D2.3 REPORT ON SYSTEM REQUIREMENTS

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Abstract	This deliverable describes the general approach to identify the system requirements within the project. The report then describes the list of system requirements, including sections on service requirements and the key performance indicators of the system, as well as the selected sustainability requirements and metrics. Finally, it also provides a set of traffic scenarios for the system dimensioning.
Keywords	Technical requirements, KPI, KVI, User Traffic Profile, Terminals

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V0	01/05/2023	Feedback from multiple meetings with EAB members in March-April 2023 to collect first unconsolidated sets of Key and Value Performance Indicators and discuss table of content.	ORA, TASF, MAR, TEL, SES, CTTC, QCOM, D4P
V0.1	14/06/2023	Updated Table of Contents, Methodology, Definitions, References, updated KPIs and KVIs.	ORA
V0.3	20/06/2023	Following T2.3 working meeting: updated KPIs, updated user traffic flows.	ORA, TASF, SES, QCOM
V0.4-0.6	10/08/2023	Following July working meetings: updated section 4.3 (performance requirements) regarding user traffic profiles.	ORA, TASF, SES, QCOM
V0.7	25/08/2023	Updated sections 2.4 (all subsections plus added 2.4.5), 3 (updated KPIs) and corresponding 4 (perf requirements that use those KPIs).	ORA, TASF, MAR, SES, CTTC, QCOM
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DISCLAIMER

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DATA: Data sets, microdata, etc.

DMP: Data management plan

ETHICS: Deliverables related to ethics issues.

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OTHER: Software, technical diagram, algorithms, models, etc.

EXECUTIVE SUMMARY

D2.3 describes the general approach to identify the system requirements within the project. In order to achieve this system requirements identification, this deliverable defines the metrics to accurately express and, when needed, quantify those requirements. This is done through the definition of Key Performance Indicators (KPIs), mainly used later in the document to formulate target values embedded in the service, functional and performance requirements themselves. In this regard, D2.3 aims at identifying the target KPIs to adequately assess the performance of enhanced capabilities and new ones that should be brought by the system, with respect to the existing 5G and ongoing 5G-Advanced NTN standards.

In addition, this deliverable also seeks to complete the traditional viewpoint solely based on performance with a dual performance and value-oriented perspective, to be able to consider prominent economic, societal, and environmental sustainability challenges. The definition of Key Value Indicators (KVIs) is therefore intended to complete the proposed set of KPIs and aims at defining additional Sustainability Requirements.

Based on this definition work, the deliverable gives a description of the Project's requirements: service, functional, performance and sustainability requirements are categorized and presented with an associated priority level. Regarding performance requirements, two representative user traffic profiles, each focusing on a target UE for the 6G-NTN system, are also described to assess the relevant performance requirements and provide a high-level reference framework for the subsequent activities of the Project, in particular those regarding the system dimensioning carried out in work package WP3.

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ABBREVIATIONS

3GPP	3rd Generation Partnership Project	**MEC**	Multi-Access Edge Computing
6G SNS IA	6G Smart Networks and Services Industry Association	**MAE**	Mean Absolute Error
AIS	Automatic Identification System	**MAPE**	Mean Absolute Percentage Error
AUC	Area Under the Curve	**mmWave**	Millimeter Wave
BOM	Bill Of Materials	**MSE**	Mean Squared Error
DL	Downlink	**NRMSE**	Normalized Root Mean Squared Error
DLP	Data Loss Prevention	**PWS**	Public Warning System
E2E	End-to-End	**QoE**	Quality of Experience
EAB	External Advisory Board	**RMSE**	Root Mean Squared Error
EMF	Electromagnetic Field	**RAN**	Radio Access Network
ESA	European Space Agency	**RIC**	RAN Intelligent Controller
FCC	(US) Federal Communication Commission	**ROC**	Receiver Operating Characteristic
GNSS	Global Navigation Satellite Systems	**RTT**	Round Trip Time
IOS	In-Orbit Servicing	**SDG**	Sustainable Development Goal
KPI	Key Performance Indicator	**TRP**	Transmission and Reception Point
KVI	Key Value Indicator	**TTFF**	Time-To-First-Fix
LI	Lawful Interception	**UL**	Uplink
LOS	Line-Of-Sight	**USAT**	Ultra-Small Aperture Terminal

UTP	User Traffic Profile	**WAPE**	Weighted Absolute Percentage Error
VLEO	Very Low Earth Orbit	**WMAPE**	Weighted Mean Absolute Percentage Error

1 INTRODUCTION

The 6G-NTN ambition is to research and develop the innovative technical, regulatory, and standardization enablers needed to ensure the full-fledge integration of the NTN component into the 6G system to meet vertical industries and consumer market expectations, promoting the European Industrial leadership in the sector, and directly contributing to the support of the Key Strategic Orientations A and B of the Horizon Europe strategic plan. In this perspective, 6G-NTN ambition is to become the NTN flagship project for the research and development of the NTN component of 6G and to drive its standardization phase in 3GPP as part of the Rel-20.

1.1 SCOPE AND OBJECTIVES

This deliverable D2.3 reports the outcomes of the activity carried out in Task 2.3 of the 6G-NTN project ("Service and Technical requirements"). It relies on the key takeaways from deliverables D2.1 and D2.2, respectively related to the use cases definition and the user requirement identification and synthesis. In that context, D2.3 focuses on the various aspects of system requirements.

In order to achieve this system requirements identification, this deliverable first develops the necessary tools to accurately express and, when needed, quantify those requirements. This is done through the definition of Key Performance Indicators (KPIs), mainly used later in the document to formulate target values embedded in the service, functional and performance requirements themselves. In addition, this deliverable also seeks to complete the traditional viewpoint solely based on performance with a dual performance and value-oriented perspective, in order to be in a position to take into account prominent economic, societal and environmental sustainability challenges. The definition of Key Value Indicators (KVIs) is therefore intended to complete the proposed set of KPIs and aims at defining additional Sustainability Requirements.

More generally, a prominent objective in writing this document is to bring out straightforward guidelines for the 6G-NTN system definition. As such, this document attempts to address all applicable objectives of the 6G NTN project, while emphasizing a short and essential number of elements that will concretely support this system definition. Thus, this deliverable should be seen as a starting point for initiating the 6G-NTN system construction. In particular, since this document was designed in the context of a research framework, its content is intended to be flexible enough to allow readjustments during the rest of the Project lifecycle, in the relevant tasks and work packages. Therefore, a constant care was provided to ensure that references to the relevant activities are properly given along the sections of this deliverable.

1.2 STRUCTURE OF THE DOCUMENT

This deliverable is structured as follows.

This introductory section is first followed by Section 2, explaining the methodology followed in this deliverable to identify KPIs and KVIs (subsections 2.1 to 2.3), but also how the different service categories were identified (subsection 2.4, itself containing paragraphs summarizing the approach taken to define the target UEs, users, services and scenarios). The intra and inter-work package relations with other tasks are detailed, to give an adequate understanding of how those concepts were defined, along with different assumptions supported by the aforementioned 6G-NTN tasks.

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Section 3 then defines the needed metrics of the project, i.e., the set of structured values which will be used to assess the performance and sustainability of the 6G-NTN system and its components. These structured values are KPIs, KVIs and User Traffic Profiles (UTPs), respectively defined in subsections 3.1, 3.2 and 3.3. This section therefore provides for each metric a context, made of definitions, reference and typical values (when applicable), focusing on what those metrics shall measure in the 6G-NTN project, and in which service and technical requirements of section 4 those will be used. It is worth highlighting that this section does not seek to delineate an exhaustive list of potentially relevant metrics, but rather investigates which parameter shall be concretely useful for the expression of the various requirements of this deliverable, which will be eventually used as reference in work packages WP3, WP4 and WP5 of the 6G-NTN project.

Moreover, based on this definition work, Section 4 gives a description of the Project's requirements: Service requirements, Functional and Performance requirements are respectively given in subsections 4.1, 4.2, and 4.3. When needed, these requirements are expressed with target values supported by KPIs and UTPs previously defined in subsections 3.1 and 3.3. The sustainability requirements, which are drawn from the analysis done in 3.2, are then summarized in subsection 4.4.

Finally, the deliverable's takeaways, perspectives and conclusion are summarized in Section 5.

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2 METHODOLOGY OVERVIEW

The relation of this task to the rest of the 6G-NTN project is illustrated in Figure 1:Figure 1:. As intra-WP2 relations are concerned, D2.3 takes its main inputs from Tasks T2.1/D2.1 (Use Cases) and T2.2/D2.2 (User Requirements). This support of both deliverables is further described in the rest of this Section (e.g., in 2.4.1 to 2.4.3, we explain how the viewpoint on respectively User Equipment, Users and Services evolves for the specific scope of D2.3, while at the same time referring to the aforementioned deliverables).

In terms of inter-work package relations, D2.3 key takeaways (including identified KPIs, KVIs, technical requirements and various target values) are meant to support many tasks addressing different components and sub-systems among work packages WP3, WP4 and WP5. In particular, the outcomes of D2.3 are intended to support the system dimensioning activities performed within WP3.

However, it is worth mentioning that the relations with many tasks from WP3, WP4 and WP5 are actually bidirectional. In that regard, many valuable initial technical inputs were collected from those tasks during the preparation of deliverable D2.3, to ensure the consistence between the claims and target values set in terms of system requirements, and what the 6G-NTN project ambitions, performance and sustainability-wise. This aspect is further described in Section 2.3, where we summarize the methodology used to collect the different KPIs and KVIs of the project.

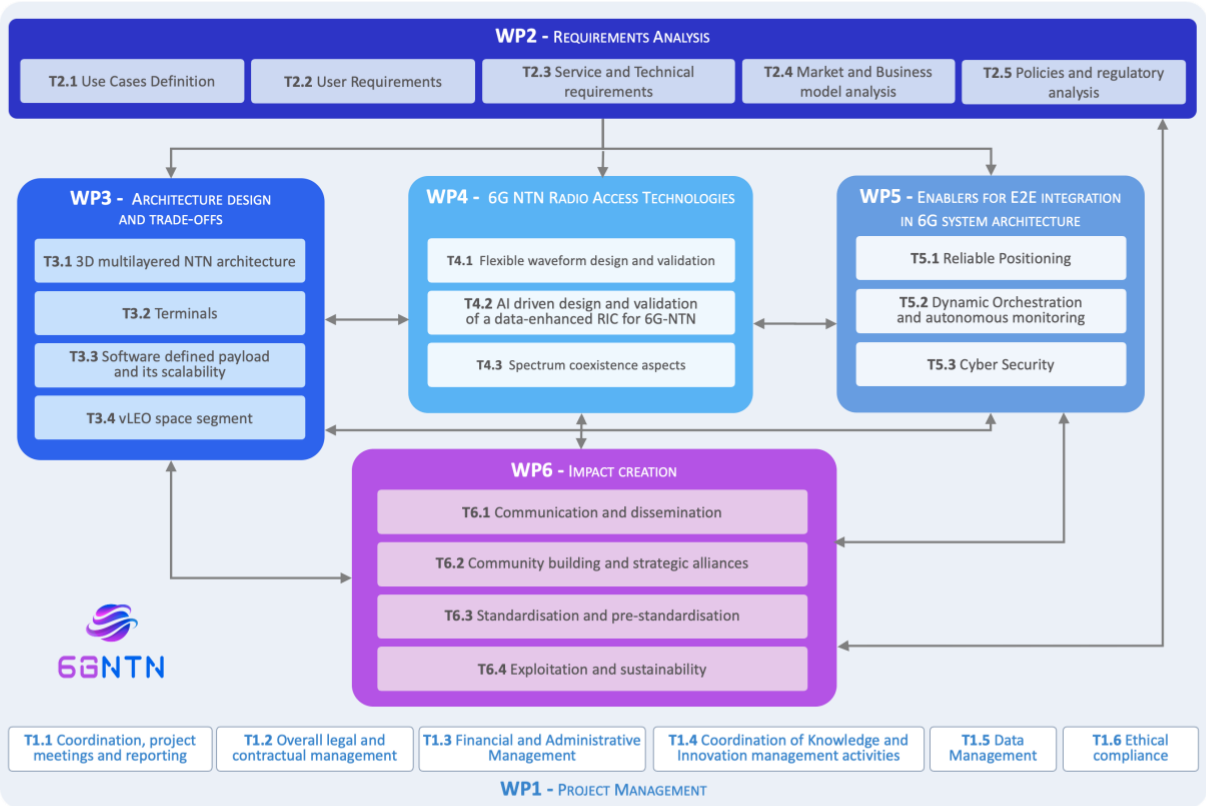

FIGURE 1: 6G-NTN WORK ORGANIZATION

Moreover, the rest of this subsection delves further into the approach taken in the project to efficiently assess the performance and overall value of the proposed 6G-NTN architecture. In general, one prominent objective for that assessment work is to focus on the specifics of the 6G-NTN system, regarding the impact of considering e.g., new technologies, optimizations, architectural assumptions, dimensioning, performance and sustainability objectives, regulations and various external constraints, business models and new value chains, among other structuring criteria. To do so, the high-level approach taken in D2.3 is twofold:

- Previous NTN generations standardized in 3GPP as Rel-17, Rel-18 and Rel-19[1] are taken as references to provide a comparison basis, performance and feature-wise. The technical requirements, which represent a key output of this deliverable, are therefore formulated, whenever possible, in comparison of the performance and features of 5G-NTN and ongoing 5G-NTN Advanced, as much as this later generation (materialized by the ongoing 3GPP Rel-19 work on NTN) can be anticipated at the time of writing this deliverable.

- This project ambitions to strongly impact the development and deployment of next generation NTN component to support the full potential of future 6G wireless communications and service infrastructure. To that end, D2.3 takes the general advances on 6G as an intrinsic context, which 6G-NTN seeks to refer to, complement and extend. In particular, most KPIs and KVIs detailed (and when applicable, valued) in this deliverable extend the corresponding indicators that belong to the 6G general framework.

It is also important to highlight that, as was stated in the 6G-NTN Description of Work, one of the Project's contributions to the Horizon Stream B (HORIZON-JU-SNS-2022-STREAM-B-01-03) relates to the establishment of a globally accepted set of KVIs and KPIs to frame future 6G developments. Taking all these elements into consideration, we outline in the following subsections the benefits and methodology to identify adapted KPIs (Section 2.1) and KVIs (Section 2.2) for the performance and value assessment of the 6G-NTN system. It is worth highlighting that for both sets of indicators, we adhere to the high-level taxonomy illustrated in Figure 2:, which we will further describe in Section 2.2.

[1] It is worth noting that a concise description on the evolution of NTN technology at 3GPP can be found in Section 2.1 of deliverable D2.1.

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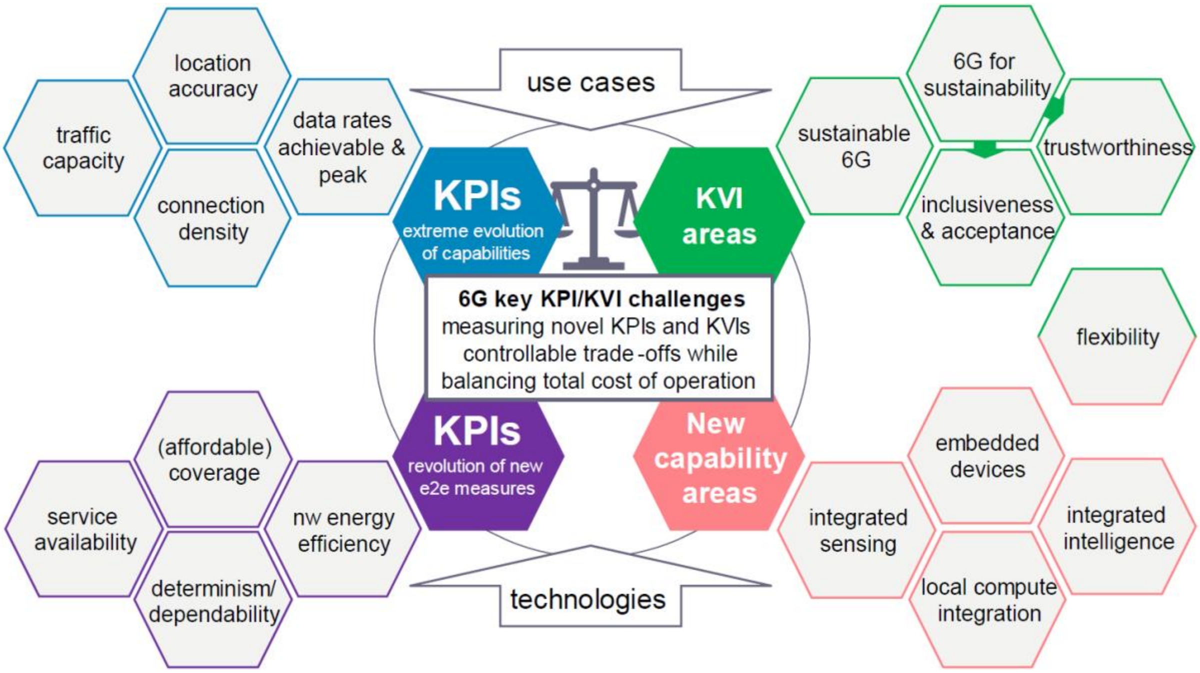

FIGURE 2: TAXONOMY OF 6G KPI AND KVI, AS IDENTIFIED IN THE EUROPEAN PROJECT HEXA-X [6]

2.1 PURPOSE OF KEY PERFORMANCE INDICATORS

Compared to 5G, 6G is expected to enhance Human and machine type communications with increased performances, enable new services based on advanced positioning and/or sensing and support the evolution of network in its ability to provide enhanced trust and coverage, while addressing spectrum and energy scarcity.

With 6G, one should distinguish the capabilities of 5G which will be enhanced from the new capabilities that will be enabled. For both cases, the NTN component has a specific role.

In this context, this deliverable **D2.3 aims at identifying the needed KPIs to adequately assess the performance of both sets of enhanced and new capabilities, with respect to the existing 5G and ongoing 5G-Advanced standards**. A first step is therefore to achieve a high-level breakdown of both groups of capabilities, and for each group identify the main subsets. On that ground, corresponding KPIs will be identified and described in Section 3.1 in order to assess the behavior of the 6G-NTN system.

The 6G-NTN components seek to contribute to enhance 5G capabilities as follows:

- **Data rates and network capacity in areas not covered by terrestrial network**: An increase by at least one or two orders of magnitude to sustain the exponential increase of the traffic is expected.

- **Coverage**: Direct connectivity from NTN will be made possible in light and in car indoor conditions.

- **Energy consumption of the network infrastructure**: Significant reduction is expected thanks to smart routing between NTN and terrestrial network nodes.

- **Positioning**: Higher accuracy and lower acquisition time in areas beyond terrestrial network coverage will be achieved.

- **Latency**: Deterministic and lower round-trip delay will be enabled in areas beyond terrestrial network coverage for example with the deployment of interconnected network nodes on very low orbiting satellites, High Altitude Platforms and drones.

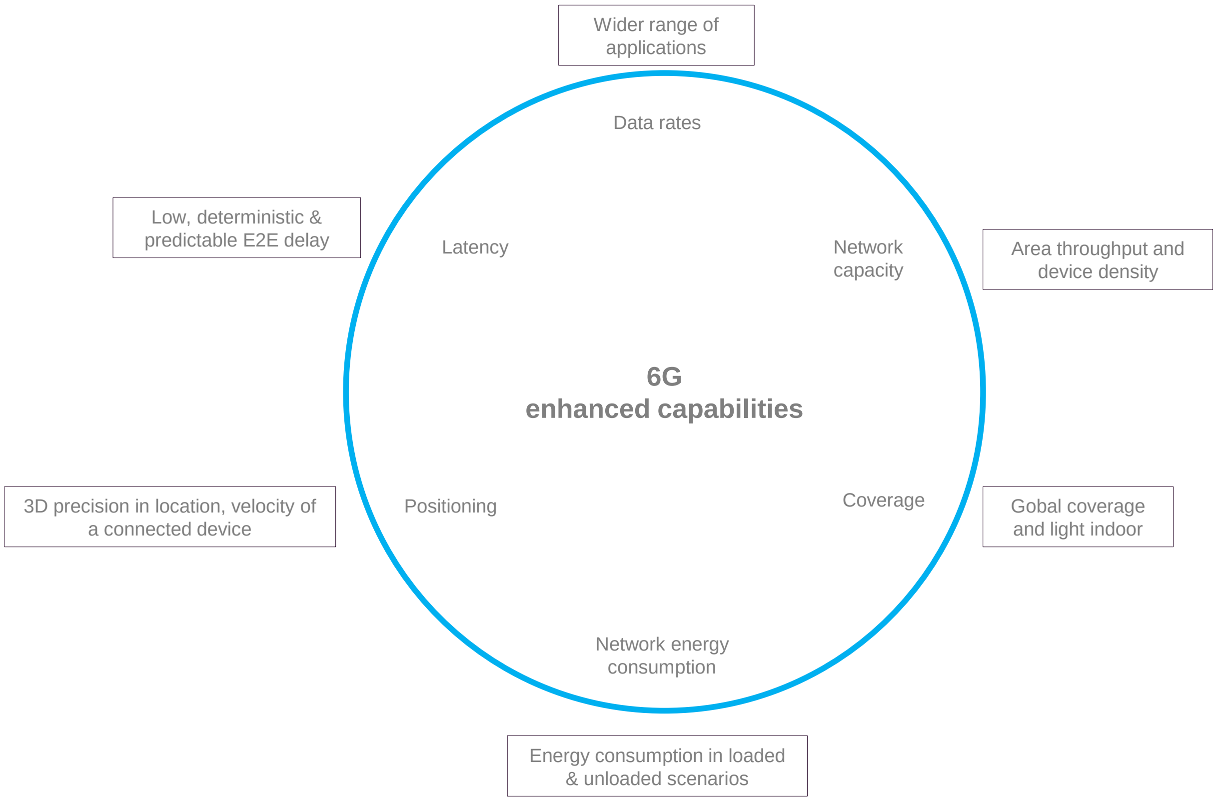

FIGURE 3: ENHANCED CAPABILITIES COMPARED TO 5G

Furthermore, regarding the new capabilities of 6G, the 6G-NTN components will contribute as follows:

- **Service availability**: True seamless service continuity will be enabled to mask any hole (no perceived service interruption, no data loss) of the terrestrial network component coverage.

- **Service versatility**: Thanks to a smart combination of terrestrial network and NTN component, it will be possible to adjust the manifold characteristics of the service (e.g., in terms of latency reliability, bandwidth, connectivity density, ...) to the targeted needs.

- **Cloud based infrastructure**: each NTN flying platforms (Satellite, HAPS or even drones) will be able to embark network nodes with edge computing and storage capabilities that can be exploited to provide faster response time for certain applications.

- **Deployment flexibility and scalability in areas not covered by terrestrial networks**: While satellite constellation typically provide a regional or global coverage, HAPS and drones may be added to reinforce the capacity in some specific areas and hence adjust the network capacity to the geographical traffic distribution.

- **Network positioning and sensing**: The network will be able to support trusted positioning and sensing services.
- **Device diversity**: Beyond pedestrian's handheld devices, the network will provide connectivity to a large range of devices mounted on board vehicle, vessels, aircraft, trains and drones (flying, surface) as well as adapted to fixed installation setting (e.g., utilities' infrastructure).
- **Security & privacy**: the NTN may reinforce the overall security framework with the distribution of advanced and robust keys to network nodes.

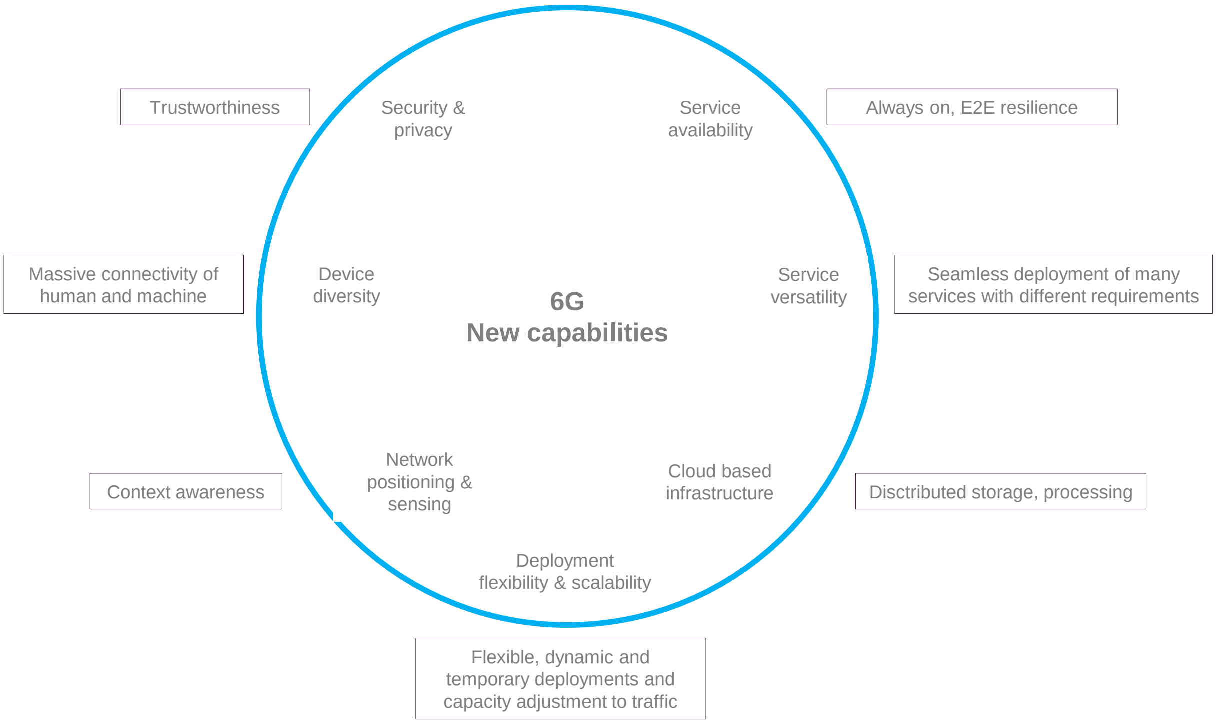

FIGURE 4: NEW CAPABILITIES ENABLED BY 6G

2.2 SUSTAINABILITY AND KEY VALUE INDICATORS

The use of KVIs in 6G stems from the intention to expand on the original network design principles underlying the development and deployment of 5G, which were, at least initially, solely performance oriented. In contrast, the 6G vision is now widely seen as encompassing both performance-oriented and value-oriented dimensions, with the value paradigm extending across many domains meant to exert a positive impact on societal values, and most critically for sustainability [5].

The United Nation's presentation of its seventeen Sustainable Development Goals (SDG 17) [2] is the outcome of years of investigation on the domain and has more recently helped structuring the Agency's global take on Sustainability in its 2030 Agenda. SDG 17 allows addressing sustainable development with an integrated approach, considering all major risks to population welfare such as climate change, disaster, pollution, biodiversity loss, degraded ecosystems, war, security, inequality, financial instability, erosion of democracy, and so on. It is believed that successfully addressing those sustainability challenges at global scale will require maximizing positive interlinkages and committing to partnerships across all sectors, including academic partnerships [3]. On that regard, one salient objective with the definition and use of KVIs in the context of 6G-NTN is to provide the means for the Project to assess how the target system will be able to achieve a positive contribution to the worldwide "*pursuit for peace and prosperity for people and the planet, now and into the future*", as stated by SDG 17. The following subsection provides a breakdown of the most straightforward areas where the 6G-NTN project is in position to design technologies and elaborate concepts able to support an effective NTN system design with reduced environmental impact, and as a whole, stronger sustainability.

It is worth noting that this breakdown follows a largely accepted classification whereby the notion of sustainability includes three major domains: **economic sustainability, societal sustainability, and environmental sustainability**. This breakdown, illustrated in Figure 5: [4], was first presented at the Stockholm EAT Food Forum in 2016.

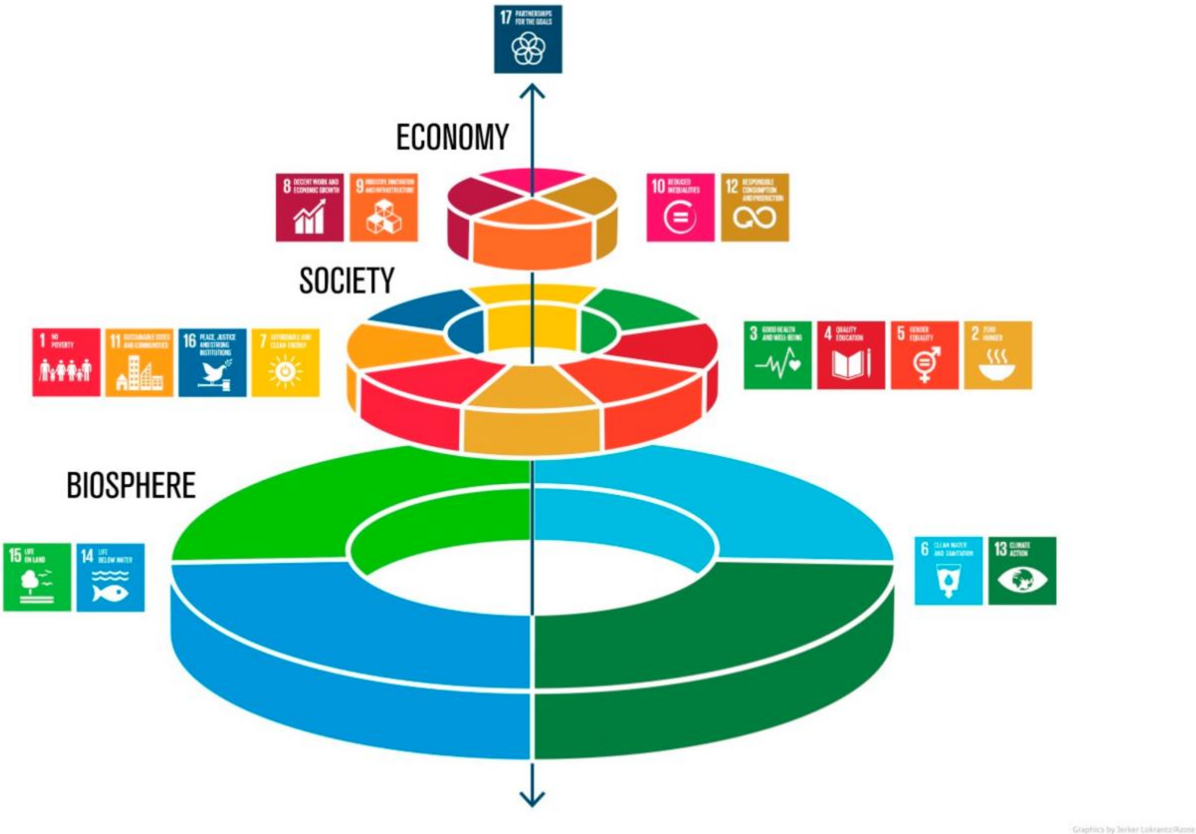

FIGURE 5: MAPPING OF THE UN 17 SUSTAINABLE DEVELOPMENT GOALS WITH A 3-DOMAIN NESTED MODEL OF SUSTAINABILITY [4]

It includes a mapping of the SDG 17 into the 3 aforementioned sustainability domains:

- **Economic sustainability** includes SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), SDG 10 (reduced inequalities) and SDG 12 (responsible consumption and production).

- **Societal sustainability** includes SDG 1 (no poverty), SDG 2 (zero hunger), SDG 3 (good health and well-being), SDG 4 (quality education), SDG 5 (gender equality), SDG 7 (affordable and clean energy), SDG 11 (sustainable cities and communities) and SDG 16 (peace, justice and strong institutions).

- **Environmental sustainability** (also referred to as 'biosphere' in Figure 5:) includes SDG 6 (clean water and sanitation), SDG 13 (climate action), SDG 14 (life below water) and SDG 15 (life on land).

- Finally, on top of these nested domains, the last sustainable development goal, SDG 17 (partnerships for the goals) is seeking to "*strengthen the means of implementation and revitalize the global partnership for sustainable development*" [2]. As such, the outputs of this deliverable regarding sustainability and the expression of KVIs relate to this goal.

Moreover, before we delve into a detailed analysis of how 6G-NTN can contribute to SDG 17, it is crucial to emphasize the dual facets of this topic. Several working groups, such as the 6G Smart Networks and Services Industry Association (6G-IA) recognize two key aspects which are "*sustainable 6G*" and "*6G for sustainability*" [5]. 6G-NTN ambitions to adhere to both these aspects:

- Sustainable 6G addresses the first-order effect of the network, meaning the direct environmental impacts of the network manufacturing and operation, such as energy consumption, CO2 emission and resource usage. In particular, Sustainable 6G refers to the design, implementation, and use of a 6G system that reduces the negative life cycle impacts of 6G systems as much as possible.**6G for sustainability** focuses on how 6G networks can drive sustainability improvements: deploying a 6G-NTN system shall contribute to the aforementioned sustainable worldwide "*pursuit for peace and prosperity for people and the planet, now and into the future*". In practice, this aspect refers to the contribution of 6G and NTN networks to the development of our society as a whole, not only in terms of telecommunications. Moreover, it is worth mentioning that the SDG 17 breakdown in sustainable development goals provides a well-grounded context to detail how the multiple envisioned 6G-NTN deployment cases can help enable this contribution.

As a result, Sustainable 6G can be seen as the *internal* analysis of 6G system sustainability, whereas 6G for sustainability structures the *external* analysis. Regarding KVIs, this deliverable aims at explaining how the 6G-NTN system will support the 6G vision according to which telecommunication networks shall also contribute to address fundamental human and societal values such as growth, sustainability, trustworthiness, and inclusion [5], [6]. This explains the need to formulate value-related goals in relation to the usage of 6G networks, as well as the need to identify KVIs, i.e., the tools to assess the fulfilment of such goals. By design, KVIs aim at complementing the assessment of performance-related capabilities with KPIs. This deliverable shall therefore concretely investigate in Section 3.2 how the KVIs related to the 6G-NTN system:

- can be identified in the framework offered by the United Nation's SDG 17,

- can be formulated, taking into account the need to accompany and extend the general 6G vision, for which traditional existing 6G KVIs will be taken as reference,

- can complement the related KPIs identified in Section 3.1, when applicable.

2.3 APPROACH TO COLLECT KPIS, KVIS AND REQUIREMENTS

As outlined in the two previous subsections 2.1 and 2.2, the identification and formulation of the appropriate KPIs and KVIs to assess the performance and value of the 6G-NTN system shall be performed by reusing and extending the corresponding indicators used in the context of 6G networks in general, as well as 5G-NTN and 5G-NTN Advanced networks, when a comparison needs to be made.

In addition, it is worth stressing that a concrete approach was taken within task T2.3 to collect all the inputs needed to identify and consolidate those indicators. In that regard, Figure 2: illustrates how, in the context of 6G-NTN project, both the careful study of use cases and underlying technologies are instrumental to elicit and consolidate the sets of KPIs and KVIs. The description of inter-task and work package relations, as previously mentioned in Subsection 1.2, allows understanding that, whether use case or technologies are considered, the main inputs to perform this work come from different sources:

- The outcomes of deliverables D2.1 and D2.2, as well as the multiple interactions held with the project's External Advisory Board (EAB) during the elaboration of these deliverables, provided the necessary support to identify the appropriate indicators when considering use cases and the user requirements.
- During the preparation of this deliverable D2.3, regular inter-work package interactions (and in particular with work packages WP3, WP4 and WP5) allowed providing a complementary technical viewpoint. This viewpoint is illustrated by the bottom-up arrow labelled 'Technology' in Figure 2: with this environment, it was possible to refine the identification of the needed KPIs for both enhanced capabilities (compared to 5G NTN) and new 6G capabilities.

2.4 ASSUMPTIONS FOR UE, USERS AND SERVICES

The rest of this section explains the rationale behind the needed adaptations in terms of viewpoint and definitions made, when needed, for inputs gathered from deliverables D2.1 and D2.2, as well as from other tasks in work packages WP3, WP4 and WP5, in terms of definition of the considered User Equipment (UE), users, services and target scenarios.

2.4.1 Considered UEs

From WP2, a usage-based UE taxonomy: From work package 2 perspective, deliverables D2.1 and especially D2.2 captured the main types of UEs of interest, and outlined the associated form factors, constraints, and user requirements. The following set of UEs was given in D2.2, Section 4:

- **Handheld UEs** (subdivided into the consumer and professional categories);
- **Drone-based UEs** (subdivided into two general classes of form factors: UEs for light drones, and UEs for heavy drones);
- **Mounted UEs** (subdivided into two main categories: stationary UEs and moving UEs (also called vehicular-mounted and referring to all types of vehicles such as trains, cars, PPDR vehicles, and so on).

From T3.4, a vision of a dual target device design: regarding UEs, assessing the performance of the devices themselves or defining the project's terminals is out of the scope of Deliverable D2.3. For that purpose, the 6G-NTN relies on the outcomes of Task T3.2 ("Terminals"), and its key deliverables D3.2 and D3.8, to work on the design of the Project's target design for the terminals. The approach here is to evaluate the enabling technologies to optimize the performance under tight installation (e.g., vehicle, drone, or building mounting), volume constraints (i.e., form factor) as defined by work package 2, while considering power consumption and Bill of Material (BOM) of two target device designs, respectively operating in sub-6GHz (C-band) and mm-Wave (Q/V band). It must be noted that this doesn't imply that two separate UEs are systematically considered for the operation on either band. In effect, for a given usage, a single UE may have two modems or two distinct radio protocols stacks.

At the time of finalizing Deliverable D2.3, the work carried out in Task T3.2 allows outlining a list of the different UE target designs, factoring in both the requirements on UEs as seen in D2.2, and an overview of the 5G RF front end modules such UEs shall be equipped with. For the purpose of this deliverable, Table 1 gives a simplified view of the different UE designs explored in T3.2 (In particular, column 3 gives the UE categories being explored in T3.2, at the time of finalizing this deliverable), and for each UE design, a mapping with the intended usage classification, as proposed in D2.2, is given. The proposed combination of UE designs is able to address the whole usage-based UE taxonomy identified in D2.2.

TABLE 1: TARGET UE DESIGNS DEFINED IN T3.2 (COLUMN 2), WITH A MAPPING OF THE USAGE-BASED UE CATEGORIES FROM D2.2

UE design	UE frontend	UE Category [T3.2]	Usage (Vertical) [D2.2]
1	UE Handheld	Handheld	Handheld UEs > Consumer, Professional
2	UE Terminal Enhanced	Automobile	Mounted UEs > Vehicular Mounted > Automobile
3	UE Handheld	Drone Light	Drone-based UEs > Drone Light
4	UE Terminal Enhanced / UE Mounted	Drone Heavy	Drone-based UEs > Drone Heavy
5	UE STA	HAP_STA + Drone_STA	Mounted UEs > Stationary Mounted > HAPS, Drone
6	UE Terminal Enhanced	Plane	Mounted UEs > Vehicular Mounted > Plane
7	UE Mounted	Maritime	Mounted UEs > Vehicular Mounted > Maritime
8	UE Terminal Enhanced	Train	Mounted UEs > Vehicular Mounted > Train
9	UE Terminal Enhanced	Bus	Mounted UEs > Vehicular Mounted > Bus

As a result, the present document's approach is to follow this designation according to the context: where we can keep a higher level of abstraction, the mention of handheld UE and Mounted UE, as defined in task T3.2, will be preferred, because it implies the use of only two UE categories and therefore simplifies the corresponding analysis. However, we need at times to bring a finer-grained distinction in terms of UEs, in which case the deliverable will refer to the denomination outlined in Table 1, when it is found that considering more specific UE designs brings distinct performance requirements that we need to capture, notably in sections 4.3.3 and 4.3.4.

2.4.2 Considered users

With D2.1 and D2.2, adopting the perspective of the end-users themselves and their needs was inherently part of the approach taken. In contrast, deliverable D2.3 primarily considers UEs (and the different UE design variations as previously presented in Table 1) as the system users, which was viewed as a suited approach for the more technical purposes of a report on System Requirements.

2.4.3 Considered services

Deliverable D2.1 (Use case report) defined an initial set of seven use cases, to illustrate the novel 6G-NTN concepts and technologies leading to the full integration between NTN and the next generation of terrestrial 6G cellular networks. D2.1's main objective is to propose a first non-exhaustive set of use cases able to illustrate the usage of the 6G NTN technology, in particular for ten different market segments (referred to as Verticals in the rest of this deliverable) including:

- Consumer,
- Automotive,
- Public Safety & Defense,
- Utilities / Infrastructures,
- Media and Entertainment,
- Railways transportation,
- Maritime transportation,
- Aeronautic / drone sector,
- Agriculture,
- and Road transportation / Smart cities.

On this basis, the list of seven use cases identified in D2.1 is summarized by Table 2.

TABLE 2: THE INITIAL SET OF USE CASES IDENTIFIED IN D2.1

UC1	Maritime Coverage for search and rescue coast guard intervention
UC2	Autonomous power line inspection using drones
UC3	Urban air mobility
UC4	Adaptation to PPDR or Temporary Events
UC5	Consumer Handheld Connectivity and Positioning in Remote Areas
UC6	Continuous Bi-directional Data Streams in High Mobility
UC7	Direct Communication over Satellites

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Furthermore, a synthetic cross-mapping between the seven considered use-cases and the ten Verticals was performed and summarized in D2.1's Table 2. This straightforward correspondence eased the interactions with 6G-NTN External Advisory Board (EAB) and the mutual understanding of the different scenarios and user stories. This work led to the collection of an initial list of raw requirements, which were associated with each use case and sub-scenario in deliverable D2.1.

However, with respect to services and involved UEs, those use case are neither exhaustive in describing all possible combinations, and neither mutually exclusive in terms of the UEs or services they refer to. In the context of this deliverable D2.3, this an important consideration to take into account when categorizing user traffic profiles in section 4.3. In effect, the proposed user traffic profiles, to be useful and practical to the project's work packages 3, 4 and 5, will need to be in a reasonably small number, with each set clearly identifying which type of user, UE and service is involved. Therefore, for that particular purpose, a set of more high-level use cases is needed to categorize user traffic profiles in section 4.3. D2.1 already identified three Service Categories defined in 3GPP TR 22.822 [1]:

- **Service Continuity**, for which users may experience conditions where a continuous connectivity cannot be offered by a single TN or a combination of TN during the journey of the UE.
- **Service Ubiquity**, which refers to the ability of NTN to complement TN coverage, which can be inherently limited in deployment, for technical or economic reasons (also known as coverage extension use cases) or which can be subject to a localized and temporary outage, e.g., in the context of a post-disaster relief use case.
- **Service Scalability**, which illustrates the ability of NTN to efficiently multicast or broadcast a similar content over a large service coverage. Traffic offloading use cases typically belong to that category.

That way, each user traffic profile defined in this deliverable will be associated to one of these Service Categories.

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3 RELEVANT METRICS

This whole section aims at giving definitions and information about all used KPIs, KVIs and UTPs that will be used in the rest of this deliverable (mainly in section 4). This section therefore provides reference and typical values, focusing on what those metrics shall measure in the 6G-NTN project, and in which service and technical requirements of section 4 those will be used. It is thus worth noting that this section does not seek to delineate an exhaustive list of potentially relevant metrics, but rather investigates which parameter shall be concretely useful for the technical work packages WP3, WP4 and WP5 of the 6G-NTN project.

The rest of this section is divided into three main parts, respectively related to the definition of KPIs, KVIs and the typical structure of UTPs.

3.1 KEY PERFORMANCE INDICATORS

The investigated KPIs were grouped into the following ten categories, which directly relate to the KPI areas previously defined in Section 2.1:

- Data rates,
- Latency,
- Availability,
- Dependability,
- Coverage,
- Positioning,
- Energy consumption,
- Security & privacy,
- Integrated intelligence,
- TN/NTN mobility.

In addition, it is worth noting that:

- **Integrated Intelligence**, while related to the Cloud-based infrastructure KPI area defined in Section 2.1, is described in its own category here, since it relies on new mechanisms and is intended to enable new capabilities for the system. Essentially, Integrated intelligence refers to the general KPIs that allow assessing the performance of AI/ML mechanisms in 6G-NTN.

- Similarly, **TN/NTN mobility** relates to a combination of service availability and service versatility, as defined in Section 2.1. But for the sake of visibility, for this important enabler of the 6G-NTN system, we more directly refer to mobility between TN and NTN segments, and vice-versa.

3.1.1 Data rates

Regarding the Data rates category, the following KPIs will be used mainly in the performance requirements associated with the UTPs, in both subsections 4.3.3 and 4.3.4.

3.1.1.1 Experienced User Data Rate

Experienced User Data Rate represents the minimum data rate needed to achieve a target Quality of Experience (QoE) [17]. This KPI is expressed in bits/s for both the downlink (Experienced User Data Rate DL) and the uplink (Experienced User Data Rate UL).

3.1.1.2 Related parameters

The following parameters are not considered as KPIs but can usefully complement them by providing complementary information on the behavioral patterns of the 6G-NTN system users. Those parameters will be used and valued in the User Traffic Patterns, defined in Section 4.3, for the purpose of expressing adequate performance requirements for the 6G-NTN system.

- **Activity Factor** is the ratio of simultaneous active UEs to the total number of UEs. In this context, an active UE is a UE exchanging data with the network [17]. This parameter is expressed as a unitless value for both the downlink (Activity Factor DL) and the uplink (Activity Factor UL).
- **Average Busy Hour Usage Rate** is expressed in bits/s for both the downlink (Average Busy Hour Usage Rate DL) and the uplink (Average Busy Hour Usage Rate UL) and is defined as:

  Average Busy Hour Usage Rate DL = Experienced Data Rate DL * Activity Factor DL

  Average Busy Hour Usage Rate UL = Experienced Data Rate UL * Activity Factor UL

3.1.2 Latency

3.1.2.1 Network Delay

Network Delay, also called End-to-End (E2E) Network Round Trip Time (RTT) latency, and expressed in s, represents the time taken to transfer a data block 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 [17]. In the context of 6G-NTN, it is the time measured from UE to Satellite to Ground Station and return in case of a transparent satellite payload, or from UE to Satellite and return in case of a regenerative satellite payload.

The typical network delays of NTN networks are dependent on the orbit used. For the “Over-the-air” part of network delay (i.e., the return trip tip over the satellite air interface), we expect around 500ms delay for GEO based NTN links, for MEO 150ms and for LEO this can depend on the LEO constellation and inter-satellite link usage, as multiple satellite hops may be needed for a link. This is typically in order of 10-50ms [1].

<u>Note</u>: for a measure of latency defined as the speediness in the computation of location, please refer to subsection 3.1.6.2.

3.1.3 Availability

3.1.3.1 Radio Link Availability

The radio link availability is the measure of time percentage the UE radio link experiences a link budget that is better than the minimum required to close the link for a minimal of a data rate. This is an average over time and possibly also over an area. Typically, the time average is a long-term average value (per month or per year average availability). It may also be measured over an average area where the UE may move.

It is measured for both directions forward link and return link and, in each case, combines uplink and downlink.

3.1.3.2 Service Availability

The service availability is the combination of the radio link availability in both directions, forward link and return link via TN or NTN. The service availability is the end-to-end availability of the service, it combines the bi-directional link, the network (Core and radio access) availability in addition to the access to the service.

3.1.4 Dependability

3.1.4.1 Reliability

Represents a measure of the packets successfully decoded, expressed as a percentage within a given time period.

3.1.5 Coverage

3.1.5.1 Mean User Density

Represents the average user density over a defined area, measured in users / km^2.

In addition, it is worth noting that the values proposed in Section 4 of this deliverable for the mean user density are indicative and need further refinements, for example to include geographical, and possibly temporal, variations over the satellite footprint. Indeed, to efficiently dimension networks and characterize operational constraints, gaining practical insights into the behavior of users' resources demand is key. This includes accounting for the realistic and non-uniform user distribution and mobility patterns, either through factual datasets or representative simulations. Depending on targeted results, such information can support network dimensioning and evaluation of architectural trade-offs (as in T3.1), optimization of radio technologies, RAN Intelligent Controller (RIC) and analysis of co-existence scenarios (as in WP4) or the design of a reference very low earth orbit (VLEO) constellation (as in T3.4).

Quite interestingly for the 6G-NTN project, open datasets can be found on real-world live marine traffic information over the entire globe, obtained from Automatic Identification System (AIS) and differentiated by vessel type (Cargo, Tanker, Cruise ships, etc.). VesselFinder and VT Explorer can be mentioned here, as main open data providers for maritime traffic, and more detail is available in D4.3. Similar data also exists for live manned aircraft traffic and is expected for drones within a few years.

However, no open dataset can be found for other types of UE, in particular related to detailed population distribution and mobility patterns, car traffic information or drones density forecast. In this case, simulation-based data is seen as great support in TN / NTN architecture design, that is: generating, through realistic mathematical models, information about UEs localization and motion over predefined areas. But having one single model for any kind of investigations may rapidly become intractable, being either to complex regarding some aspects or oversimplified regarding others. For example, to analyze network dimensioning at a large scale, there is no need to consider a user mobility pattern with a 1m-accuracy. Therefore, depending on the utilization that is foreseen for required simulation-based datasets, different space & time granularity levels should be considered, so as to provide valid inputs for other tasks and work packages of the 6G-NTN project.

Although providing a more accurate characterization of how the users are distributed over the area of interest, and how they move, is clearly out of the scope of this deliverable, we provide a few insights on potential models for the considered UTPs, at different space & time granularity levels.

3.1.6 Positioning

Positioning of UE is critical for the operation of 6G NTN. Since the introduction of 3GPP Rel.18, NTN has attracted considerable interest due to many applications, including emergency services. In the ongoing work in Task 5.1 for WP5, we consider explicit positioning using LEO-satellites for location and verification purposes in scenarios where Global Navigation Satellite Systems (GNSS) signals be weak or unavailable. To this end, we shall propose, study, and evaluate candidate positioning methods as part of the primary objective of Project's Task T5.1.

The foremost KPIs in the context of positioning are described in the rest of this paragraph.

3.1.6.1 Position accuracy

This a measure of the 3D error, evaluated as Euclidean distance, between the true location and the computed location of the UE. It has the unit of meters [m]. Two types of the position accuracy are usually distinguished as:

- Horizontal position accuracy, which is the error projected onto the Earth's surface. Hence, a horizontal accuracy of *x* [m] indicates that the computed location is within a circle of radius *x* [m] about the true location.
- Vertical position accuracy, which is the error in the direction normal to the Earth's surface. Thus, a vertical position accuracy of *y* [m] indicates that the computed location is within *y* [m] above, or below the true location.

To account for the statistical nature of various measurement errors, and hence the computed location, position accuracy is generally stated in conjunction with a percentile number. Thus, *x* [m] of horizonal position error at *z*-percentile indicates that *z*% of UEs (among a large sample of trials) show a horizontal position error within *x* [m]. Equivalently, location evaluation error at a UE, is smaller than *x* [m] *z*% of the time.

3.1.6.2 Latency

It is a measure of the speediness in the computation of location, defined as the time-interval between the triggering of the computation of location and the availability of the same. It is measured in units of milliseconds [ms]. The latency observed when a location computation is triggered for the very first time is an important related metric that is typically used to compare location determination algorithms and is referred to as the Time-To-First-Fix (TTFF). The TTFF is usually larger than the average latency.

3.1.7 Energy consumption

3.1.7.1 Energy Efficiency

As defined in [20], the required energy efficiency metric may be calculated from a knowledge of:

- T_{SN} satellite network throughput;
- A_{SN} satellite coverage area;
- P_{SN} satellite network consumption (including satellite terminals).

The energy per bit ECI $_{E/B}$ can be calculated by dividing the total power consumed by the satellite network (as calculated in clause 7.4.1) by the total throughput of the satellite (e.g. 0,5 Tbps).

$$ECI_{E/B} = P_{SN} / T_{SN} \qquad [W/kbps]$$

The power per unit area ECI $_{P/A}$ can be calculated by dividing the total power consumed by the satellite network (as calculated in clause 7.4.1) by the total coverage area for the satellite network in km^2.

$$ECI_{P/A} = P_{SN} / A_{SN} \qquad [W/km^2]$$

Where

A_{SN}	Coverage Area of a Satellite Network
ECI	Energy Consumption Index
$ECI_{P/A}$	Energy Consumption Index (Power per Unit Area)
$ECI_{E/B}$	Energy Consumption Index (Energy per Bit)
N_{SG}	Number of Satellite Gateways
N_{ST}	Number of Satellite Terminals supported (by a satellite network)
P_{SG}	Power consumption of a Satellite Gateway
P_{SN}	Power consumption of a Satellite Network
P_{ST}	Power consumption of a Satellite Terminal
T_{SN}	Throughput of a Satellite Network

Note: It is worth mentioning that unlike other KPIs mentioned in Section 3, these energy efficiency metrics $ECI_{E/B}$ and $ECI_{P/A}$ are not directly used in any of the expressed requirements of Section 4. However, work on energy consumption based on this type of metric can be expected in the next period of the Project lifecycle in work packages 3 and 4. Therefore, the authors of this deliverable kept these KPIs for the sake of illustration and representativity, although they are not evaluated in the rest of this document.

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3.1.8 Security

Security KPIs encompass a wide range of metrics that provide insights into various aspects of an organization's security posture. They can be broadly categorized into three main groups:

3.1.8.1 KPIs Related to Attacks:

These KPIs focus on the detection and mitigation of security incidents and attacks. They include metrics such as:

- Incident Response Time measures how quickly security incidents are addressed,
- Phishing Click-Through Rate assesses user susceptibility to phishing attacks,
- Firewall Rule Violations tracks breaches in network defenses, and
- Network Anomaly Detection monitors unusual patterns that might indicate a breach.

3.1.8.2 KPIs Related to User Behavior:

These KPIs revolve around the actions and compliance of employees and users.

- User Authentication Failures: measures the number of failed login attempts, which can indicate unauthorized access attempts.
- Employee Security Training Completion assesses how well the workforce adheres to security training requirements, contributing to a more security-conscious environment.
- Password Policy Compliance examines the adherence to password complexity and expiration policies.

3.1.8.3 KPIs Related to System Vulnerability:

These KPIs focus on the health of an organization's systems and infrastructure.

- Patch Management Compliance assesses the organization's effectiveness in keeping systems up-to-date with security patches,
- Data Loss Prevention (DLP) Policy Violations monitors and reports incidents involving sensitive data breaches.
- Encryption Adoption Rate measures the extent to which data in transit is encrypted, indicating protection against eavesdropping.

These three categories of KPIs collectively provide a holistic view of a system's security posture, helping to identify weaknesses, prioritize resources, and improve overall security resilience. By tracking and analyzing these metrics, 6G-NTN project can proactively manage security risks and respond effectively to threats and vulnerabilities.

3.1.9 Integrated intelligence

Enhancing Integrated Intelligence in 6G Networks involves harnessing the power of AI, ML, and Deep Learning models to deduce network behaviour. Within the context of 5G and 6G networks, several data-driven challenges necessitate intelligent decision-making, as outlined below:

- **Traffic Classification**: This challenge revolves around the classification of network traffic, where Machine and Deep Learning algorithms are trained using diverse data attributes such as average packet size, packet arrival times, protocols, and IP numbers. These models are then employed to classify target applications and services effectively.

- **Traffic Prediction**: Predicting network traffic is a complex task, often treated as a regression or time series problem. Historical traffic data for specific areas, whether cumulative or service-specific, serves as input. This data enables the anticipation of future traffic patterns, aiding in network optimization.

- **Admission Control**: The role of integrated intelligence in 5G and 6G networks extends to permitting or denying service requests. This dynamic function optimizes resource allocation while concurrently upholding Quality of Service (QoS) standards, ensuring efficient network operation.

- **Resource Management**: Resource management capitalizes on historical network demand data and resource utilization statistics to efficiently allocate resources to slices dedicated to specific services. Advanced forecasting techniques are employed to predict resource needs over different time scales, encompassing long-term, mid-term, and short-term intervals. This proactive resource allocation strategy ensures the sustained delivery of a stable QoS.

In summary, the evolution of Integrated Intelligence in 6G Networks necessitates the seamless integration of AI and machine learning techniques to tackle complex challenges such as traffic classification, prediction, admission control, and resource management. These efforts are pivotal in ensuring optimal network performance and an enhanced user experience in the forthcoming era of advanced telecommunications.

3.1.9.1 Training time

The training time consists of the period required to build the AI/ML model from the available dataset. The training time is measured in the considered operational resource (physical computer, cloud service) able to perform the training. This particular KPI holds significant importance, particularly in relation of the complexity of the AI approach implementation in the network.

3.1.9.2 Model re-training period

This parameter delineates the frequency at which a model should undergo updates or retraining. Essentially, the retraining interval is influenced by the rate at which data is deposited into our data storage. For the efficient training of models, retraining should function as a background task responsible for updating and versioning the latest model artifacts.

3.1.9.3 AI/ML model precision

The main distinction here in terms of errors used for evaluation should be on classification and timeseries regression models. In particular:

- For **Classification problems** (Traffic Classification, Admission Control) errors that will be considered are:
    - Accuracy, F1 Score, Receiver Operating Characteristic (ROC) Curves, ROC Area under the Curve (AUC) Score, Precision Recall Curves, Confusion Matrices, False Positive Rate, False Negative Rate, True Negative Rate, Negative Predictive Value.

- For **Timeseries Regression problems** (Traffic Prediction, Capacity Forecasting, Resource Management) errors that will be considered are:
    - Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Normalized Root Mean Squared Error (NRMSE), Weighted Absolute Percentage Error (WAPE), Weighted Mean Absolute Percentage Error (WMAPE).

3.1.9.4 Inference time

It is the time elapsed for providing an output given a specific input. This KPI also important as in the described Use Cases the decision must be made in a very short period of time.

3.1.10 TN/NTN mobility

As an important characteristic, 6G-NTN would require to natively support integrated TN and NTN. As one example, 6G-NTN targets at an improved user experience when the UE switches its connection from one network type to another network type, e.g., to avoid a connection drop, to reduce/avoid service interruption, and/or to reduce/avoid data loss. It is also noted that a fast-moving NTN platform (e.g., a satellite) could also cause all the UEs under its coverage to switch its connection frequently (e.g., very a few minutes), though the UEs themselves may not be moving quickly. In this case, the mobility events triggered for the vast amount of UEs may also require an efficient design to reduce the amount of signaling overhead involved in a 6N-NTN mobility procedure.

Thus, it is critical to investigate the efficiency of how 6G NTN can support a mobility event, e.g., to switch a UE between TN and NTN, or to switch a UE between two NTN nodes. Accordingly, the following KPIs can be considered to evaluate a technical solution developed for supporting the UE's mobility.

3.1.10.1 Successful mobility rate

This KPI refers to the number of mobility processes with a successful completion, thus not yielding to cell/satellite reselection processes or connection release, among all mobility processes.

3.1.10.2 Service interruption duration

Duration of the service interruption within a successful mobility process, which corresponds to the time duration during which a user terminal cannot exchange user plane packets with network.

3.1.10.3 Packet loss

The amount of lost user plane packets during or due to a mobility process.

3.1.10.4 Signalling overhead

The amount of signalling overhead to be transmitted over the air interface to facilitate a mobility.

<u>Note</u>: It is worth mentioning that unlike other KPIs mentioned in Section 3, these integrated intelligence metrics (successful mobility rate, service interruption duration, packet loss and signalling overhead) are not directly used in any of the expressed performance requirements

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of Section 4. However, work on this category of metrics can be expected in the next period of the Project lifecycle in work packages 3 and 4. Therefore, the authors of this deliverable kept these KPIs for the sake of illustration and representativity, although they are not valued in the rest of this document.

3.2 KEY VALUE INDICATORS

In this subsection, we address sustainability through the three SDG 17 domains: economic, societal and environmental sustainability, as previously outlined in Section 2.2. For each domain, we detail how 6G-NTN can enable both the *sustainable 6G* and *6G for sustainability* goals.

3.2.1 Economic sustainability

3.2.1.1 Global and affordable network coverage

Economic sustainability, according to the United Nation's SDG classification, is first a matter of **decent work and economic growth (SDG 8)** and of **reduced inequalities (SDG 10)**. In fact, about four billion people still do not have access to the Internet, and 90% are from developing countries [6]. Moreover, to ensure an equal access to information and knowledge, in both emerging and established markets, in urban, rural and remote territories alike, networks will need to serve more people on larger geographic coverage, with affordable prices for the population, and when needed, with greater data rates. In that regard, both goals can benefit from the deployment and operation of 6G-NTN networks, whose intrinsic TN – NTN complementarity will significantly help bridging the Digital Divide, notably in terms of geographic coverage, affordability and data rates.

Furthermore, the effort towards bridging the Digital Divide will be a key factor to support innovation from people who previously were out of geographical, educational or economical reach. This will therefore have a strong impact on **SDG 9 (industry, innovation and infrastructure)**.

3.2.1.2 Resilient network coverage and services

The 6G NTN system may guarantee the continuity of the economic activities, which in their vast majority rely partially or totally on a communication infrastructure, even in case of events that would have generally meant a degradation or discontinuity of telecommunication services (natural disaster, war, political instability, ...). This ability of 6G NTN system to guarantee services would contribute to economic sustainability and SDG 9 in particular by allowing economic agents such as people and companies to keep their economic activities active, even under unexpected events, which in turn mean less risks to have economic growth precluded by these events and also reduced inequalities between areas affected by these events and areas not affected.

3.2.1.3 Energy consumption

A general trend for the successful development of 6G technologies is that they ambition to "*transform networks into an energy-optimized digital infrastructure*" and to "*deeply revise the full resource chains of wireless networks towards sustainability and carbon neutrality*" [6]. 6G-NTN adheres to this ambition by first tightly including the topic of energy consumption and energy optimization in all major components of the targeted system. Concretely, among the ten objectives supporting the development of the 6G-NTN system, five explicitly take into account the different aspects of energy consumption for the design of the considered sub-systems:

- **Objective 1 (Identify the target service and operational requirements for 6G Non-Terrestrial Network component)**, for which the present deliverable D2.3 represents a key output, seeks to identify energy consumption and carbon footprint targets for an economically viable, affordable and sustainable approach. These targets are being outlined in the current section, and further expressed in terms of target requirements in Section 4.
- **Objective 2 (Design/sizing of a 3D NTN component with space and ground segments)**, through its output deliverable D3.1 and subsequent iterations D3.5, D3.6 and D3.7, notably seeks to minimize the component's carbon footprint as well as its energy consumption, while meeting the other defined functional and performance targets.
- **Objective 3 (Design trade-off and assessment of compact terminals targeted by the 3D NTN component)** is materialized through key deliverable D3.2 and subsequent iteration D3.8. This work allows defining what the compact terminals targeted by 6G-NTN should entail, particularly in terms of trade-offs with respect to architecture, installation, technology (Antenna, modem) as well as performance, explicitely taking into account constraints such as power consumption aspects, with a special emphasis on energy efficiency.
- **Objective 4 (Design flexible software defined payload across flying platforms and frequency bands)** notably seeks to refine the concept of Space-Edge Computing by studying how NTN node onboard capacity can allow virtualizing part or all payload usual physical resources. Methodology-wise, the payload design is based design trade-offs, which includes energy consumption for the different payload virtualization configurations, depending on platform types. This design trade-off approach is presented in deliverable D3.3.
- Finally, the work carried out in 6G-NTN to meet **Objective 7 (Design and development of dynamic orchestration of Virtual Network Functions in a 3D network for 6G)** is also based on a trade-off design approach. At large, the investigated solution is intended to address limited resources and latency issues induced by the software defined satellite payloads on the one hand and dynamic deployment and adaptation requirements with energy efficiency on the other hand.

Furthermore, beyond the design stages, it is also important to mention how an integrated TN – NTN network such as 6G-NTN will contribute to speeding up the transition to renewable electricity. It can be observed that TN 6G systems will increasingly integrate renewable energy supply solutions, in particular for the deployment of 6G mobile sites [6]. In that regard, the NTN segment being prominently powered by solar energy at operational stage, the design and global deployment of integrated 6G TN-NTN solutions shall help decrease the current contribution of the ICT sector to the total carbon footprint of the society, and therefore contribute to SDG 9.

3.2.1.4 Circular economy

Another strong enabler for meeting the objectives set by SDG 9 is how circularity is addressed in production processes: it is a model of production and consumption, which "*involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible*" [7]. Adhering to this model implies reducing waste to a minimum, and when a product reaches the end of its life, its materials are kept as much as possible within the economy, thereby creating further value instead of waste.

On this topic, it is worth considering how the 6G-NTN architecture stands, especially regarding the production processes of its non-terrestrial segments. To that end, two perspectives must be considered:

- First, 6G-NTN can support the general industry, innovation and infrastructure ecosystem targeted by SDG 9, to concretely implement a circular economy model. As an integrated 6G architecture with space-based segments, 6G-NTN ambitions, through its global network coverage, to enable key deployment cases, e.g., to "*enable lifetime monitoring of a product from manufacture to disassembly, ensuring that re-usable and recyclable elements are not wasted*" [8]. Likewise, improving tracking and tracing of goods, as offered through the positioning services of 6G-NTN, can help leveraging waste collection systems, thereby supporting better recycling processes.

- But beyond providing support for other industries to achieve their own SDG 9 objectives, 6G-NTN may also directly integrate circularity in its own production processes, notably by adhering to ESA's vision of a sustainable and safe space environment. ESA has most notably developed the 'Space for a Green Future' Accelerator, which is a 'co-governed & independent non-profit partnership of Green Transition actors united under a common banner, engaging governments, businesses, multilateral institutions, civil society groups, end users and citizens to develop practical space-based solutions supporting carbon neutrality and greening of society by 2050' [16]. Among the levers to implement this vision, the Agency has been seeking to stimulate and enable the developing market in the context of commercial In-Orbit Servicing (IOS) [9]. In the longer term, such IOS services shall result in the creation of a 'Circular Economy in Space' in cooperation with industry and partners [10]. Naturally, until this environment matures, seeking to minimize losses at end-of-life stage for space-based equipment will be inherently limited by the current standards and technologies regarding space debris mitigation and state-of-the-art regarding satellite decommissioning.

3.2.1.5 Eco-design

Finally, the space-based services can help improve the real-time monitoring of environmental changes, which is key to optimized production processes in many industries, in which the amount of chemicals and other compounds is kept minimal, thanks to the nominal production environment. With key features such as global seamless coverage, large range of data rates and advanced positioning offered by the 6G-NTN architecture, this type of environmental monitoring can scale up with the needs of distributed and large-scale production processes. In addition, those features can support the monitoring and forecasting of emissions along supply chains, which is a highly needed tool to establish environmental standards and how efficient eco-design processes can be implemented in manufacturing facilities and supply chains from the industry, thereby addressing the challenges posed by SDG 9.

Moreover, it is important to mention another aspect of the applicability of the eco-design: while the former paragraph explained how 6G-NTN can help supporting eco-design in the industry at large, another question is how a 6G-NTN system can itself rely on eco-design principles, and to what extent. For a 6G-NTN system that integrates non-terrestrial components, including a satellite constellation, particular attention needs to be given to the key drivers that can allow achieving high production volumes with minimal resources needed for optimized manufacturing processes, while at the same time ensuring affordable production costs.

In this regard, advances in key technological fields can significantly leverage such key drivers: on the TN and NTN segments alike, components heavily rely on electronics. Improving the sustainable conception at the system level will greatly depend on the advances made on semiconductor technologies, including the use of new generations of micro-architectures (e.g.,

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chiplet-based design, in contrast with current monolithic dies). Those should help reducing material waste at the manufacturing stage.

3.2.2 Societal sustainability

3.2.2.1 Inclusion

A first general observation regarding societal sustainability is that the improvement of society as a whole through SDG 1, SDG 2, SDG 3, SDG 4, SDG 5, SDG 11 and SDG 16 can mechanically benefit from the support of an increased population service coverage, as featured by the 6G-NTN solution. In effect, addressing Digital Inclusion, which not only spans geographical network coverage but also the affordability, efficiency and simplicity of the connectivity, can be seen as a fundamental enabler to be in position to better tackle complex challenges such as the reduction of inequalities in terms of wealth, hunger, health, education, territories, peace, access to justice and institution. This can be seen as the societal counterpart of seeking to bridge the Digital Divide, which has already been discussed in Section 3.2.1.1 with an economic viewpoint.

3.2.2.2 Health

Addressing **SDG 3 (good health and well-being)** can first be considered with inclusion in mind, for which previous section 3.2.2.1 generally applies. But beyond that initial observation, the 6G-NTN system can offer more specific levers to efficiently support SDG 3. In effect, featuring a global, seamless and affordable network coverage, together with adapted bitrates and QoS and resilient positioning services, can trigger the uptake of advanced digital health services, which include: telemedicine and remote consultations, remote health-monitoring, possibly through the massive deployment of biosensors (e.g., for heart rate or blood pressure monitoring), which can in turn be foundational for the successful development of disruptive health applicative perspectives such as universal, personal and preventive healthcare [6]. Moreover, 6G-NTN can lever a wide types of preventive mechanisms beyond the specific topic of preventive healthcare.

Another relevant aspect of this question of health is about the transparent assessment of potential impacts of 6G on the human body and health in general. More precisely, it is increasingly important, especially when taking into account all lessons learnt from 5G deployment, to ensure that objective target values can be understood and used by all stakeholders, including the greater public. Therefore, the aspect of higher Electromagnetic Field (EMF) awareness shall be an integral part of addressing health-related needs and expectations from end users by formulating societal requirements.

- During the last century, environmental exposure to man-made sources of EMF has been noticeably increasing with the industrial growth in general, and of various technologies including but not limited to electricity, electronics and radiocommunications. As a result, the population is now exposed to a complex mix of natural and man-made electric and magnetic fields with a wide range of frequencies. As a result, there has been a growing societal concern over the possible effects on health from this type of permanent exposure [11].

- In that regard, 6G and integrated 6G-NTN networks need to assess their own impact on this topic of EMF awareness. In general, for terrestrial networks, there is a concern for both endpoints of the access network (i.e., both at the base station and the UEs). The context is however different for NTN, since by principle, the distance from emitting NTN radio nodes to earth surface implies the handling of relatively low signals, compared to the TN environment, and in turn low-level EMF emission from the satellites and NTN nodes in general. However, like in TN networks, there is a need to carefully assess the EMF impact from the use of the 6G-NTN UEs themselves. It is worth noting that, considering the specifics of a NTN architecture, UEs may need to transmit to NTN nodes at higher power level, thereby generating a higher EMF impact. As a result, a 6G-NTN solution shall need to follow 6G EMF-awareness guidelines such as those produced by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [12] [13] or adaptations of those guidelines at national level [11]. In addition, there is a need to give a particular attention on the components of the 6G-NTN architecture (e.g., regarding the mobile handset endpoint) which are likely to generate specific impact in terms of EMF exposure.

3.2.2.3 Trustworthiness

Trustworthiness can be considered as a transverse subject, since all defined SDG require the support of an adequate level of data confidentiality, integrity and privacy, to ensure that all objectives will be properly enforced, in the respect of fundamental human rights. It is important to highlight that although Trustworthiness is mentioned in the section about societal sustainability, it can also support economic sustainability, in particular SDG8 and SDG9.

Furthermore, it is also worth mentioning dependability, which is often defined as measure of a system's Availability, Reliability, Safety, Integrity and Maintainability [14], and is therefore related to trustworthiness. In effect, it is observed that applying security measures to the appliances of a system generally improves the dependability by limiting the number of externally originated errors, according to the Error taxonomy developed in [14].

3.2.3 Environmental sustainability

This area is structured by four relevant Sustainable Development Goals: SDG 6 (clean water and sanitation), SDG 13 (climate action), SDG 14 (life below water) and SDG 15 (life on land). In general, it is important to highlight that 6G for sustainability seeks to help addressing those goals, and in this context also, 6G-NTN can support this effort by notably supporting a wide range of space-based earth observation use cases. Such use cases can potentially provide a significant leverage to support those SDGs and more generally, environmental sustainability.

Finally, this subsection has given a concise breakdown of the UN's SDG 17, which provides a fairly general description of the worldwide sustainability challenges ahead. This description was structured into several Key Value areas, with a high-level description of how, and to what extent, 6G TN and 6G NTN systems shall be involved to support those. Based on this analysis, the corresponding sustainability requirements for the project will be derived further in this deliverable, in Subsection 4.4.

3.3 USER TRAFFIC PROFILES

In this last part of Section 3, we give a brief outline of how User Traffic Profiles (UTP) were defined in the context of this deliverable. A UTP is essentially a collection of KPIs and other input parameters that are valued together. With the right valuation (i.e., consistent with a targeted deployment scenario), a UTP is meant to be useful to quickly understand how a traffic model may be set up and dimensioned. This structure (shown in Table 3) is essentially a convenient and compact way to present a series of KPIs, and it will be used in the next section to express performance requirements for the 6G-NTN system.

TABLE 3: STRUCTURE OF A USER TRAFFIC PROFILE (UTP)

Field Type (KPI, parameter)	**Reference**	**Description**
Experienced User Data Rate KPI	§3.1.1.1	Is defined according to the reference for both DL and UL.
Activity Factor Parameter	§3.1.1.2	Is defined according to the reference for both DL and UL.
Busy Hour Data Rate Parameter	§3.1.1.2	Is defined according to the reference for both DL and UL.
Latency KPI	§3.1.2.1	This KPI can be considered as a delay envelope within which the other data rate-related target values must hold true.
Mean User Density KPI	§3.1.5.1	Gives a general density target which, according to the future needs of the dimensioning studies that may use those UTPs, can be further refined into a fine-grained user density map with the parameter User Distribution.

4 SERVICE AND SYSTEM REQUIREMENTS

Based on the definitions provided in Section 3, this Section now gives a description of the Project's requirements, broken down as follows:

- The Service, Functional and Performance requirements are respectively described in subsections 4.1, 4.2 and 4.3. When needed, these requirements are expressed with target values supported by KPIs and UTPs defined in subsections 3.1 and 3.3.

- The sustainability requirements, which are supported by the general context and categorization outlined in 3.2, are then summarized in subsection 4.4.

Note that in the rest of this section, Tables 4 to 7, 9 and 11 associate priorities with each considered requirement, therefore providing an indication whether the requirement should be considered as essential (with priority P0 in the considered tables) or optional (with priority P1) for the correct operation of the 6G-NTN system. Furthermore, when the priority associated to a given requirement is likely to be reassessed at a later stage of the project development, a footnote is added for the considered requirements, together with an indication of the Project work packages in which the analysis work will be carried out.

4.1 SERVICE REQUIREMENTS

The following requirements STR-SERV-01 to STR-SERV-06 given in Table 4 provide a general overview of how the 6G-NTN shall behave, in the context of the most general services offered to its end users. This list is not intended to delve into the specifics of given service – scenario combinations, but instead ambitions to highlight the commonalities in terms of service requirements found in most deployment scenarios.

TABLE 4: LIST OF SERVICE REQUIREMENTS

Unique Identifier Domain	**Priority[2,3]**	**Requirement Description**
STR-SERV-01 Coverage	P0	The 6G-NTN component should be designed/sized to achieve a typical radio link availability of 99.5% in C-band and 99.00% in Q/V-band in line-of-sight conditions.

[2] P0: essential requirement; P1: optional requirement.

[3] For the relevant service requirements, the prioritization rationale follows the principle that for 6G-NTN, we build on the advantages of NTN coverage and prioritize the complementary advantages of satellite, coverage and service availability over service area, the availability is also a high priority, secure connections, QoS are important bout could be handled outside the 6G-NTN context if a connection basis is working.

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STR-SERV-02 Availability	P0	The 6G-NTN component should be designed/sized to achieve similar service availability to typical satellite networks.
STR-SERV-03 Security & privacy	P1**Error! Bookmark not defined.**	The 6G-NTN system shall be capable of a secure dedicated network for emergency usage in a dedicated area and between dedicated users.
STR-SERV-04 Service versatility	P0[4]	The 6G-NTN system shall be capable of service-based quality of service management, in particular for voice, messaging, data, video services, M2M, critical communications.
STR-SERV-05 Coverage (and light indoor)	P0[4]	The 6G-NTN system shall be able to serve a 6G-NTN handheld UE in light indoor conditions, i.e., in presence of 10-15 dB of building penetration loss.
STR-SERV-06 Coverage (and light indoor)	P1	The 6G-NTN system shall be able to account for all specific regulation (in particular, spectrum usage or transmit power) which may apply for considered sectors.

4.2 FUNCTIONAL REQUIREMENTS

The 6G-NTN functional requirements STR-FUNC-01 to STR-FUNC-43 are summarized in Table 5. This set of requirements allows defining the different modes of operations (i.e., the general features) of the 6G-NTN system. Most of these functional requirements applies to all potential deployment scenarios, with the remark that STR-FUNC-25 to STR-FUNC-28 are more specifically detailing the functional requirements on the 6G-NTN system when it serves UEs with dynamic mobility patterns. All of these requirements are detailed in next paragraph 4.2.1.

In addition, this subsection is further completed with the additional paragraphs 4.2.2 and 4.2.3, which address the functional requirements in the context of more specific use cases, respectively related to high-mobility UEs (such as encountered in the contexts of aviation, maritime and railways) and to direct UE-satellite-UE communications (which qualify the ability of the system to operate, for a given amount of time at least, in isolation of the ground network, e.g., when there is no available feeder link).

[4] This will be subject to prioritization of the use cases in relation with the final deliverable WP2.4 on market and business analysis

4.2.1 General requirements

It is also worth highlighting that the following functional requirements are sorted by domains, which mostly refer to the set of enhanced and new capabilities, as defined in Section 2.1 by Figure 3: and Figure 4:. On that basis, the general functional requirements mainly refer to:

- **Coverage**: STR-FUNC-{01, 04, 12-14, 18-19, 23}
- **Energy consumption** of the network infrastructure: STR-FUNC-{34, 47}
- **Service versatility**: STR-FUNC-{02-03, 06, 09, 15-19, 21, 23-25, 35}
- **Cloud-based infrastructure**: STR-FUNC-{5, 07-11, 20-21, 37}. Other close topics are associated with related requirements: Network orchestration with STR-FUNC-{09-11, 13, 22}, Network monitoring with STR-FUNC-36 and the specific case of RAN disaggregation, explicitly mentioned in STR-FUNC-021 but also partly applicable to requirements STR-FUNC-{08-11}.
- **Deployment flexibility and scalability**: STR-FUNC-{09, 12-13, 19-20, 22, 28}
- **Network positioning and sensing**: STR-FUNC-{24, 26, 29-33}
- **Security & privacy**: STR-FUNC-{24, 31, 33, 38-43}

TABLE 5: LIST OF GENERAL FUNCTIONAL REQUIREMENTS

Unique Identifier Domain	**Priority**[2]	**Requirement Description**
STR-FUNC-01 Coverage	P0	The 6G-NTN system SHALL provide a 6G-NTN UE with direct satellite access for the delivery of 6G services.
STR-FUNC-02 Availability, Service versatility	P0	The 6G-NTN system, SHALL grant a 6G-NTN UE the option to select either NTN or TN communication link, depending on the associated subscriber profile and the availability of the considered links.
STR-FUNC-03 Availability, Service versatility	P0[5]	The 6G-NTN system shall foresee a mechanism to lossless and seamless transition (i.e., without traffic loss and without significant impact on the services), between the TN connection and the NTN connection, as well as between two NTN cells at the same or different segments/layers.

[5] The priority can be subject to change, e.g., w.r.t. the technical investigation and development in WP3

STR-FUNC-04 Coverage	P0	The 6G-NTN system shall foresee a service coverage greater than [TBV % of service area].
STR-FUNC-05 Cloud-based infrastructure	P0[6]	The 6G-NTN system shall foresee edge compute and edge storage functionality to support the defined services.
STR-FUNC-06 Service versatility	P0[5]	The 6G-NTN system shall foresee efficient means to send unicast, broadcast and multicast information to a defined location, user group in a manner that is either linked to the mobile network operation or in a mode that is targeting all 6G-NTN UE devices. This multicast mode shall be possible also in private networks for security services coverage.
STR-FUNC-07 Cloud-based infrastructure	P05	The 6G NTN system shall operate within a hardware- and software-constrained environment with limited capability, e.g., in terms of computational complexity, power supply, data storage, carriage weight.
STR-FUNC-08 Cloud-based infrastructure	P06	The 6G NTN system shall support to distribute network functions (e.g., RAN functions, CN functions, and/or MEC) of the system to different entities.
STR-FUNC-09 Service versatility, Cloud-based infrastructure, Deployment flexibility and scalability	P06	The 6G NTN system shall support to deploy the different entities carrying distributed network functions at the same or different segments (e.g., space, air, and/or ground), as well as at the same or different layers (e.g., GEO, MEO, and/or LEO at same or different altitudes).
STR-FUNC-10 Cloud-based infrastructure, Orchestration	P06	The 6G NTN system shall support to configure the network function distribution at an entity semi-statically or adaptively.
STR-FUNC-11 Cloud-based infrastructure, Orchestration	P06	The 6G NTN system shall support to configure the network function distribution with a granularity of per-entity, per UE, per slice, and/or per service.
STR-FUNC-12 Deployment flexibility and scalability, Coverage	P16	The 6G NTN system shall support to inter-connect different NTN entities at the same or different segments (e.g., space, air, and/or ground), as well as at the same or

[6] The priority can be subject to change, e.g., w.r.t. the technical investigation and development in WP3, WP5

		different layers (e.g., GEO, MEO, and/or LEO at different altitudes).
STR-FUNC-13 Deployment flexibility and scalability, Coverage, Orchestration	P06	The 6G NTN system shall support to utilize the inter-connection among different NTN entities for different/various network tasks, such as for coordination, configuration, computation distribution, data collection, and mobility support.
STR-FUNC-14 Coverage, dependability	P15	The 6G NTN system shall support advanced connectivity technology, such as carrier aggregation, dual connectivity, multi-Transmission and Reception Points (multi-TRP), and/or cell-free operation, for the purpose of performance improvement, e.g., capacity boost, seamless and lossless mobility.
STR-FUNC-15 Service versatility	P16	The 6G NTN system shall enable a tight integration, inter-connection, and/or inter-action between the air-space control center and the network coordination-and-configuration entity.
STR-FUNC-16 Service versatility	P16	The 6G NTN system shall support joint control and communication, e.g., by leveraging the integrated, inter-connected, and/or inter-acted air-space control center.
STR-FUNC-17 Service versatility	P05	The 6G NTN system shall support an NTN entity as both a network node and a UE at the same time.
STR-FUNC-18 Service versatility, Coverage, Dependability	P0[7]	The 6G NTN system shall support a TN cell and an NTN cell, which operate on the same or adjacent frequency band, with at least partially overlapping coverage area.
STR-FUNC-19 Service versatility, Coverage, Deployment flexibility and scalability	P07	The 6G NTN system shall support two NTN cells, which operate on the same or adjacent frequency band and are served by two NTN entities at the same or different segments/layers, with at least partially overlapping coverage area.
STR-FUNC-20 Deployment flexibility and scalability, Cloud-based infrastructure	P16	The 6G NTN system shall support to deploy edge computing at an NTN entity, e.g., a LEO/MEO/GEO satellite, a HAPs, and/or a drone.

[7] The priority can be subject to change, e.g., w.r.t. the technical investigation and development in WP3, WP4

STR-FUNC-21 Service versatility, Cloud-based infrastructure, RAN disaggregation	P0[8]	The 6G NTN system shall be able to deploy radio intelligent controllers in both space and ground segments. Controllers could be located in different geographical areas.
STR-FUNC-22 Deployment flexibility and scalability, Orchestration	P08	The 6G NTN system shall be able to reconfigure the available resources of the 3D multilayered network according to time-variant and heterogenous traffic demands.
STR-FUNC-23 Service versatility, Coverage, Dependability	P0[9]	The 6G NTN system shall support a versatile physical layer efficiently of facing the channel impairments of TN and NTN links (whichever the orbit used) in both C and Q/V bands.
STR-FUNC-24 Network positioning and sensing, Security & privacy	P0[10]	The 6G NTN system shall grant access to the network when the GNSS service is not available.
STR-FUNC-25 Device diversity (high-mobility UE), service versatility	P1[8]	The 6G NTN system shall support high-speed mobile UEs in all its regular operations, including the case of NTN-NTN or NTN-TN inter-system mobility.
STR-FUNC-26 Device diversity (high-mobility UE), network positioning and sensing	P1[8]	The 6G NTN system shall support precision positioning with an adequate accuracy level[11], even when serving high-mobility UEs.
STR-FUNC-27 Service availability, Device diversity (high-mobility UE)	P1[8]	The 6G NTN system shall operate nominally even when UEs experience rapid changes in radio propagation

[8] The priority can be subject to change, e.g., w.r.t. the technical investigation and development in WP3, WP4, and WP5

[9] The priority can be subject to change, e.g., w.r.t. the technical investigation and development in WP4, WP5

[10] The priority can be subject to change, e.g., w.r.t. the technical investigation and development in WP5, held in both tasks T5.1 and T5.3.

[11] At large, the mentioned accuracy level may stem from a few centimetres to a few metres and depends on the considered use cases. Paragraph 4.3.2, which deals with vehicular/automotive use cases consistent with D2.1 UC6, gives reference values for 5G NTN in that context. Moreover, the mentioned accuracy level shall be considered in the three dimensions (i.e., also in altitude, to support drone precision positioning.)

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		conditions, e.g., when transitioning from clear-sky to obstructed conditions.
STR-FUNC-28 Deployment flexibility and scalability, Device diversity	P1[8]	The 6G NTN system shall fairly serve UEs, even in case of non-uniform user geographic distribution.
STR-FUNC-29 Network positioning and sensing	P0	The 6G NTN system shall provide accurate and reliable location of UE that can serve as alternative to using GNSS.
STR-FUNC-30 Network positioning and sensing	P0	The 6G NTN system shall provide an accurate positioning for Public Warning System (PWS) services.
STR-FUNC-31 Network positioning and sensing, security & privacy	P0	The 6G –NTN system shall provide a service positioning for Lawful Interception (LI).
STR-FUNC-32 Network positioning and sensing	P0	The 6G-NTN system shall reliably know the location information of UE for charging and billing call services.
STR-FUNC-33 Network positioning and sensing, security & privacy	P0	The 6G-NTN system shall reliably know the location information of UE for data retention policy in cross-border scenario and international regions.
STR-FUNC-34 Energy efficiency	P1	The 6G-NTN system shall be able to account for battery constrained UE, such as drone mounted UE.
STR-FUNC-35 Service versatility	P1	The 6G NTN system shall support transitions between NTN and private TN.
STR-FUNC-36 Network monitoring	P1	The 6G NTN system shall support the monitoring of network and expose KPIs, whatever the TN or NTN connectivity, to inform the UE about potential degradation (in real-time and / or in prediction).
STR-FUNC-37 Cloud-based infrastructure	P1	The 6G NTN system shall support flexible offloading of data processing, depending on the UE capabilities, on an on-demand basis.
STR-FUNC-38 Security & privacy (encryption)	P1[9]	The network must support end-to-end encryption of data transmitted over the NTN network.
STR-FUNC-39 Security & privacy (authentication and authorization)	P1[9]	Robust user authentication and authorization mechanisms must be implemented to ensure that only authorized users and devices can access the network.

STR-FUNC-40 Security & privacy (key management)	P1[9]	The network must have secure key management systems in place to generate, distribute, and update encryption keys.
STR-FUNC-41 Security & privacy (network segmentation)	P1[9]	The network should be logically segmented to isolate critical infrastructure and data from less secure areas to prevent unauthorized access.
STR-FUNC-42 Security & privacy (secure communications)	P1[9]	The network must employ secure protocols and technologies for communication between ground stations and satellites.
STR-FUNC-43 Security & privacy (incident response)	P1[9]	An incident response plan must be established to respond promptly to security breaches and disruptions.

Therefore, the list of general functional requirements, as given in Table 5, form a set of core features that the 6G NTN system, depending on the considered use case, shall need to support. As an illustration, regarding service versatility, requirement STR-FUNC-03 is related to lossless and seamless mobility between TN and NTN and is expected to be needed in all kinds of use cases. It is completed by STR-FUNC-25 by explicitly mentioning that such features should also apply when the system serves high-mobility devices. In this light, the support of the use cases studied in deliverable D2.1 can be partially met by a combination of those general functional requirements. However, depending on the type of use case, additional functional requirements may be needed. In the following subsections, we show how specific use cases (vehicular/automotive as in D2.1 UC6, drone-based as in D2.1 UC2 and UC3, direct-UE-to-satellite-to-UE as in D2.1 UC7) need (or do not need) the expression of additional functional requirements.

4.2.2 Requirements for uses cases with high-mobility UEs

Generally speaking, vehicular/automotive use cases as described in D2.1 UC6 require most functional requirements expressed in Table 5. In effect, STR-FUNC-01 to STR-FUNC-37 will be generally needed to support the core 6G NTN system features, while more specifically, STR-FUNC-25 to STR-FUNC-28 are useful to specify how this same need to support and serve, in the context of these use cases, UEs with high-mobility patterns. Those four specific requirements are useful to ensure that the needs expressed in the user requirements D2.2 deliverable are met by the 6G NTN system, notably regarding D2.2 §3.8, “Mobility Operational Scenarios”: “*There are common mobility/network transition scenarios, that regardless of the UE type, must meet a certain level of end-user requirements, i.e., not leading to a noticeable interruption or unacceptable service degradation*.”

Furthermore, it is worth noting that no additional requirement solely specific to vehicular use case has been identified, since the aforementioned requirement may also apply to any use case with high-mobility UEs (e.g., aviation, maritime and railways. This notably explains why STR-FUNC-25 to STR-FUNC-28 were kept in the list of general functional requirements due to their multi-purpose nature.)

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4.2.3 Requirements for direct UE-to-satellite-to-UE use cases

In contrast, use case UC7 from D2.1 requires specific mechanisms from the 6G-NTN system, which go beyond what current 5G NTN solutions can deliver. Table 6 therefore summarizes which specific additional functions are needed from the 6G NTN system to support this type of direct UE-to-satellite-to-UE use cases, in which the 6G NTN system needs to operate as nominally as possible, despite the feeder link(s) being unavailable, at least temporarily.

TABLE 6: LIST OF FUNCTIONAL REQUIREMENTS FOR D2.1 UC7

Unique Identifier Domain	**Priority**[2]	**Requirement Description**
STR-FUNC-44 Direct UE-satellite-UE	P1[5]	The 6G NTN system shall be able to inform a UE that a direct communication over satellite(s) without an available feeder link is supported.
STR-FUNC-45 Direct UE-satellite-UE	P1[5]	The 6G NTN system shall be able to authenticate and authorize a UE and an application in the UE to use satellite communication when there is no available feeder link.
STR-FUNC-46 Direct UE-satellite-UE	P1[5]	The 6G NTN system shall be able to assist and control a UE to detect a peer UE is reachable with satellite communication when there is no available feeder link.
STR-FUNC-47 Direct UE-satellite-UE	P1[5]	The 6G NTN system shall be able to set up a satellite communication between two UEs, when there is no available feeder link.
STR-FUNC-48 Direct UE-satellite-UE	P1[5]	For QoS control, the 6G NTN system shall be able to control and configure a satellite communication between two UEs when there is no available feeder link.
STR-FUNC-49 Direct UE-satellite-UE	P1[5]	The 6G NTN system shall be able to support a satellite communication between two UEs served by the same satellite, when there is no available feeder link for the satellite.
STR-FUNC-50 Direct UE-satellite-UE	P1[5]	The 6G NTN system shall be able to support a satellite communication between two UEs served by the different satellites that are connected via ISL, when there is no available feeder link for both the satellites.
STR-FUNC-51 Direct UE-satellite-UE	P1[5]	If a UE changes from the coverage of one satellite to another (due to the movement of the UE and/or the satellites), the 6G NTN system shall support an end-to-end communication path switch when there is no available feeder link.

STR-FUNC-52 Direct UE-satellite-UE	P1[5]	If a UE changes from the coverage of one satellite to another (due to the movement of the UE and/or the satellites), the 6G NTN system shall maintain service continuity with minimum service interruption of the satellite communication when there is no available feeder link.
STR-FUNC-53 Direct UE-satellite-UE, Energy efficiency	P15	The impact of a communication in the 6G NTN system without an available feeder link on radio resource usage, satellite usage and UE power consumption should be minimized.
STR-FUNC-54 Direct UE-satellite-UE, Connection density	P15	The 6G NTN system shall take into account a potentially large number of concurrently communicating UEs, when there is no available feeder link.

4.3 PERFORMANCE REQUIREMENTS

This section gives a summary of the requirements identified to enable the performance assessment of the 6G-NTN project. Those requirements are expressed in two ways:

- The general performance requirements, which may systematically apply to the system (or in more specific conditions explicitly described along with the requirement), are given in section 4.3.1 as a list of requirements, each with a unique name identifier.
- In complement, since one of the primary purposes of this deliverable D2.3 is to support Objective 1 of the 6G-NTN project (as described in the Project's Description of Work), and more precisely to outline two reference traffic scenarios for the dimensioning of the system, the subsequent sections 4.3.3 and 4.3.4 define two specific User Traffic Profiles (UTPs, as previously mentioned in Section 3.3), along with associated performance requirements. The intention with this set of UTPs was to define illustrative, yet sufficiently comprehensive Traffic Profiles, that can reasonably support the performance assessment of the 6G-NTN system in a large range of conditions, with both main target UEs defined by the Project (i.e., the handheld UE and the Mounted UE, as defined in section 2.4.1).

4.3.1 General Requirements

Table 7 gives a list of the general performance requirements of the project. This list is structured into the following functional domains:

- **Integrated Intelligence** - Integrated Intelligence Components are of crucial importance in the decision making of Resource Management and for predicting network's behaviour. STR-PERF-01 to STR-PERF-04 support the assessment of Integrated Intelligence features in the 6G-NTN system.
- **Network positioning and sensing** are described in STR-PERF-05 and STR-PERF-05.

TABLE 7: LIST OF GENERAL PERFORMANCE REQUIREMENTS

Unique Identifier Domain	**Priority**[2]	**Requirement Description**
STR-PERF-01 Integrated Intelligence	P0	The 6G-NTN system shall be able to keep Integrated Intelligence training times below a few minutes.
STR-PERF-02 Integrated Intelligence	P0	The 6G-NTN system shall be able to keep Integrated Intelligence model re-training periods larger than one day.
STR-PERF-03 Integrated Intelligence	P0	The 6G-NTN system shall be able to keep Integrated Intelligence inference times below a second and in the order of milliseconds.
STR-PERF-04 Integrated Intelligence	P1	The 6G-NTN system shall be able to provide models with precision > 80%.
STR-PERF-05 Network positioning and sensing	P1[10]	The 6G-NTN system shall be capable of providing a positioning accuracy such as sub meter-level, ±1 [m] and decimeter-level, ±10 [cm], with latencies as low as 0.5 ms, according to the demands of the application.
STR-PERF-06 Security & privacy (incident response time)	P1[9]	A common benchmark for incident response time is to aim for a mean time to respond of under one hour for high-priority incidents.

- **Security & privacy** is described in STR-PERF-06 through a requirement regarding **incident response time**. Beyond that requirement, it is worth highlighting that other performance requirements, which cannot be valued yet, at the time of publishing this deliverable, should complete STR-PERF-06. These additions, which should later be identified within work package WP5, should encompass:
    - **Firewall Rule Violations**: for that requirement, it is worth noting that the reasonable target value for Firewall Rule Violations can vary significantly depending on the specific network, its size, complexity, and its security policies. KPI values should be established based on the project's risk tolerance, the criticality of the network, and the effectiveness of security controls in place.
    - **Network Anomaly Detection**: A reasonable KPI value for Network Anomaly Detection might include a target false positive rate. The true positive rate is also important. A higher detection rate indicates that the system effectively identifies actual anomalies or security threats.
    - **User Authentication Failures**: A common approach is to target zero or close to zero authentication failures as a KPI for user authentication. This, like the two other new potential requirements, will be defined in the next period of the 6G-NTN project activity, within work package WP5.

4.3.2 Requirements for uses cases with high-mobility UEs

This paragraph builds on the general performance requirements described in previous Section 4.2.1, by providing example context in which, in particular, requirement STR-PERF-05 may apply. Similarly to what was described in Section 4.2.2 for the functional requirements, the following list was initially formulated with the example of vehicular/automotive use cases as described in D2.1 UC6 in mind. But it is well worth noting that requirement STR-PERF-05 may also apply in other cases involving the use of high-mobility UEs, such as in contexts of aviation, maritime and railways.

On this basis, the following applicative contexts regarding the specific performance requirement STR-PERF-05 can be given:

- Regarding sub meter-level positioning accuracy, a corresponding requirement is formulated by the 5G Automotive Association (5GAA) in [18]. It can be noted that in this reference document, the considered positioning precision value is mainly required for vehicular use cases that include route navigation, traffic jam warning, general left turn assist and the ability to perform lane-accurate positioning.

- Regarding decimeter-level positioning accuracy, it is worth mentioning that in the context of vehicular use cases, [18] gives the exemplary requirement of 0.5 m positioning accuracy associated to collision risk warning services in vehicular deployment cases, while [19] expresses a more stringent positioning precision in its stories 1/1a.

4.3.3 Requirements for Handheld UE

The following performance requirement STR-PERF-07 allows defining a general performance target for consumer handheld UEs.

TABLE 8: UTP1-BASED PERFORMANCE REQUIREMENT FOR HANDHELD UE

Unique Identifier Domain	**Priority**[2]	**Requirement Description**
STR-PERF-07 Data rates and network capacity	P0	The 6G-NTN system SHALL be able to serve consumer handheld UE with the performance specified in Table 9 via User Traffic Profile UTP1.

This requirement is supported by the values set for User Traffic Profile UTP1, in Table 9. UTP1 gives the performance targets for two types of radio conditions. In the general case, handheld UEs are located outdoors and the subsequent performance targets in line 'UTP1 target' of Table 9 applies.

TABLE 9: USER TRAFFIC PROFILE UTP1 FOR CONSUMER HANDHELD UE

User Traffic Pattern	Experienced User Data Rate		Activity Factor		Busy Hour Usage Rate		Latency	Mean User Density
	DL	UL	DL	UL	DL	UL		
	Mbps		%		Kbps		ms	user/km^2
UTP1 target	20	2	0.5	0.01	100	0.2	< 30	0.3
UTP1 light indoor	0.01	0.01			0.05	0.001		

In addition, handheld UEs may be served in light-indoor radio conditions, which is a case also addressed by the 6G-NTN system, albeit with specific performance targets. Line 'UTP1 light indoor' therefore values the corresponding performance KPIs and relevant parameters. In such conditions, the performance target evolve as follows, compared to the general outdoor case:

- Light indoor conditions are expected to be particularly challenging regarding Experienced User Data Rates, which explains the significantly lower downlink and uplinks targets in Table 8, compared to those from outdoor conditions.

In the next two subsections 4.3.3.1 and 4.3.3.2, we describe how the target performance values set in Table 8 apply to a large range of use cases related to the Handheld UE category.

With respect to the user distribution, and as detailed in Section 3.1.5.1 "Mean User Density", UTP1 could be further specified for different space & time scales:

- **For analyses related to a single UE only** (e.g., Beam tracking, Impact of Doppler effect, Antenna design and integration on the UE, etc.), there is a priori no need to account for a detailed user distribution pattern, excepting maybe for interference scenario, in which case an aggregated view of other users is sufficient (that is, the actual mean user density). However, in this case, an accurate modelling of the user mobility pattern is essential. For light indoors, the mobility pattern is expected to be quite limited, but for outdoors at up to 20km/h, different patterns could be considered depending on the use case, such as almost linear trajectories, random walk model, etc.

- **For small-scale analyses** (e.g., small cell footprints, as for LEO satellites), the user distribution for UTP1 could be considered as uniform and modeled, for example, by a Poisson Point Process with the provided mean User Density. Given the high velocity of LEO satellites relative to considers users for UTP1, the UE mobility pattern should have minimal effects on expected results, and users could be considered as static within the cell.

- **For large-scale analyses** (e.g., large satellite footprints, dimensioning of multiple LEO satellites, etc.), the user distribution can be hardly considered as uniform and more accurate characterization is required, depending on the use case. It could be modeled, for example, thanks to a Poisson Cluster Process or a Matern Cluster Process [21].

4.3.3.1 Service ubiquity for Handheld UE

As previously introduced in Section 2.4, service ubiquity generally refers to scenarios taking benefit of the ability of NTN to complement TN coverage. In effect, TN coverage can be geographically limited in its deployment, for technical or economic reasons, or which can be subject to a localized and temporary outage. This service category therefore encompasses deployment scenarios such as cellular coverage extension or temporary coverage in a context of planned event or post-disaster coverage, for which the performance target values set in Table 8 are relevant. As such, parts of use cases UC4 (Adaptation to PPDR or temporary events) and UC7 (Direct communications over satellites) defined in deliverable D2.1 relate to this category.

4.3.3.2 Service continuity for Handheld UE

As explained in Section 2.4, service continuity refers to scenarios for which users may experience conditions where a continuous connectivity cannot be offered by a single TN or a combination of TN during the journey of the UE. Therefore, transitioning between TN and NTN, and vice-versa, is a prominent feature of this service category of scenarios. This service category encompasses various deployment scenarios that revolve around an end-user journey out of his regular TN coverage, during which the transitioning between TN and NTN coverage, and more generally the continued user Quality of Experience (QoE), both need to be optimal. In that regard, parts of deliverable D2.1 use cases UC1 (Maritime coverage for search and rescue coast guard intervention) and UC5 (Consumer Handheld connectivity and positioning in remote areas) both apply to this service category. In the context of service continuity, the User Traffic Profile UTP1 from Table 8 also applies to the category of services for Handheld UE. In this context, the considered target values can be commented as follows:

- In terms of general case, the analysis carried out withing 6G-NTN task T2.3, which led to this deliverable D2.3, concluded that, deployment scenarios set aside, the performance target values themselves are essentially similar to those of service continuity for that type of UE. Performance requirement STR-PERF-07 and related UTP1 given in Table 8 therefore also apply.
- When considering the more specific case of a trekker service continuity in relation with D2.1 UC5, data rate requirements and user distributions are respectively driven by the trekker service needs and mobility patterns. This is a specific deployment environment, for which some KPIs (Experienced User Data Rates) and parameters (Activity Factor) would need to be further adapted:
    - The **Experienced User Data Rates values** may significantly differ from those of the general case given in UTP1. In the context of use case UC5 from D2.1, the service requirements differ from general cases, with more data rate needed on the UL than on the DL due to asymmetric applicative needs.
    - It is also observed that for use case UC5, the **Activity Factor** parameter values for the DL and the UL may be significantly higher than those given in the general case of UTP1, also because of applicative needs.

4.3.4 Requirements for Mounted UE

Similarly, the following performance requirement STR-PERF-08 allows defining a general performance target for Mounted UEs.

TABLE 10: UTP2-BASED PERFORMANCE REQUIREMENT FOR MOUNTED UE

Unique Identifier Domain	**Priority**	**Requirement Description**
STR-PERF-08 Data rates and network capacity	P0	The 6G-NTN system SHALL be able to serve USAT UE with the performance specified in Table 10 via User Traffic Profile UTP2.

This requirement is also supported by the values set for User Traffic Profile UTP2, in Table 11. UTP2 gives general performance targets for typical services addressing Mounted UEs.

TABLE 11: USER TRAFFIC PROFILE UTP2 FOR MOUNTED UE

User Traffic Pattern	Experienced user Data Rate		Activity Factor		Busy Hour Usage Rate		Latency	Mean User Density
	DL	UL	DL	UL	DL	UL		
	Mbps		%		Mbps		ms	user/km^2
UTP2 target	250	125	2.0	2.0	5	2.5	< 30	0.38

It is worth noting that for UTP2, it is assumed that the Mounted UEs are located outdoors.

Furthermore, the following subsections 4.3.4.1 and 4.3.4.2 give an overview of the applicability of UTP2 to assess the performance of the 6G-NTN system in the context of multiple types of service categories (including service ubiquity and service continuity).

With respect to the user distribution, and as detailed in Section 3.1.5.1 “Mean User Density”, UTP2 could be further specified for different space & time scales:

- **For analyses related to a single UE only**, and for UTP1, there is a priori no need to account for a detailed user distribution pattern, excepting maybe for interference scenario, in which case an aggregated view of other users is sufficient (that is, the actual mean user density). But an accurate modelling of the user mobility pattern is essential and should include rotational degrees of freedom. In particular for ships and drones, the yaw, roll, pitch can vary a lot and impact the perceived satellite elevation for this UE and the link budget.

- **For small-scale and large-scale analyses**, the user distribution for UTP2 should be tailored to the use case. For example, it could be linear trajectories for ships or drones.

4.3.4.1 Broadband service ubiquity for Mounted UE

Service ubiquity for broadband Mounted UE includes deployment scenarios such as delivering permanent direct-to-home connectivity or serving nomadic users such as the Mounted UEs of PPDR teams in a post-disaster context (e.g., to establish temporary headquarters on a site of operations). Therefore, parts of user flows from UC4 (Adaptation to PPDR or temporary events) and UC7 (Direct communications over satellites) from deliverable D2.1 also apply to this service category. In this regard, performance requirement STR-PERF-08 and User Traffic Profile UTP2 are relevant to assess the general performance of the 6G-NTN connectivity to this type of UEs.

4.3.4.2 Broadband service continuity for Mounted UE

At large, User Traffic Profile UTP2 is less relevant to this service category, in which we may generally assume that UEs exhibit non-static speeds in the context of service continuity scenarios. As described in deliverable D2.1, such use cases include UC2 (Autonomous power line inspection using drones), UC3 (Urban air mobility) as well as UC6 (Continuous Bi-directional Data Streams in High Mobility). Should the need to assess the performance of the 6G-NTN system in those contexts also arise, UTP2 could be adapted accordingly. The considered adaptation would notably target DL and UL Experienced User Data Rate KPIs, which should be revised (and often lowered to a more realistic value) to be adapted to the considered scenario in which Mounted UEs exhibit non-static speeds. Likewise, related parameters such as the DL and UL Activity factors should then be refined to account more accurately for the behavior of the Mounted UEs in those specific scenarios. Finally, fine-tuning UE behavioral parameters such as User Density, User Distribution and UE maximum speed would allow the considered performance assessment to be more relevant.

4.4 SUSTAINABILITY REQUIREMENTS

In this last part of Section 4, we now express the main sustainability requirements of the project. Those requirements are directly derived from the description of the United Nation's SDG 17 framework which was given in Subsection 3.2, together with a breakdown of the most relevant Key Value areas for the 6G-NTN system.

Those requirements are expressed in Table 12, together with a reference to the corresponding Key Value area(s) that were detailed in Subsection 3.2. These backlinks are useful when the requirements refer to regulatory, normative or development initiatives and framework since the general context and references (when applicable) were given in those subsections.

TABLE 12: LIST OF GENERAL SUSTAINABILITY REQUIREMENTS

Unique Identifier Domain (subdomain)	**Priority**[2]	**Requirement Description**
STR-SUST-01 Trustworthiness (dependability, resilience)	P0	The 6G-NTN system shall be designed to offer a high level of dependability by supporting highly reliable communication and location services.
STR-SUST-02 Trustworthiness (privacy)	P0	The 6G-NTN system shall preserve the privacy of sensitive end-user data (e.g., location information, network monitoring data). To that end, all NTN-related privacy requirements stated for 3GPP Rel.17 onwards shall be

		considered for the design of the privacy features of the 6G-NTN system[12].
STR-SUST-03 Inclusion (fairness)	P0	The 6G-NTN system shall be designed to enable access to the same set of services for all the population, irrespective of their home geographic location, in a fair and transparent way.
STR-SUST-04 Inclusion (affordability)	P0	The 6G-NTN system designed shall rely on an economic viability analysis seeking to identify a pricing point able to support an affordable, high speed and low latency network connectivity, even in in low-density populated areas.
STR-SUST-05 Energy consumption	P0	The 6G-NTN system shall be at least as efficient as reference 6G TN regarding energy consumption indicators. To that end, the design of the 6G-NTN system design shall take into account a large range of advanced power saving features in all operation modes. In particular, when designing the air interface and the compact terminals, the project will leverage the advances of 3GPP technologies in this area, apply and optimize it in the context of NTN for 6G.
STR-SUST-06 Circular economy Eco-design	P1[13]	The 6G-NTN system shall refer and when applicable adhere to the developing space-based circular economy frameworks and initiatives, such as the European Space Agency's 'Space for a Green Future Accelerator' [16].
STR-SUST-07 Health	P0	The 6G-NTN system shall be able to assess and minimize its impact regarding EMF exposure.
STR-SUST-08 Health	P0	The 6G-NTN system shall follow the existing international and national 6G EMF-awareness guidelines (e.g., those of ICNIRP [12] [13]).

[12] An example of NTN-related privacy requirement was stated by 3GPP SA3 (Security) and SA3-Li (Lawful intercept) experts in their liaison statements to 3GPP RAN Work groups as part of the Rel-17 Work Item "Solutions for NR to support non-terrestrial networks (NTN)" [15]. The subsequent requirement statements in further Rel.18 onwards shall also be analysed and considered.

[13] The priority of this requirement, which refers to growing but at the date of finalizing this deliverable, largely undeveloped frameworks, may be subject to change, e.g. w.r.t. the normative investigation carried out in WP6 during the second period of the 6G-NTN project lifetime.

5 CONCLUSION

Deliverable D2.3 performed the 6G-NTN system requirements identification. With the adequate Key Performance Indicators, Key Value Indicators and User Traffic Profiles, and leveraging the outcomes of previous deliverables D2.1 and D2.2, this deliverable gave a description of the Project's requirements, broken down into service, functional, performance and sustainability categories. In addition, the priority of each requirement was analyzed and expressed, which was a useful exercise to understand the confidence level associated with each given priority at the time of finalizing this deliverable, and in which work package(s) of the Project these priorities should be further refined, and more generally how the requirements expressed into this deliverable shall support the technical activities in the next period of the Project lifecycle, in particular in work packages WP3, WP4, and WP5.

Moreover, a continuous attention was given to the expression (and when applicable, valuation) of those requirements, to ensure that the supported technical tasks will be able to rely on ambitious, yet realistic target values and more generally, inputs for the subsequent dimensioning, design, and optimization activities of the 6G-NTN Project.

To conclude, this deliverable has presented a list of requirements to enable the necessary open thinking process, that will in turn support the system design activities held in the other tasks of the 6G-NTN project. Deliverable D2.3 is intended to be exhaustive, addressing all the improvement and new targeted points defined in the Project proposal objectives. However, being published in the context of a research framework, all mentioned KPIs, KVIs and requirements should be seen as a supporting basis for the work of the subsequent work packages activities, instead of a rigid (and possibly blocking) set of objectives and target values. In that regard, this deliverable has carefully highlighted, where applicable, that specific requirements (e.g., regarding network positioning, energy consumption, integrated intelligence, security, and privacy, and more generally related to the 6G-NTN system dimensioning) shall be further analyzed within the relevant tasks from work packages 3, 4 and 5, during the next planned stages of the Project.

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