of fact, the availability of satellite links is pivotal for the success of rescue operations as well as general communication means between the affected areas and decision centres (civil protection authorities, data processing centres, etc.). Traffic demands of the general public strongly increase at such events which should not prevent communications of the involved organisations. Upon progressive restoration of the terrestrial infrastructure, the satellite connectivity will be in turn used in conjunction with the terrestrial one. On the other hand, more public safety operations in remote areas (*e.g.*, poorly connected environments) may still require the use of satellite networks due to the limited coverage offered by the existing terrestrial infrastructure or their restricted capacity, which may not be sufficient to provide broadband connectivity to all users. In such a sense, the extension of terrestrial connectivity by means of satellite capacity is regarded as key option to break the digital divide and hence meet the goals of minimum broadband requirement set by EC in terms of the so-called Digital Society targeting 100 Mbit/s for all European households.

The sudden and high demand of capacity combined with priority needs for first responder critical communications leads to challenging spectrum demands for a relatively short period of time. As such, the ITU recommends in [17] a dynamic spectrum allocation and basically adds (if still available) extra channels of public networks to the PPDR network. In some countries, first responder organizations for their operations have dedicated frequency bands for 4G/5G systems, (*e.g.,* 400MHz and 700MHz in France). It's envisaged that these frequencies are used to deploy temporary setups for responding the disaster situation or permanently in areas of high risk such as nuclear plants. This leads to a variety of communication services options for first responders (dedicated networks combined with public networks and satellite) which can be temporary in tactical bubbles or permanently.

7.1.1 Scenario

According to the description provided in the previous section, two main sub-scenarios can be identified:

- Aftermath of a disaster (natural or man-made), subdivided into consecutive increments of connectivity (illustrated in Figure 7: PPDR scenario during a disaster event). In the first increment, the terrestrial connectivity is completely disrupted or at least end-to-end connectivity cannot be established because the overall local network is partitioned. In such a case the availability of connectivity means (*e.g.*, satellite-based) will be fundamental in order to a) allow rich content information exchange between first responders, b) share of information and collaborative frameworks between first responder teams positioned in far areas though part of the same incident areas, and c) general data connectivity between the affected population and other parties. To support rescue groups the provision of indoor communication is required where possible. Applications of involved organisations in this scenario include push-to-talk (PTT) for voice communication, video transmission, and other mission-critical data such as positions, pictures, alerts etc. Different types of UEs are considered in this scenario: first responder handhelds, backhaul links to forward command posts, vehicular communication such as fire trucks and aerial communication such as helicopters and drones. In this case, it is conceivable to establish direct access between UEs and satellites in Frequency Range 1

(FR1), or alternatively use backhaul connectivity over Frequency Range 2 (FR2). The use of IAB is needed for indoor and off-network communication. Support from regenerative satellite payload provides additional resilience and may further improve data connectivity especially in terms of reduced latency. Given the high traffic demand that may arise from the general public during emergencies, utilizing a regenerative satellite can help mitigate the risk of having the feeder link act as a bottleneck, which could impede proper communication. As such, it is reasonable to assume 5G RAN to be operational by means of the existing radio towers (*e.g.*, gNBs) or by deploying dedicated transportable units offering multi-connectivity means (*i.e.*, satellite, 5G, etc.). Then, upon partial or total restoration of the terrestrial infrastructure connectivity, the capacity joint offered by satellite and terrestrial networks will be shared across subscribers by means of optimised traffic sharing and load balancing solutions. In this context, the possibility of multi-radio dual connectivity approach would be also appealing, because of the possibility for a UE to connect simultaneously through two separated RANs, though with some technical challenges.

- Nominal public safety operations in underserved areas, where command & control (C2C) of medical services, police, or fire-brigades' operations may require complementing the scarce terrestrial infrastructure capacity with that possibly offered by satellite links. In such a case, depending on the traffic demands, network saturation conditions, and overall location of users (some users may be located in sub-areas with decent terrestrial connectivity, other in sub-areas with harsher connectivity conditions), part of the traffic could be offloaded to the satellite network. Hence, also this scenario may benefit from a dual case, although the availability of more network resources would be used to allocate user traffic to either of the available networks. As such, the overall connectivity concept will be pretty much oriented to service distribution through a heterogeneous network architecture.

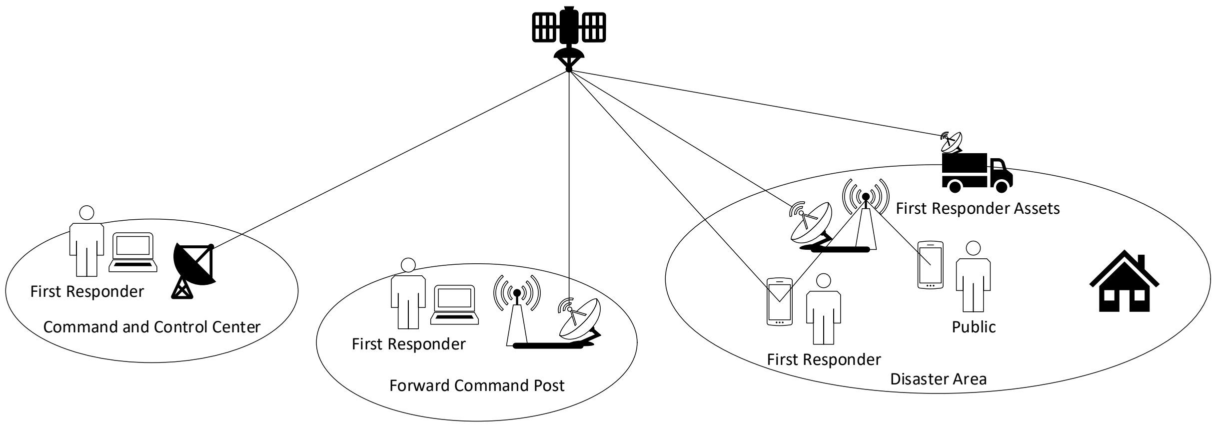

Figure 7: PPDR scenario during a disaster event

In both scenarios, the availability of regenerative satellite would be an added value to have more effective data distribution between the involved parties, possibly saving some delay and better utilising the available bandwidth resources offered by the satellite feeder link. Optionally, a two-tier satellite setup with LEO constellations possibly off-loading traffic towards a GEO one can be also envisioned, although this configuration is probably beyond the focus of an Advanced 5G context.

7.1.2 Pre-conditions

- First responder organization has a subscription with terrestrial and non-terrestrial operators to provide 5G network service.
- Terrestrial infrastructure is damaged and (partially) not available.
- User has either a UE that supports direct connection to satellite or is connected by a base station backhauled by satellite, *e.g.*, at command posts.
- Command post is based in a safe zone away from operation on the field.

7.1.3 Service Flows

- First responders communicate in the field and to command and control centers via MCS (MC-PTT, MC-data and MC-video communication). This includes group communication and the related synchronisation and prioritisation requirements
- Communication is backhauled through NTN access for forward command posts.
- First responders have priority access to TN and NTN resources compared to public. (priority access to IAB+ resource pre-emption possible)
- First responder operation is deployed inside a building with no line of site visibility to satellite; communication to control center is hopped UE to UE back to NTN back to command center (IAB)
- Optionally: warning information is broadcasted to public UEs in FR1 while the terrestrial network is down on a private PPDR PLMN
- First responder operation communication switch to TN (MCPTT seamless handover from NTN to TN)

7.1.4 Post-conditions

Communication service for first responder organisation is setup. Afterwards communications to and for the general public can be provided, prioritizing the first responder communication to no block their task.

After the event, the terrestrial infrastructure is successively restored until normal operations can continue as in pre-incident conditions. NTN solutions support during this time by providing additional capacity.

7.1.5 Existing features partly or fully covering the use case functionality

The system in use for this is case in EUROPE is TETRA which is a dedicated communication system for first responders. However, like for any terrestrial communication system there is a risk for malfunction caused by the disaster event. Furthermore, TETRA supports only limited data exchange and has high costs for user devices since it is a dedicated system.

3GPP started to work on Mission Critical Communication (MCX) within Release 13 with PTT services and requirements collection. Following releases added further mission-critical services (MCS) such as mission critical data and video but also additional functionality like user authentication and service authorization, group call management, and security features.

Several operational devices exist which provide rapidly deployable communications based on Wi-Fi or LTE terminals backhauled by satellite.

7.2 SERVICE AND USER REQUIREMENTS SPECIFICATION

The PPDR use case is a challenging and complex environment with a multitude of critical services and requirements. In particular, 3GPP defines mission critical as “quality or characteristic of a communication activity, application, service or device, that requires low setup and transfer latency, high availability and reliability, ability to handle large numbers of users and devices, strong security and priority and pre-emption handling.”

7.2.1 Detailed description of 5G and Satellite Services

Service capabilities

The MCS include three types each with different traffic structure:

- MC-PTT, *i.e.*, voice transmission
- MC-Data
- MC-Video

In general, they are critical services, include point-to-point and multi-point communication and are bi-directional, *i.e.*, they make use of the forward and the return link. Furthermore, it is real-time and non-real and can be all, intermittent and continuous traffic, periodic and aperiodic.

Positioning service are required.

Device characterization

The PPDR use case includes a variety of actors using different devices such first responders in the field using handhelds, command posts provide backhauled access points for computers and handhelds, and vessels like trucks and helicopters. For example, 3GPP TS 22.280 [18] mentions as a requirement “being able to communicate in real time with helicopters and aircraft is a basic need”. Drones are used as well as IoT devices such as wearables and other sensors.

Consequently, also the size, weight and power consumptions are varying as well as the mobility pattern.

7.2.2 Detailed specification of Requirements

7.2.2.1 Mission Requirements

The following covers the requirements of first responder organizations, it does not include needs for the communication of and to the general public.

Table 15: Use case 2.2 Mission Requirements

REQ TYPE	REQ_ID	Priority	Justification	Related Components	REQ Description

MIS	UC2.2-MIS_1	Essential	Use Case	RAN	The NTN RAN shall back-up terrestrial infrastructure during disaster events
MIS	UC2.2-MIS_2	Essential	Use Case	RAN	The NTN RAN shall cover white spots of terrestrial networks
MIS	UC2.2-MIS_3	Essential	Use Case, 3GPP	UE, RAN, Core	The NTN system shall support Mission Critical Services
MIS	UC2.2-MIS_4	Essential	Use Case	UE	The NTN system shall support highly mobile environments (e.g. helicopters)
MIS	UC2.2-MIS_5	Essential	Use Case	UE	The NTN system shall be able to support private network or prioritize first responder communication
MIS	UC2.2-MIS_6	Essential	Use Case	RAN	Communication of first responder organization shall be prioritized

7.2.2.2 User Requirements

Existing service requirements for this use case are for example collected in 3GPP TS 22.280 [18] and related documents. TS 22.179 [19] covers the requirements for MCPTT, TS 22.281 [20] for MC video and TS 22.282 [21] for MC data, respectively.

Table 16: Use case 2.2 User Requirements

REQ TYPE	REQ_ID	Priority	Justification	Related Components	REQ Description
USR	UC2.2-USR_1	Essential	3GPP	UE, RAN, CORE	The system shall support MC-PTT, MC-Data and MC-Video
USR	UC2.2-USR_2	Essential	3GPP	UE, RAN, CORE	The UE shall be able to perform group calls (36 to 150 simultaneous MC-PTT Group Calls shall be supported per incident)

USR	UC2.2-USR_3	Essential	3GPP	UE, RAN, CORE	Group calls shall be synchronized
USR	UC2.2-USR_4	Essential	3GPP	UE, RAN, CORE	Voice and video transmission shall be synchronized
USR	UC2.2-USR_5	Essential	3GPP	UE, RAN, CORE	Communication shall be protected
USR	UC2.2-USR_6	Essential	3GPP	UE, RAN	User speeds of 450 km/h (160 km/h for video) shall be supported
USR	UC2.2-USR_7	Essential	3GPP	UE, RAN	User altitudes of 15.000 ft shall to be supported
USR	UC2.2-USR_8	Essential	3GPP	UE, RAN, CORE	The NTN system shall be able to setup connections fast (1 second for immediate data communication and 3 seconds for normal ones)

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8 USE CASE 2.3 GLOBAL PRIVATE NETWORKS

8.1 DESCRIPTION

With the allocation of private frequencies to 5G, many industries are now testing local 5G networks in their specific environments, aiming to develop small size connectivity islands addressing their specific communication requirements. The requirements include network isolation and own security and administration as well as low latency and increased reliability and flexibility.

However, the large companies include multiple locations, not being limited to a single factory or hospital, instead having locations all around the world. These locations need to be connected in a reliable and secure manner. Until now, such connectivity was achieved through the development of enterprise networks which use terrestrial network backhauls to be able to coordinate the different local administrative domains. No solution for 5G was yet considered, as currently, the private 5G campus networks still concentrate on the initial development of single campuses.

In this framework, it is widely recognized that, for having efficient processes, the different connectivity islands will have to be integrated in a company-wide, spanning worldwide network. The requirements for the integration include especially isolation and privacy of the communication. Here satellite networks are having a major advantage as a single satellite operator can offer such a backhaul solution as well as a coordinated 5G network, not being necessary to send the data traffic over multiple untrusted Internet autonomous systems. Instead, a comprehensive "VPN"-like service adding to this a coordinated control can be offered with guaranteed resource reservations and inter-connectivity islands mobility.

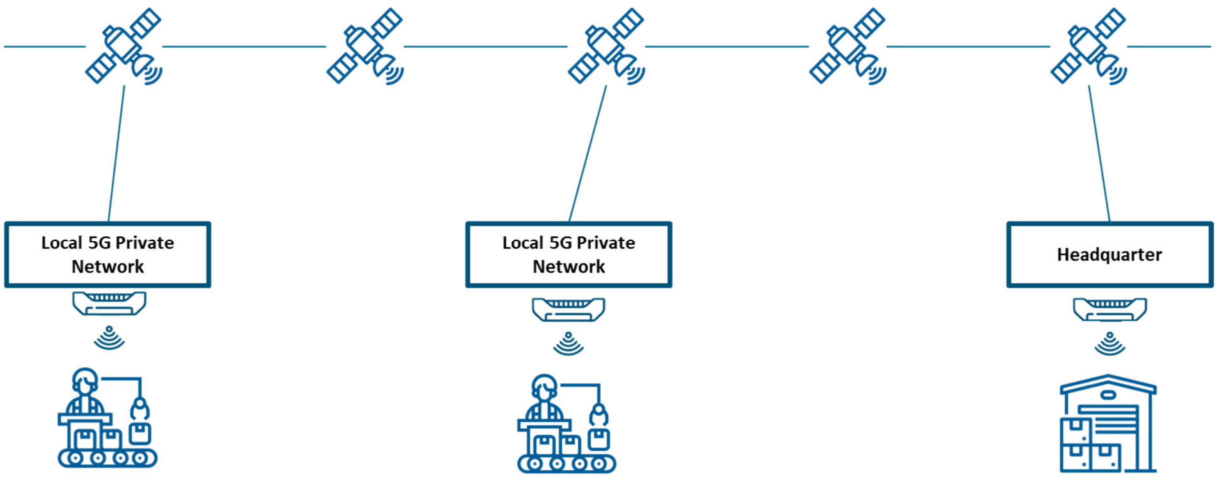

Figure 8: Global networks - A highly distributed network of connectivity islands

These capabilities are optimized by the deployment of Inter-satellite Links (ISLs) which enable a space-only data path between the different locations. Although not immediately obvious, the ISLs due to their communication characteristics, even though passing data through longer distances, should be able to provide comparable and even lower end-to-end delay compared to the terrestrial optical backhauls for the intercontinental type of communication (*e.g.*, it is expected that a connection between Berlin and Sydney to have half the delay the same connection has over terrestrial backhauls).

The following vertical use cases can significantly benefit from such a coordinated global connectivity service for private networks:

- Public domain infrastructure.
- Connecting the embassies of a country within a coordinated network
- The administration of a country – especially global distributed countries such as France or UK would highly benefit from being enabled with a trustful, privacy aware distributed network.
- Logistics – connecting the logistic chains require global networks. Be it materials or shipping of commercial products, logistic use cases need to reach and control mobile and distributed locations.
- Industrial networks – to be able to deploy the machinery and integrate with logistic chains across the multiple shop floors, possible located in different areas of the world.
- eHealth for hospitals – to be able to deploy the same equipment in multiple hospital locations and also to coordinate the distribution of the patient information between the different locations.
- More nomadic use case: construction sites, mining, concert tours of major artists – to be able to provide the connectivity for a very large number of heterogeneous devices which are not necessarily continuously placed at the same location and not for the complete time of the functioning of the use case. For example, construction sites have devices of multiple types of multiple owners in the different phased of the building. Furthermore, these devices when completing their task in a location, they will be transferred to another.

Furthermore, the new networks are meant to work together in a coordinated manner across the different entities. However, how this interoperability will be achieved is considered as a later concern in the development of the use case and thus, not included in the current use case development.

8.1.1 Scenario

The following main deployment scenarios are identified:

- Large scale enterprise network with administrative headquarter – *e.g.*, embassies or factories. Multiple connectivity islands each offering local private connectivity for the local devices as well as end-to-end connectivity between the different islands using a single backhaul operator. This includes the deployment of local data path components as well as of a minimal control plane and the coordination of the access control through a central headquarters administration. This scenario is specifically beneficial for use cases where the different connectivity islands have significant compute capabilities and local administrative capabilities such as embassies of a country and the external affairs ministry or a large production company such as Volkswagen.
- Deployment model includes a local UPF in each location and a core network distributed between locations and headquarter + a coordination with SD-WAN across the satellite system.

- Large scale enterprise network with direct/short path connectivity – for distributed environments with no possibility or limited possibility of deployment of local components such as construction sites or other nomadic networks, the local data path or the local core network could be deployed in the directly connected space nodes.

- It also includes the deployments with RAN in space, a situation in which there is no need for having terrestrial deployed components in the connectivity islands, instead being better placed next to the gNB in space. In this scenario, the connectivity islands can be composed of all the devices in each area which are connected to a single satellite.

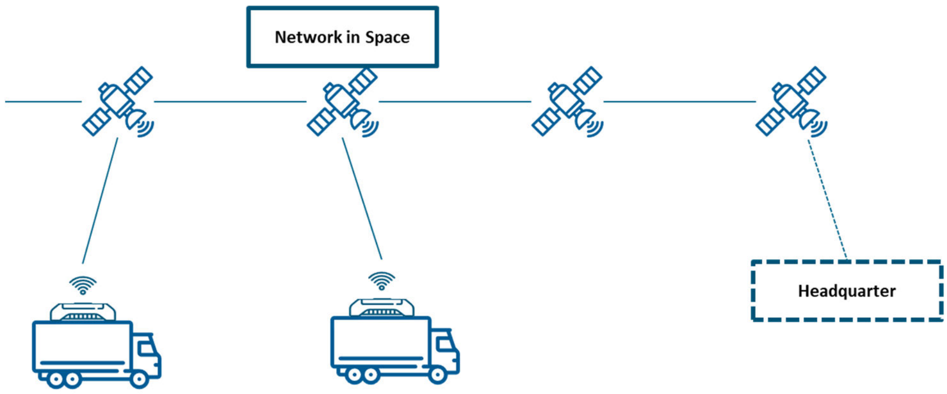

Figure 9: Global Networks - Large scale enterprise network with space deployed network

- Large scale enterprise network with ultra-reliable space-deployed core network – this scenario differs from the previous deployments by removing the dependency of the central core network deployment in the headquarters. Instead, this is replaced by a space-deployed, distributed deployment which enables the enterprise network not to depend on the headquarter single point of failure.

- Large scale enterprise network with nomadic connectivity islands – this scenario represents an extension for all the previous scenarios towards a dynamic network topology. Specifically, a connectivity island in the global enterprise could appear at a given moment in time for a given duration, this requiring the reconfiguration of the network to efficiently supply the services to the new location.

8.1.2 Pre-conditions

The deployment of connectivity islands which require global connectivity.
A satellite system able to handle single operator connectivity to the specific locations.

8.1.3 Service Flows

- Addition of new subscribers / identities to the network and their distribution to the appropriate locations.

- Authentication and authorization of devices registering to the network in different connectivity islands.

- Establishment of local connectivity data sessions and of end-to-end data sessions across the satellite system.

- Establishment and termination of connectivity islands.

8.1.4 Post-conditions

Maintaining the service quality during the sessions considering the topology changes in the satellite networks.

8.1.5 Existing features partly or fully covering the use case functionality

Until now, most of the developments in the use case area concentrated on limited optimizations:

- Deployment of components in space is only in the initial proof-of concept. They require to be integrated into a full system with considerations on network function placement.

- The development of ISLs provides the means to provide end-to-end data paths between connectivity islands only through space nodes. Although several routing solutions were proposed, these were not engineered to be included into a 5G system, where also the interoperability between transport control and core network is needed.

8.2 SERVICE AND USER REQUIREMENTS SPECIFICATION

8.2.1 Detailed description of 5G and Satellite Services

In this section, we expand on the information provided in Section 9.1 by offering more detailed descriptions and refined requirements for the global private networks use case. Specifically, we focus on elucidating the specific nature of the connectivity services provided to the users and delve into its network management aspects.

Service capabilities

The global private networks use case represents an extension of the existing distributed enterprise networks in the direction of providing globally the end-to-end connectivity while using a single satellite operator as connectivity provider instead of the multiple terrestrial autonomous systems.

Because of this, we assume that the main data traffic characteristics will follow the same patterns as within the current enterprise networks, [18], [19]. These include mostly:

- Near real-time data exchanges in bursts including the exchange of logs and configurations. This include regular exchanges of monitoring information as well as data storage of specific information in the headquarter as introduced by remote users (Data, Non-real time, Intermittent, Aperiodic or periodic, TCP).

- Internet, web-like type of access to private data of the enterprise characterized by smaller or larger download bursts (Data, Near-real time, Intermittent, aperiodic, TCP).

On top of this the foreseen communication requirements brought by the new digitalization of services should be added, including:

- large-scale data synchronizations with the enterprise central cloud including daily backups especially of monitored information (Data, Near real-time, Intermittent, periodic, TCP).

- Support for voice or video calls between the users of the different networks, as well as locally if possible (Data, Real-Time, Continuous, aperiodic, UDP or TCP).

- Potentially: remote control of devices, including factory machinery for maintenance and debugging purposes. This would not be feasible for actual runtime processes as it highly depends on a long delay backhaul more expensive and less reliable than a local controller (Data, Real-time, intermittent, potentially critical, aperiodic, UDP or TCP).

- Potentially: transfer of large amount of data for the service purposes such as in case of video services the transfer of content or for data forensics in case of incidents (Data, non-real time or near-real time, Intermittent, aperiodic, UDP or TCP).

To this, a hierarchical network management solution should be considered with local handling of different incidents and with escalation towards the headquarters location. This functionality addresses the performance of the network, failures, and security breaches. The data traffic includes alarms and logs of the specific incidents in uplink and new commands and configurations in downlink.

- **Device characterization**

The global private networks address mostly fixed networks. As such there are no strict limitations on the devices (VSAT) although smaller antennas and automatic direction would be a very large benefit from the perspective of commodity. LOS should be found during the placement of the antenna.

For the nomadic private network islands, the same considerations as for the fixed networks apply. LOS should be found during the placement of the antenna.

For the mobile private network islands, a specific antenna which would be able to communicate when moving such a handheld or a specifically designed antenna for vehicles would be preferred. In this case also a careful attention should be given to power consumption. It is assumed that LOS is not guaranteed and as such intermittent network availability should be considered at the services level.

The same set of terminals should be used for all the different connectivity islands as a use case commodity. This presumes that the terminals should comply to the regulations in all the countries where they are placed, requiring a significant regulatory convergence.

- **Network management aspects**

In the global private network, we expect to have a significant number of devices connected to each connectivity islands. However, as the satellite network is used for the interconnection between different connectivity islands, mostly as a backhaul, only a few of these devices would use it.

As such, even though we could safely assume a density of 10.000 devices / 300 sqm in case of a dense 5G factory shop floor or 100.000 devices in case of a 5G connected hospital, the device density will not be impacted as most probably a single terminal will be deployed for each connectivity island, with potentially a second one for redundancy in critical use cases.

The data traffic consists of parts which are real-time and would require prioritization, near real-time for which a relatively large, but still limited delay should be achieved and non-real-time data traffic which should be scheduled at appropriate times when the network is unlikely to

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become congested. Depending on the exact deployment situation, we expect to have a high traffic variability and a high traffic heterogeneity.

8.2.2 Detailed specification of Requirements

8.2.2.1 Mission Requirements

Table 17: Use case 1.2 Mission Requirements

REQ TYPE	REQ_ID	Priority	Justification	Related Components	REQ Description
MIS	UC2.3-MIS_1	Essential	Use Case; 3GPP	RAN	The NTN System shall select or configure the most appropriate link depending on QoS requirements (*e.g.*, latency, jitter, guaranteed data rate). Note: For instance, in the case where both LEO and GEO links are available, delays sensitive applications may then be routed in priority to LEO.
MIS	UC2.3-MIS_2	Essential	Use Case	RAN	A few identified UEs in the network shall act as IAB donor in order to grant access to IAB receiver.
MIS	UC2.3-MIS_3	Essential	Use Case	RAN	The NTN RAN shall overlap the geographical coverage of multiple TN RANs (global level)
MIS	UC1.2-MIS_4	Essential	Use Case	RAN - CORE	A core network shall be installed for the global network.
MIS	UC1.2-MIS_5	Essential	Use Case	RAN	The NTN shall support different forms of connectivity (FWA and IAB).
MIS	UC1.2-MIS_6	Optional	Use Case	Core	The core network may pertain to a terrestrial operator and could potentially be installed in space

8.2.2.2 User Requirements

Table 18: Use case 2.3 User Requirements

REQ TYPE	REQ_ID	Priority	Justification	Related Components	REQ Description
USR	UC2.3-USR_1	Essential	Use Case	UE	The global network UE should be able to connect anywhere to the global network.
USR	UC2.3-USR_2	Essential	Use Case	UE	The UE shall not be impacted by any parallel terrestrial network.
USR	UC2.3-USR_3	Essential	Use Case	UE	The data path between two UEs shall be secured e.g. through the usage only of the global network (no need of interconnection with other operators like for transport)
USR	UC2.3-USR_4	Essential	Use Case	UE	Data paths shall have the shortest delay possible e.g. minimal redirects to ground stations.

Additional to these requirements, the following absolute minimal requirements to make the service work:

- e2e latency < 1000ms (the lower the best)
- e2e capacity/flow > 1Mbps
- Reliability of 99%

9 CONSOLIDATED KPIS

In this section, we characterize the main objectives of TN / NTN integration, and we identify KPIs able to evaluate the performance of the 5G-STARDUST system with respect to these concepts. To this end, three families of KPIs have been identified:

- **Family 1:** User Application capabilities,
- **Family 2:** Service Continuity,
- **Family 3:** Service Ubiquity,

Each family is associated with its own set of KPIs, that can be used across the scenarios selected for simulations and for PoCs within WP4, WP5, and WP6, depending on their scope. It must be highlighted that some KPIs may be more adapted to large-scale simulations, and less to PoC. That's why each of them is marked as:

- **R for Recommended**, which indicates that the considered KPI may help assess the system performance with respect to User Application capabilities, Service Continuity, Service Ubiquity and System Internal Performances, and that, at the time of writing of this deliverable, no obvious factor impeding such measurement has been identified yet.
- **O for Optional**, which indicates that the considered KPI may be quite challenging to measure or requires specific setups to provide relevant results. Typically, KPIs targeting the performance of large-scale scenarios may not be fully adapted to PoC.
- **NA for Not Applicable:** which indicates that the considered KPIs cannot be measured or is not relevant for the targeted scenario. For example, in a one-user experimental setup measuring the handover performance, the expected number of user requiring handovers is obviously equal to one.

Note that such marking is indicative and final decision on KPIs will be made within WP4, WP5, and WP6, for the considered simulation and PoC scenarios.

9.1 FAMILY 1: KPIS FOR USER APPLICATION CAPABILITIES [20]

This first family refers to classical KPIs and following definitions are inspired from the 5GMOBIX project [21]:

- **KPI_1.1:** User experienced data rate (DL and / or UL), which is the data rate as perceived at the application layer, *i.e.*, effectively received (DL) or transmitted (UL) by the user and measured at the application layer. It corresponds to the amount of application data (bits) correctly received within a certain time window (lasting as long as a reasonable communication session in the context of the investigated scenario), with sufficient sampling granularity.
- **KPI_1.2:** End-to-end Latency, which has been defined in 3GPP TS 22.261 as the "time that it takes to transfer a given piece of information from a source to a destination, measured at the communication interface, from the moment it is transmitted by the source to the moment it is successfully received at the destination".

- **KPI_1.3:** User service packet error rate, which refers to the amount of application layer packets which have not been successfully delivered (within the user service time constraint) divided by the total number of sent packets.

Note that KPI_1.1 is also known as *goodput* and must be greater than or equal to the minimum data rate required by the user application. Depending on the scenario, it can be instantaneous or averaged, and may be complemented by different network throughput measurements. Such throughput is here defined as the instantaneous data rate as perceived at the network layer between two selected endpoints. These endpoints may belong to any segment of the overall network topology, but at same protocol stack layer.

Then, KPI_1.2 can be measured by considering the timestamps of the application packet and required synchronization between the source and the destination. As for KPI_1.1, it can be complemented by latency measurements of the different network segments or of the contribution of the control plane to the overall end-to-end latency.

Wrap-up: the proposed KPIs are summarized within Table 19.

Table 19. Summary of KPIs from family 1: User application capabilities

Ref.	KPI	Unit	Simulations/Testbeds	PoC
KPI_1.1	User experienced data rate	Mbps	R	R
KPI_1.2	End-to-end Latency	ms	R	R
KPI_1.3	User service packet error rate	%	R	R

Table 20. Targeted values for KPIs of family 1 – if applicable or known

Ref.	UC 1.1	UC 1.2	UC 2.1	UC 2.2	UC 2.3
KPI_1.1	360Mbps/plane (DL); 180Mbps/plane UL [1]	50 Mbps (DL) / 10 Mbps (UL)	50Mbps (DL) 25 Mbps (UL) [1]	500Mbps (DL); 500Mbps (UL) [22]	1Mbps/device (UL); 2Mbps/device (DL)
KPI_1.2	Max 280ms (GEO/NGSO max transmission delay) + 30ms (5G system delay) [1]	Max 280ms (GEO/NGSO max transmission delay) + 30ms (5G system delay)	Max 30ms (LEO max transmission delay) + 30ms (5G system)	300ms	Max 300ms (Transmission delay) + 30ms (5G system delay)
KPI_1.3	Multiconnectivity with NGSO: 0,004% [23]	Multiconnectivity with NGSO: 0,004% [23]	Multiconnectivity with NGSO: 0,004% [23]	10^{-6} [20]	Multiconnectivity with NGSO: 0,004% [17]

9.2 FAMILY 2: KPIS ASSOCIATED WITH SERVICE CONTINUITY

Service continuity has been defined in 3GPP TS 22.261 as the “uninterrupted user experience of a service that is using an active communication when a UE undergoes an access change without, as far as possible, the user noticing the change.” Such definition remains quite open, and more details are required to specify what is an “access change”, an “uninterrupted user experience,” and what is meant by “without noticing the change”. Such details obviously depend on the considered use case. Nevertheless, we propose in this sub-section a general approach to better characterize service continuity.

With respect to 5G-STARDUST, we focus on network layer switching, sometimes called “TN / NTN handovers”, in a multi-connectivity context, defined as follows.

Network layer switching: In the investigated 3D multi-layer context, it refers to a change of network layers of UEs in active communication, whatever the considered system architecture (transparent / regenerative payload, functional split, etc.), the implied procedures (*e.g.*, roaming or handovers in a RAN sharing model) or the cause of such switching (*e.g.*, user mobility, planned or unplanned network event, etc.).

This umbrella term thus encompasses inter-PLMN handovers, redirections within a traffic steering system, roaming, handover, etc. To illustrate such switching, we can consider a user which is transitioned from a TN connectivity to a NTN connectivity (or conversely), from a LEO to GEO service (or conversely).

In practice, KPIs to assess service continuity at network layer switching should capture the effects of related network events. To this end, we extend the approach of [5G-MOBIX] and propose to isolate the various phases of such “access change” and define the following events in time, as illustrated in the following Figure:

- t0: start of measurements (passive monitoring)
- t1: event E, which implies to switch n Users from one network layer to another
- t2: start of the network switching of the first user, *i.e.*, t2 = min (t2,i) where
  - $t_{2,i}$: start of the network layer switching of User i ϵ [1,n]
  - $t_{3,i}$: end of the network layer switching of User i ϵ [1,n]
- t3: end of the network layer switching of the last user, *i.e.*, t3 = max (t3,i)
- t4: end of measurements

Figure 10. Timeline for Network layer switching

PHASE 1 - Preparation of the network layer switching (Pre-switching): In the timeline, this phase corresponds to the time elapsed between t_1 and t_2. The event E of t_1 refers to what triggers the need to switch networks, for example a terrestrial base station switch-off for energy savings, a natural disaster damaging the terrestrial network, a load balancing decision or, simply, a mobile user leaving the terrestrial coverage. It may be initiated by the serving PLMN or detected by the user, on-demand or based on long-term forecast. It may be unplanned, predictable, or fully deterministic.

Two first KPIs related to this preparation phase can be proposed to assess service continuity:

- **KPI_2.1:** Preparation phase duration, measured as t_2 - t_1.
- **KPI_2.2:** Number of expected attempts of network layer switching events, or equivalently number of users expected to require network layer switching.

Depending on the Use Case, KPI_2.1 can capture, among others, the effects of the network service deployment time (from the initiation of the service deployment until it reaches full operational capacity) or the UE detection time (including, for example, the expiration of 3GPP timers which trigger frequency scanning to find a new network). Note that KPI_2.1 may be composed of both standardized elements (*e.g.*, 3GPP thresholds) and proprietary ones (e.g. chipset configuration). Measuring such a KPI can be quite easily envisaged for simulations, but is much more challenging within a PoC, as it requires tight clock synchronization between the different components of the experimental setup. Therefore, the utilization of KPI_2.1 will be validated in other WPs.

Next, KPI_2.2 reflects a network perspective and aims to capture the effects of network dimensioning, density of users (*e.g.*, a whole region to re-connect in a PPDR scenario versus a single user in mobility to be switched from TN to NTN) but also their activity factor. As for KPI_2.1, the detailed characterization of KPI_2.2 varies depending on whether simulations (in particular, large-scale simulations) or experimental testbed (*e.g.*, one user, one TN base station and one emulated NTN base station) is considered.

PHASE 2 - Network layer switching execution (In-switching): This second phase corresponds to the time elapsed between t_2 and t_3 and aims to assess how successful was switching from the network perspective. To make an analogy with legacy intra-PLMN handovers, proposed KPIs for PHASE 2 are as follows:

- **KPI_2.3:** Execution phase duration, measured as $t_3 - t_2$ or as $t_{3,i} - t_{2,i}$ for user i. This KPI may raise the same challenges as KPI_2.1 when it comes to experimental setup.
- **KPI_2.4:** Switching attempt rate, defined as the number of effective attempts of network layer switching events divided by KPI_2.2.

- **KPI_2.5:** Switching success rate, defined as the number of successful switching events divided by KPI_2.4.

- **KPI_2.6:** Number of drop calls or communication terminations, due to failed switching.

Such KPIs highly depend on the considered system architecture (including functional split for the space segment) and role models (in particular, roaming vs RAN sharing).

PHASE 3 - Network Layer switching continuity (Post-switching): This third phase corresponds to the time elapsed between t_3 and t_4 and aims to assess how successful was switching from the user perspective. Related KPIs should reflect potential performance evolutions, compared to the initial situation (before event E), and can be further characterized on a per-UC basis. A few examples are given in the following:

- **KPI_2.7:** User rate evolution, defined as the average user experienced data rate (i.e. KPI_1.1) after t_3 (or $t_{3,i}$ if the focus is on User i) divided by average user experienced data rate before event E.

- **KPI_2.8:** User latency evolution, similarly defined as the ratio of the experienced latency before E and after switching, for user i or averaged among users.

- **KPI_2.9:** User application failure ratio, defined as the percentage of users who experienced application service failure despite a successful switching from a network perspective, for example because the experienced rate (resp. latency) after switching is lower (resp. higher) the minimal target value, or because the switching was too long for the application service, that is: $t_{3,i} - t_{2,i} >$ survival time[4].

Wrap-up: Proposed KPIs for Service Continuity are summarized in Table 21.

Table 21. Summary of KPIs from family 2: Service Continuity

Ref.	KPI	Unit	Simulations/testbeds	PoC
KPI_2.1	Phase 1 duration	s or ms	R	O
KPI_2.2	# expected switching attempts	/	O	NA
KPI_2.3	Phase 2 duration	s or ms	R	O

[4] *Survival time* has been defined in 3GPP TS 22.261 as the time that an application consuming a communication service may continue without an anticipated message. Equivalently, Maximum time period a communication service may not meet the application's requirements before there is a failure on the application layer, such that the communication service is deemed to be in an unavailable state.

KPI_2.4	# effective switching attempts	/	O	NA
KPI_2.5	Switching success rate	%	R	R
KPI_2.6	Number of drop calls	/	O	O
KPI_2.7	User rate evolution	%	O	O
KPI_2.8	User latency evolution	%	O	O
KPI_2.9	User application failure ratio	%	O	O

9.3 FAMILY 3: KPIS ASSOCIATED WITH SERVICE UBIQUITY

Integrating TN and NTN is often perceived as a synonym of connectivity everywhere at any time. Main KPIs associated with this idea are reliability and availability, defined as follows:

- **Reliability (3GPP TS 22.261):** Percentage value of the packets successfully delivered to a given system entity within the time constraint required by the targeted service out of all the packets transmitted. It is often measured as the Mean time between failures (MTBF) or Probability of no failure within a specified period of time.

- **Availability (3GPP TS 22.261):** Percentage value of the amount of time the end-to-end communication service is delivered according to a specified QoS, divided by the amount of time the system is expected to deliver the end-to-end service.

Such time-related KPIs can be however quite tricky to measure within a PoC or a testbed. Indeed, an availability of 99,5% (resp. 99,99%) is equivalent to a downtime of 7,20 minutes (resp. 8.64 seconds) per day, which would imply to run simulations / testbeds for an excessively long time.

Therefore, within 5G-STARDUST, we propose to focus only on Service Ubiquity, that is, “connectivity everywhere”, and we propose to target KPIs to measure the efficiency of coverage extension **and to assess initial network access (different from network layer switching) and coverage extension**. Such KPIs are highly related to the following parameters:

- **User service area**: the geographical zone where the targeted user service is expected to be available. Such area is not necessarily worldwide, at a given time for a given end-user. For example, it can be restricted to the geographical zone where a natural disaster occurred (PPDR use case) or to an isolated zone around an ambassy (use case about global private networks).

- **Network coverage area:** the geographical zone where some network services are available, with expected QoS.
- **User device density**, which may represent a simple average user density or may capture more complex user distribution.
- **Activity factor:** the ratio of simultaneous active UEs to the total number of UEs, where active means the UEs are exchanging data with the network and have one or more connections established.

Technical efficiency of coverage extension: LEO constellations are usually structurally inefficient on a techno-economical point of view and each satellite is often in effective activity only 20% of time. To assess network efficiency, we propose the following KPIs:

- **KPI_3.1:** Area efficiency, defined as the User service area divided by the Network coverage area.
- **KPI_3.2:** Area Traffic Capacity, which is the total traffic throughput served per unit area (in Mbit/s/km2).
- **KPI_3.3:** Area Spectral Efficiency, defined as the total traffic throughput served per unit area per hertz (in Mbit/s/Hz/km2).

Ideally, KPI_3.3 = 1, *i.e.*, the user service area is equal to the network coverage area (optimal Network-as-a-Service deployment), but it is rarely the case, especially given large satellite footprints. Most of the time, KPI_3.3 < 1, *i.e.*, the network footprint is larger than what is effectively needed for the user service and the network may be over-dimensioned. This may have significant impact on the price per bit and general cost of the solution. In some case, we may have KPI_3.3 > 1, for example close to national borders, where some satellite cells must be turned off to avoid cross-border interference and fit national regulation.

Initial network access KPIs: It is often stated that NTN provides 100% service ubiquity. However, there are main reasons for which a user may not be able to access NTN:

- **3GPP procedure failure:** which can occur whatever the type of 3GPP network.
- **Network dimensioning:** The NTN may not be able to manage as much traffic load and as many users as TN, and some users may be prioritized over others (such as for PPDR use cases).
- **Business reasons:** There is no roaming agreement between the TN service provide and the NTN service provider (or at least, no adequate one given the user SLA), the pricing of NTN services is too high, etc.
- **Regulation & Security:** Some critical applications such as governmental ones may be restricted in the choice of the connectivity service provider.
- **Battery limitation:** NTN access generally consumes more power, which may limit its usage for devices not connected to the power grid, as it may be the case for isolated rural scenario in some MEA regions.

- **Weather conditions:** Typically, NTN access in FR2 cannot be guaranteed in case of rain, such that a link availability of 99,95% - 99,99% is often considered.

To capture such effects and assess the performance of initial network access, we propose the following KPIs, usually considered for TN:

- **KPI_3.4:** Number of expected connection establishments,
- **KPI_3.5:** Number of connection establishment effective attempts,
- **KPI_3.6:** Connection establishment success rate, defined as the number of successful connection establishments divided by KPI_3.5,

where "connection establishment" can be adapted to the investigated scenario and can stand for Application-layer handshake, PDU Session establishment, RRC Connection, Data Radio Bearer establishment, or any other type of connection.

In particular, the ratio of KPI_3.5 over KPI_3.4 can be a good measure of the impact of non-technical reasons stated above, that is: business, regulation & security and weather conditions.

Wrap-up: Proposed KPIs for Service Ubiquity are summarized in Table 22.

Table 22. Summary of KPIs from family 3: Service Ubiquity

Ref.	KPI	Unit	Simulations/testbeds	PoC
KPI_3.1	Area efficiency	/	R	R
KPI_3.2	Area Traffic Capacity	Mbit/s/km2	O	NA
KPI_3.3	Area Spectral Efficiency	Mbit/s/Hz/km2	O	NA
KPI_3.4	# expected connection establishments	/	O	NA
KPI_3.5	# connection establishments attempts	/	O	NA
KPI_3.6	Connection establishment success rate	%	R	R

10 EXPECTED IMPACT ON KEY VALUES

An overview of the results is presented in Table 23. It should be noted that this is an initial set of KVs and KVIs that does not exclude other sets, with a more complete view, that may be furthered in other tasks like T7.4.

From 5G-STARDUST proposal had been defined a set of KVIs like digital inclusion, business value, economic growth, new value chain, Open collaboration, and open innovation.

In order to do the exercise, we have followed the next steps:

1. Step 0: Identify the stakeholders involved and the social pain points.
2. Step 1: KVs Examples.
3. Step 2: KVI Examples.
4. Step 3: Enablers of usage.
5. Step 4: Quantification of KVIs with KPIs.

Table 23: Key Values Indicator

Use Case	Stakeholders	KVs Examples	KVI Examples	Enablers of usage	Quantification of KVIs with KPIs
1.1 Maritime, railway, airway neutral-host cell	• Final Users cannot eMBB connectivity when they are traveling (only business seat, economical divide)	• Digital Inclusion	• Access to broadband services in remote/no reachable areas	• Ubiquitous coverage for eMBB	• Fraction of world population covered by broadband mobility
	• MNO/SNO: MNO cannot provide 5G connectivity out of TN limits.	• Operators opportunity • Business value	• Integrated TN-NTN networks access to new business opportunities for MNO/SNO	• Seamless connectivity • 3D networks and coverage	
	• Transport companies: Connectivity in mobility is too complex and non-3GPP (Wifi 802.11ab)	• Economical sustainability and innovation	• Cost-efficiency of broadband access in remote areas • Number of activities that can be performed anywhere	• Operational cost efficiency • Low-cost scalability and expandability • Multi-connectivity	
		• Societal sustainability	• Promote traveling; Increase usage efficiency of Internet in remote areas	• Ubiquitous coverage for basic MBB • TN/NTN convergence • service orchestration • Low-cost connectivity	• User monthly cost of service

1.2 Residential Broadband	• MNOs: high energy consumption at each site to maintain coverage access, even if no user at all. In rural areas with limited access to power grid, tricky management of energy sources (needs battery or secondary sources, such as fuel-powered generators), cannot fully trust renewable energy sources due to their high variability (wind, solar, etc.)	• Economical sustainability and open innovation • Energy saving • Resilience of network	• Energy savings • Relaxed operational maintenance of the energy source for macro-BS (which can be hardly reachable because, for example, located at high sites to cover a wider area and many villages) • Sharing of expenses with local stakeholders	• Coordination of NTN / TN stakeholders • Seamless connectivity 3D networks and coverage • TN/NTN convergence • Service orchestration;	• Saved kW per downtime hour
	• Customers: long periods with no connectivity service at all, once no more energy at BS	• Digital inclusion	• Access to broadband services in remote/no reachable areas	• Ubiquitous coverage for eMBB	• Fraction of world population covered by broadband mobility
	• Household 2: (which can be a company, an administration, a clinic, a school, etc.): Can be expensive to	• Economical sustainability and innovation	• Additional revenues can be obtained by offering connectivity services	• Operational cost efficiency • Low-cost scalability and expandability • Multi-connectivy	• Additional revenues per user or per Mbps or per downtime hour

	maintain NTN access alone				
2.1 Vehicle connected	• Car OEM • Tier1 vehicle control unit supplier • Mobile network operators	• Business value • New value chain	• End customer: Higher satisfaction due to the automatic correction of defaults and the fact on counting on an updated vehicle with new services and features (HD maps, software update). • OEM & Tier1: Important reduction in the default correction cost without going to the garage. • Functional growth – The vehicle can receive new functionality after leaving the factory. Potential to sell new features after the car is produced.	• Ubiquitous coverage for eMBB • Coordination of NTN / TN stakeholders • Exchange between the on-board and off-board systems	• Number of vehicles updated per month • Time to complete updates per vehicle
	• Regulations • Public safety answerings points (PSAPs)	• Open innovation • Functional growth • Digital Inclusion	• End customer – Safer experience • Authorities – Lower costs for medical	• Ubiquitous coverage for and NG eCall services	• Number of NG eCall service using NTN

			care, shorter response times	• Coordination of NTN / TN stakeholders • Legally required service for certain markets (EU)	
2.2 PPDR	• First responder agencies have communication need in order to complete their task in protecting the society and responding the disaster	• Societal sustainability • Environmental sustainability • Personal health and protection from harm	• Access to communication services in disaster areas	• Ubiquitous coverage • Seamless connectivity	
	• General public has a communication need during disaster events and in the aftermath, e.g. receive alerts, to get instructions, or to know relatives are fine.	• Societal sustainability • Personal health and protection from harm	• Access communication services in disaster areas	• Seamless connectivity • 3D networks and coverage	• Traffic offloaded
	• MNO/SNO: MNO cannot provide 5G connectivity out of TN limits or after disaster event.	• Operators opportunity • Business value	• Integrated TN-NTN networks access to new business opportunities for MNO/SNO	• Seamless connectivity • 3D networks and coverage	• Traffic offloaded
2.3 Global Networks	• Private network owners requiring secure and reliable connectivity worldwide.	• Economical sustainability and open innovation • Energy saving • Resilience and security of network	• Energy savings • Providing a network for very sparse network owners	• Seamless worldwide connectivity ;	• Number of "connectivity islands" connected without being bound to interconnection

	• Being able to provide a network for dedicated services, with high security and highly reliable • Resource effective and very fast deployment of private networks				through terrestrial networks.
		• Digital inclusion	• Access to same private broadband services no matter of local connectivity	• Ubiquitous coverage for any connectivity scenario without terrestrial infrastructure	• Fraction of world population covered to use the same private network
	ecure and reliable onnectivity for the same etwork equipment orldwide would not be ossible (Due to different onfigurations from the perator)	• Economical sustainability and innovation	• Additional revenues can be obtained by offering private connectivity services	• Operational cost efficiency • Low-cost scalability, cross-border mobility, easy configurability and expandabiliy	• Additional revenues per private user owner (wholesale)

11 SELECTION OF SCENARIOS FOR POC DEMONSTRATIONS

5G-STARDUST has set ambitious targets in the sense that starting from the identification and analysis of a comprehensive set of use cases (developed within Task 2.1) enabled by the envisioned integrated TN-NTN architecture (within Task 3.1), project team is to derive mission and user requirements (T2.2).

In the end, a set of use-cases is to be selected and prioritized for Proof-Of-Concept phase (T2.3). Purpose is to detail expected functional results and monitored KPIs so that test plans, procedures and validation can be performed.

11.1 SCENARIO SELECTION PROCEDURE

From a project execution perspective, performing the scenario selection procedure (as part of Task 2.3) in the early phase of the project is quite challenging as the use cases analysis requires additional iterations (reflected in the consolidation of the system architecture as part of deliverable D3.2), mainly because:

- Architecture activities as part of WP3 have just started, with the final outcomes of WP3 expected at the end of the first year of the project (i.e. M12);

- The identified set of Requirements necessitate an additional iteration before reaching consolidation;

- Major questions - a little bit aside the mainstream of the anticipated activities - have just been identified and not addressed yet. For instance integrating TN along with NTN will impact the existing "business role model" and raise a few question such as "*who is the service provider responsible for the users' credentials" (SNO ? MNO ? Virtual MNO ? other new role ? …).* In the end, the way the service providers interact with each other may influence the procedures to realize TN/NTN switching. More consolidated analysis of these aspects is planned in the early phase of T7.3 and then reflected in the system architecture consolidation part of WP3.

On top of that there are a few other side-criteria that may influence the scenario selection:

- **Market analysis** would tend to drive the selection toward scenarios that may represent major potential adoption for this emerging NTN type of services;

- **5G-STARDUST objectives** and initial technical proposal who focus on TN/NTN integration;

- **Industry technical roadmap** may drive the selection toward scenarios requiring features with sufficient level of maturity to de demonstrated during PoC;

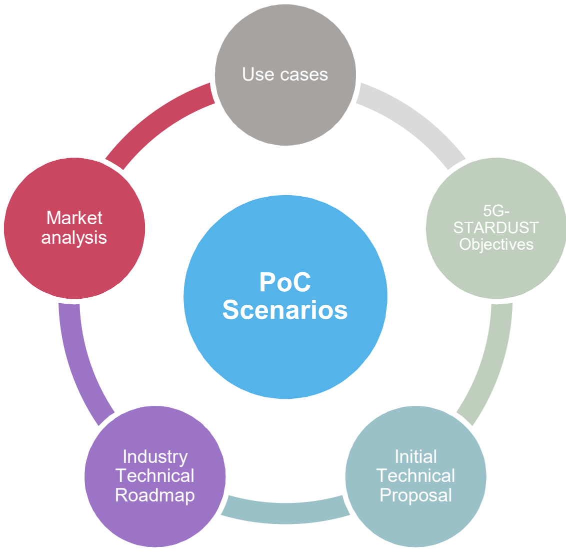

Figure 11: 5G-STARDUST Project workflow and T2.3 related tasks.

In the end, a first iteration is here proposed to rank use case in a "measurable" approach, trying to balance pros and cons around all the identified cases. This is illustrated in the Table 24.

11.2 PRIORITIZED LIST OF SCENARIOS

According to this first iteration, elaborated in the previous table it appears that 5G-STARDUST should focus on, in increasing priorities:

- UC1.2.c : Residential broadband: TN to NTN backup for energy saving purpose
- UC1.2.a : Airway Scenario.
- UC2.3 : Global Private Network

Rationale is that preliminary assessment has shown that these use cases:

- seem mature enough - i.e. with sufficient level of understanding among partners -to engage the subsequent tasks;
- engage limited dependencies;
- still have a lot of potential to elaborate on the core of 5G-STARDUST which is about TN/NTN integration.

Table 24: 5G-STARDUST Use case prioritization assessment

Use case	Title	Main features	impact wrt <u>potential market adherence</u> Ability to demonstrate complimentary TN / NTN usage		Challenges		Grade
UC1.1.c	[Hispasat] Airway Scenario	* IAB * NTN backhaul * User switching from TN-cell to NTN hot-spot	3	**High** : Air traffic NTN is a natural extension to extend TN connectivity while on the air and TN and NTN do not overlap in this case	-1	* cross-border / international roaming topic may complexify the use case analysis ; * 2 terminals needed (UE + IAB)	2
UC1.2.a	[Orange] Residential broadband : LEO or GEO depending on Qos	* NTN backhaul	1	**Low** : this case seem less probable as we consider a sub-case where TN & NTN-**LEO** & NTN-**GEO** would overlap	-1	* would require to duplicate set of satellites 1 LEO + 1 GEO	0
UC1.2.b	[Orange] Residential broadband : IAB for residential broadband	* IAB * Fiwed Wireless Access * EAP-SIM	1	**Low** : Fixed Wireless Access might not be the most frequent usage, still this use case does illustrate a valid TN/NTN complimentary usage	-1	* 2 terminals needed (UE + IAB)	0
UC1.2.c	[Orange] Residential broadband : TN to NTN backup for energy saving purpose	* NTN / TN switching * suppose bi-band terminal	2	**Medium** : even if Fixed Wireless Access is not the most frequent usage, it does illustrate a valid TN/NTN complimentary usage	0	* no major test setup complexity identified so-far.	2
UC2.1	[CTTC] V2X autonomous/ remote DRIVING	* Space edge computing	2	**Medium** : Applicability/relevance of NTN in the context of V2X usage still to be confirmed	-2	* Autonomous driving is a complete field of study that may gor far beyond the scope of 5G stardust. * a more detailed discussion is required to elaborate on space edge computing : what type of services are envisaged ? What are the impatcs on the space segment dimensioning (processing ? power ? consumption ?)	0
UC2.2	[DLR] : PPDR	* IAB * NTN Backhaul	1	**Low** : niche market	-1	* 2 terminals needed (UE + IAB)	0
UC2.3	[Fraunhofer] Global Private Network	* space off-load * space only datapath	2	**Medium** : even if Global private network calls for features that are by essence enabled by NTN, this use case does not involve much TN	-1	* 2 terminals might be needed (UE + IAB) * 2 satellites may be required when addressing inter satellite handover (considered as being out of intial scope)	1

11.3 FUNCTIONAL CHAINS

This section presents the functional chains principles that are required to support the test plan elaboration introduced afterwards in this document. When required, use cases will then point to appropriate functional chain.

11.3.1 NTN and TN functional chain along with UE NTN direct access

Following figure gives a simplified possible option for integration of TN (in green) and NTN (in blue). In this setup,

- the UE is able to connect directly to the NTN RAN in FR2. The UE is, in this case, a VSAT type of terminal, or ESIM as per the 3GPP wording.
- NTN and TN could interoperate, for example, either through roaming or RAN sharing.

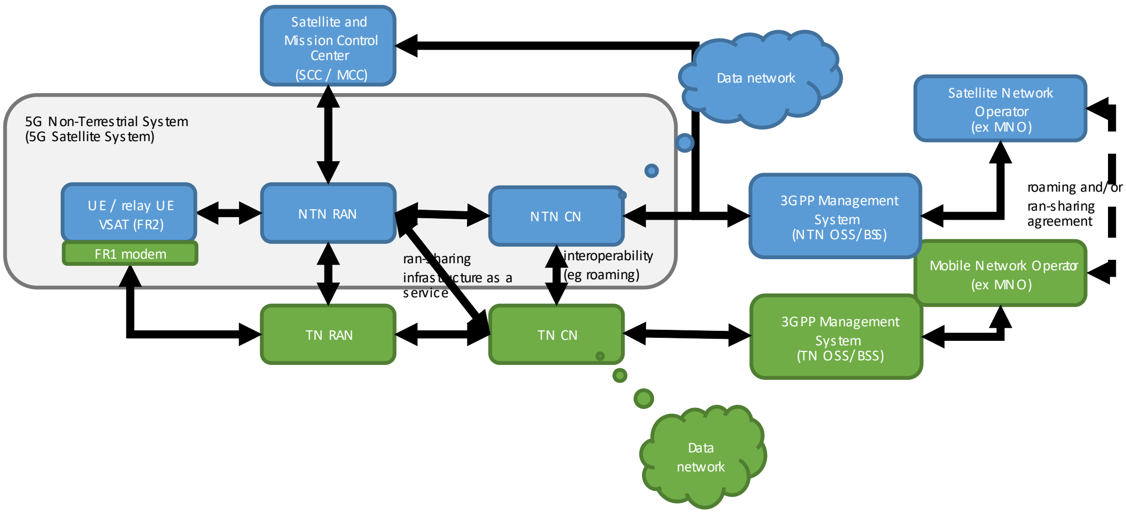

*Figure 12: NTN and TN functional chain along with UE NTN **direct** access*

11.3.2 NTN and TN functional chain along with UE NTN indirect access

In this setup there are two UEs, one relaying the communication to the other: the IAB Node is connected to satellite in FR2, the handset is connected to the IAB node in FR1.

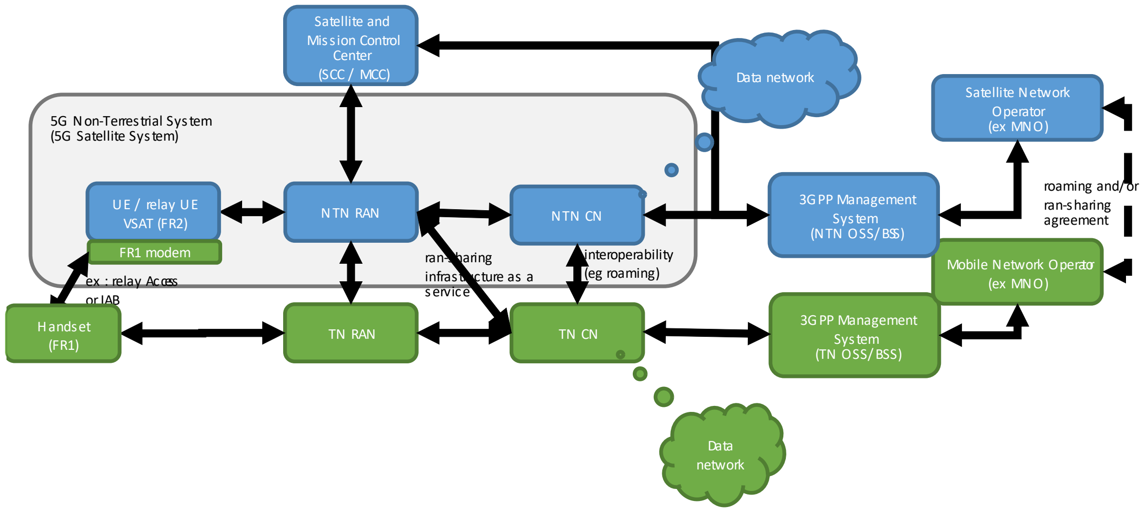

*Figure 13: NTN and TN functional chain along with UE NTN **indirect** access*

11.4 TEST PLAN PRINCIPLE

This section is aimed at detailing the expected functional results and monitored KPIs so that test plans, procedures and validation can be performed. The test plan definition will be actually defined and further elaborated in the following phases of the project, i.e. WP3 and WP6.

11.4.1 UC1.2.c Residential broadband: TN to NTN backup for energy saving

11.4.1.1 General Description

The general architecture concept supporting "Residential broadband" use case is depicted in Figure 12.

11.4.1.2 Test plan purpose

11.4.1.2.1 Purpose #1: NTN functional chain integration

- As a general purpose, this setup shall enable end-to-end NTN functional chain integration (in blue).
- Expected functional results shall be assessed in terms of:
  - "User application capabilities" as per ad-hoc KPIs provided in Section 9.1. For example:
    - user experienced data-rates,
    - end-to-end latency,
    - etc …

11.4.1.2.2 Purpose #2: TN functional chain integration

- In the same manner, this setup shall enable end-to-end TN functional chain integration (elements of Figure 12 highlighted in green)
- Expected functional results shall be assessed in terms of:
  - "**User application capabilities**" as per ad-hoc KPIS provided in Section 9.1. For example:
    - user experienced data-rates,
    - end-to-end latency,
    - etc …

11.4.1.2.3 Purpose #3: gNB functional split evaluation

- Additional purpose of this setup is to contextualise a test plan enabling to assess the impact of different gNB functional split options, i.e. embarking full or part of gNB onboard satellite.
- Expected functional results shall be assessed in terms of:
  - **"System internal performance capabilities"** as per ad-hoc KPIs provided in Section 9. For example:
    - intra-gNB layer data rates,
    - end-to-end latency,
    - foreseen satellite payload power consumption,
    - etc …

11.4.1.2.4 Purpose #4: TN and NTN interconnection trade-off evaluation

- Additional purpose of the test plan is to assess and evaluate a few possible means to "interconnect" TN and NTN. These possible means shall:
  - reflect a few (contractual) relationships that may be agreed between the respective TN and NTN service providers. These will be defined in the next phases (namely within T7.4) of the project and may adopt the following general principles:
    - RAN sharing;
    - Roaming;
    - "Space payload as a service";
    - Others…
  - take into account the possibility that the required dual-band terminal can be connected to TN and/or NTN:
    - either simultaneously

        - or one network at-a-time
    - implement state-of-the-art type of procedures to switch between TN/NTN such as:
        - inter-PLMN type of handover;
        - Core Network switching;
        - Multi-connectivity switching;
    - Evaluate different triggering conditions:
        - CN initiated;
        - UE initiated.
- Expected functional results shall be assessed in terms of:
    - **Service continuity** as per ad-hoc KPIs described in 9.2 ;
    - **Service ubiquity** as per ad-hoc KPIs described in 9.3.

11.4.2 UC1.2.a: Airway scenario

11.4.2.1 General description

General architecture concept supporting "Airway scenario" use case is the Figure .

11.4.2.2 Test plan purpose

11.4.2.2.1 Purpose #1: IAB integration

The general purpose of the test plan is adding IAB terminal into the end-to-end functional chain.

Expected functional results shall be assessed in terms of:

- **Service continuity** as per ad-hoc KPIs provided in Section 9.2;
- **Service ubiquity** as per ad-hoc KPIs provided in Section 9.3.

11.4.3 UC2.3: Global private Network

11.4.3.1 General Description

The general architecture concept supporting "Global Private Network" use case is depicted in Figure 8 and in Figure 9. Although this use case can be implemented without having any core network related functionality in space, this situation is highly not optimized as data paths may become too long. Instead, it would be important to consider a solution with partial core network located in space nodes close to the gNB.

As elaborated in D3.1, a set of architecture models can be considered for the deployment. The main role of the demonstrations is to show whether such a functionality deployment is feasible, to eventually assess the benefits of the deployments and to be able to provide a first dimensioning indication.

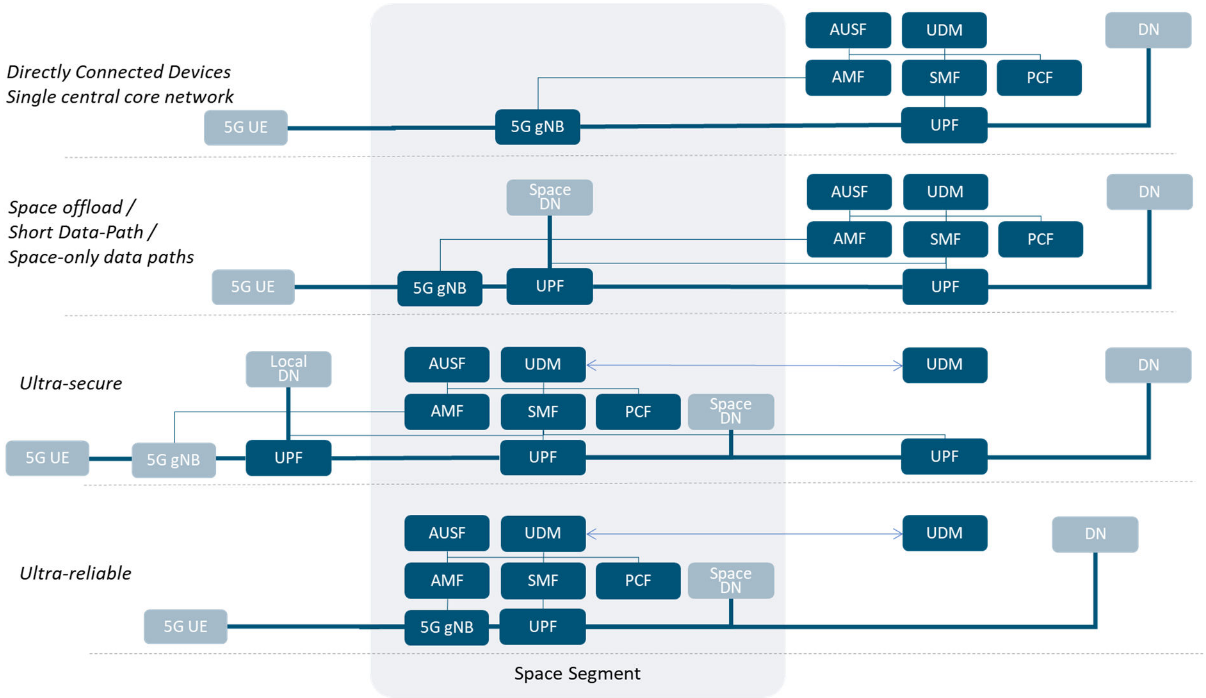

Figure 14: UC1.2.c – Possible Core network split that can support "Global Private Network" Use Case.

11.4.3.1.1 Purpose #1: testing the feasibility of the core network functionality deployment in space

General purpose of the test plan is to assess and evaluate the feasibility of the most promising functional split for space core network deployments.

- Expected functional results shall be assessed in terms of:
  - End-to-end system interoperability:
    - Possibility to deploy continuous data paths with UPF in space;
    - How the core network functions are selected when core network components are deployed in space;
    - Where the subscriber state is maintained;
    - Handover feasibility.
  - Practical assessment of the benefits of space deployment of core network components:
    - Shorter data paths;
    - Shorter control plane paths;
    - Subscriber state distribution and high availability.
  - Practical assessment of the different deployment options (e.g., a single UPF per orbit, a single core network per orbit, etc.):
    - Resources consumed.

    - Procedures duration

- Quantification of the service – understanding the resources needed for each of the connected devices and their service by measuring the resource consumption of the different procedures.

12 CONCLUSIONS

In this deliverable, we have analysed and identified the scenarios of the 5G-STARDUST project. The objective of 5G-STARDUST is to design, develop, and demonstrate a satellite system that is flexible and integrated with ground infrastructure through a self-organizing network architecture, utilizing multi-orbit, multi-constellation technology, transparent and regenerative space nodes, with the aim of providing NTN services for 5G/6G networks.

The 5G-STARDUST project scenarios encompass two main areas of focus:

- Dual Connectivity, which explores hybrid networks between Non-Terrestrial Networks and Terrestrial Networks, utilizing a unified radio interface to provide eMBB to end users with the support of multi-orbital satellites.
- Architecture and Service Distribution, which involves defining architectures and systems for various use cases, including regenerative payloads, eMBB, URLLC, and distributed systems. This area provides different use cases that leverage multi-orbital satellites and hybrid networks scenarios.

To define and apply these scenarios to the 5G-STARDUST scope, various use cases have been studied in this document. These use cases represent the first definitions that will be further analysed and elaborated during subsequent tasks and work packages. Also, the three main families of KPIs have been consolidated: User Application capabilities, Service Continuity, and Service Ubiquity.

The selected use cases include:

- Maritime, railway, airway neutral-host cell;
- Residential broadband;
- Vehicle connected;
- PPDR;
- Private global networks.

The integration of hybrid networks and the role of satellite technology are currently a reality. Satellites can facilitate the rapid deployment of 5G networks by providing eMBB coverage, low latency with LEO satellites and utilizing regenerative payloads to enhance network performance.

In conclusion, this deliverable defines the selected use cases and scenarios that drive the definition of the overall 5G-STARDUST user and system requirements and hence its architectural foundation, along with the PoC implementation and demonstration. The companion deliverable D2.2 will complete the picture, by providing a preliminary market analysis (that feeds into WP7).

Then, WP3 will define a high-level E2E architecture aiming at a flexible and autonomous integrated SatCom terrestrial system and their related integration with terrestrial infrastructures capable of supporting E2E network service provisioning, on the basis of WP2 inputs. The PoC will build, validate, and demonstrate the use cases defined in this deliverable.

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