6GNTN

D6.3 STANDARDISATION, EXPLOITATION AND SUSTAINABILITY STRATEGY AND PLAN

Intermediate Version

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Abstract	This document highlights the standardisation activities carried out with the support of the 6G-NTN project. It introduces a preliminary development and deployment plan for the system and considerations for the exploitation plan. Last Sustainability aspects of 6G-NTN are addressed covering the environmental footprint and handprint of 6G-NTN based systems.
Keywords	Standardisation, Exploitation, Sustainability

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V1.0	08/08/2024	Approval and submission	Alessandro Vanelli-Coralli (UniBo)

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* R: Document, report (excluding the periodic and final reports)
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EXECUTIVE SUMMARY

This document highlights the standardisation activities carried out with the support of the 6G-NTN project. Given that the standardisation of 6G (study and normative phase) have not yet started in 3GPP, it relates to pre standardisation effort. The work plan at 3GPP of the project is also provided.

A development and deployment plan for 6G-NTN based satellite networks has been initiated assuming that 5G-NTN based Space segment could be refurbished to roll out some initial 6G-NTN satellite network.

Sustainability aspects are also being addressed covering the environmental footprint and handprint of 6G-NTN based systems

In terms of footprint, one should distinguish between the

The intrinsic footprint of the NTN component in 6G with the following aspects to be considered: energy efficiency, EMF exposure, Hazard and scarce material consumption, Waste potential handling, and the migration between 5G-NTN and 6G-NTN,

The potential contribution of NTN component to the footprint of 6G thanks to smart off-loading of signaling and traffic between terrestrial and non-terrestrial networks and enablers for optimum spectrum usage between TN and NTN,

The handprint of NTN component in 6G, includes impact on society with a focus on Impact on digital divide and Impact on transportation sector (i.e. aeronautical, maritime, railway, land vehicle).

This will enable to set some sustainable friendly design principles

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ABBREVIATIONS

3GPP	3rd Generation Partnership Project
6G IA	6G Industrial Association
AI	Artificial Intelligence
APS	Articles, Preparations, or Substances
BFN	Beam Forming Network
CENELEC	Comité européen de normalisation en électronique et en électrotechnique
EIRP	Effective Isotropic Radiated Power
EMF	Electric and magnetic fields
ETSI	European Telecommunication Standards Institute
EU	European Union
DVB	Digital Video Broadcasting
FPA	Flat Panel Antenna
FR	Frequency Range
GEO	Geostationary Earth Orbit
GNSS	Global Navigation Satellite System
GSO	Geo Synchronous Orbit
HAPS	High Altitude Platform System
IEC	International Electrotechnical Commission
IETF	Internet Engineering Task Force
IMT	International Mobile Telecommunications
ISL	Inter Satellite Link
KPI	Key Performance Indicator
KVI	Key Value Indicator
LCA	Life Cycle Assessment
LEO	Low Earth Orbit
LNA	Low Noise Amplifier

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MEO	Medium Earth Orbit
MNO	Mobile Network Operators
NGSO	Non Geo Synchronous Orbit
NTN	Non-Terrestrial Networks
QoS	Quality of Service
RAN	Radio Access Network
RRM	Radio Resource Management
RSPG	Radio Spectrum Policy Group
SAR	Specific Absorption Rate
SDO	Standardization Organizations
SME	Small Medium Enterprise
SNO	Satellite Network Operators
SSB	Synchronization Signal Blocks
SNS-JU	Smart Networks and Services – Joint Undertaking
SSIG	Satellite Standardization Interest Group
TN	Terrestrial Networks
TR	Technical report
UE	User Equipment
UAV	Uncrewed Aerial Vehicles
UxV	Any Uncrewed Vehicles
VLEO	Very Low Earth Orbit
VSAT	Very Small Aperture Terminal
WP	Work Package

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1 INTRODUCTION

This deliverable presents the standardisation, exploitation, and sustainability strategy and plan as well as reporting on the activities pursued in the first reporting period and indicating the plan for the second part of the project. It has been led by Task 6.4, with inputs from Task 6.3.

2 STANDARDISATION

2.1 RECALL OF THE PROJECT'S STANDARDISATION TASK AND OBJECTIVES

This task focuses on planning and implementing the 6G-NTN standardization actions, which aim to provide contributions to the relevant SDOs and pre-standardization interest groups, in close collaboration with the 6G-IA pre-standardization group. In particular, this task will:

Promote a new study item on NTN for 6G to be carried out as part of Rel-20 with emphasis on techniques addressed in this project, especially to define the Q/V band as NTN band (Tx/Rx RF performance of UE and satellite access node, RRM requirements), the radio protocol, the support of regenerative payload scenarios, the high accuracy and reliable positioning method, the spectrum sharing enablers (NTN/NTN and NTN/TN co-existence analysis), monitoring/control enablers for AI driven RAN.

Coordinate with the SSIG - Satellite Standardisation Interest Group, https://artes.esa.int/projects/alix active since early 2018 and gathering more than 50 satellite industry stakeholders - to collect the initial support and then promote to the rest of the 3GPP eco-system the relevant project's outcomes. Notice that most SSIG members have already supported the preliminary NTN roadmap in 3GPP prepared by TASF including NTN enhancements for Rel-18 and beyond.

Identify the 3GPP technical specifications (*e.g.,* related to 3GPP RAN WG1, WG2, WG3, WG4) that needs to be adapted to support the proposed techniques.

Prepare/promote technical contributions to demonstrate the feasibility of the researched features such as new waveform design principles, enablers for AI driven radio interface and radio resource management, zero interruption TN-NTN mobility scheme, spectrum sharing for satellite access network as part of a 3GPP release 20 study item.

Coordinate with relevant stakeholders from mobile, satellite and verticals industries having interest in NTN standardization in 3GPP.

Contribution to ETSI for the development on a harmonized standard for ultra-small aperture terminals operating in Q/V band

Prepare contributions in view of the possible development plan for the IMT-2030 satellite component's vision, the Performance requirements, the Evaluation criteria & method and a Submission template."

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2.2 ACHIEVEMENTS

2.2.1 EUROPEAN COMMISSION

2.2.1.1 RADIO SPECTRUM POLICY GROUP (RSPG): DIRECTORATE-GENERAL FOR COMMUNICATIONS NETWORKS, CONTENT AND TECHNOLOGY

In response to the RADIO SPECTRUM POLICY GROUP Opinion on « 5G developments and possible implications for 6G spectrum needs and guidance on the rollout of future wireless broadband networks », referenced European Commission's Brussels, 25 October 2023, RSPG23-040 FINAL, the 6G-NTN consortium prepared a joint response which can be found in the annex of this deliverable.

2.2.2 European Telecommunication Standards Institute (ETSI)

2.2.2.1 ETSI conference on Non-Terrestrial Networks, a native component of 6G, 3-4th April 2024 in Sophia Antipolis/France

Alessandro Vanelli-Coralli and Nicolas Chuberre have been instrumental in the organisation of the above mentioned conference which details are available at https://www.etsi.org/events/2306-etsi-ntn-conference

They contacted ETSI representatives and proposed this conference project in October 2023. Once the conference was endorsed by ETSI management, both have been appointed as members of the Program Committee and as key-note speakers:

- Nicolas Chuberre, ETSI TC SES Vice-Chair and 6G-NTN Technical Manager, Thales Alenia Space
- Alessandro Vanelli-Coralli, 6G-NTN Project Coordinator, University of Bologna

This conference has gathered 204 participants, face to face, from worldwide and was the first of its kind to allow exchange of ideas on Non-Terrestrial Networks in the context of 6G.

It has been an opportunity, for the 6G-NTN project (via its coordinator) to present its views on NTN in the context of 6G. See:

https://docbox.etsi.org/Workshop/2024/04_ETSI_6G_NTN/SESSION%2005/S5_02_VanelliCoralli.pdf

Beyond, research and innovations aspects, plans for standardisation have been discussed in both 3GPP and ETSI context.

During the conference, a white paper has been published "Vision on Non-Terrestrial Networks in 6G system (or IMT-2030), Use Cases, Requirements, and Possible Standardisation approach: A Perspective from the 6G-NTN Project" co sourced by 6G-NTN participants (Thales Alenia Space France, Ericsson Sweden and Ericsson France, Qualcomm France, SES Techcom, Thales – SIX, Telit Cinterion, GreenerWave, Martel Innovate, Digital for Planet, CTTC, German Aerospace Center – DLR, Alma Mater Studiorum – University of Bologna) See paper at

https://www.etsi.org/images/Events/2024/NTN_CONFERENCE/6G_NTN_White_Paper_Vision-on-NTN-in-6G_r01_v04.pdf

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2.2.2.2 ETSI Webinar, Essential Discussions about Non-Terrestrial Networks, for 6G, 16 May 2024

Following the ETSI conference previously described, a webinar was organised : https://www.etsi.org/events/2399-webinar-non-terrestrial-networks-for-6g

As part of the webinar, a panel discussion took place moderated by David BOSWARTHICK (Director New Technologies, ETSI) with the following participants

- Javier ALBARES BUENO, Head of 5G/6G Program, Smart Network and Services Joint Undertaking
- Maria Guta, Senior 5G 6G SatCom Solutions Architect in the European Space Agency (ESA)
- Alessandro Vanelli Coralli, 6G-NTN Project Coordinator
- Nicolas CHUBERRE, 3GPP NTN Rapporteur, Thales

This live webinar was viewed by 323 persons (Live and On-demand viewers). Around 22 questions were raised from the audience.

- 225 viewed the webinar live
- 98 viewed the webinar on-demand until 23/05/2024
- Total number of Pre-registrations: 476
- There has been 129 downloads of the attachments:
- 96 clicks to access the web page of the recent ETSI Conference on “Non-Terrestrial Networks, a Native Component of 6G
- 33 downloads of the webinar slides (PDF format)

According to ETSI (i.e. Mr David Boswarthick)the attendance to the webinar demonstrates a very successful event and largely comparable with other webinar organised on other 6G related topics the rating of the webinar received so far by attendees: **5 out of 5** !

2.2.3 3GPP

2.2.3.1 3GPP RAN

Several project partners among which Thales, Ericsson, Telit, and Qualcomm have promoted successfully the support of regenerative payload in the Rel-19 work plan (See Rel-19 RAN2 led NR_NTN_ph3 WID and IoT_NTN_Ph3 WID).

Note: This 5G advanced standardization activity on Regenerative payloads may be considered and leveraged for 6G NTN.

2.2.3.2 3GPP Stage 1 Workshop on IMT2030 Use Cases, 8-10th May 2024 in Rotterdam/The Netherlands

The agenda of the workshop and the list of documents presented can be found at https://www.3gpp.org/ftp/workshop/2024-05-08_3GPP_Stage1_IMT2030_UC_WS

As it was not possible to introduce the 6G-NTN contribution to the ETSI workshop to the 6G SNS JU, this 6G-NTN has been lately introduced to the introduced GSOA presentation (Global Satellite Operator Association) in SWS-240008 "NTN evolution into 6G for IMT-2030 Use Cases", Satellite (GSOA). See in the annex of this document.

In addition, Nicolas Chuberre has been invited to take part in a panel discussion "6G Drivers for Verticals" gathering representatives of various vertical sectors. See agenda of the workshop. Nicolas put emphasis on the role of NTN in 6G to support ubiquitous and resilient connectivity.

Note: that the views presented by Nicolas Chuberre during this panel don't necessarily represent the views of other 6G-NTN partners.

2.2.3.3 3GPP SA1#106 meeting, 27-31st May 2024 in Jeju/Korea

Leveraging 6G-NTN project outcomes, Thales prepared and submitted a contribution (S1-241235) calling for the creation of a Rel-20 6G study item focusing on "ubiquitous and resilient connectivity" use case family and addressing the following use cases related to NTN:

- Direct connectivity to smartphones/wearable devices
- Broadband connectivity to land vehicles
- Broadband connectivity to drones (or UxV)
- High speed broadband connectivity to public transportation platforms (Aircraft, Railway, Maritime, ..)

Note: This Thales contribution does not necessarily reflect the views of other 6G-NTN partners.

2.2.4 Satellite Standardisation Interest Group (SSIG)

Professor Alessandro Vanelli and Nicolas Chuberre have engaged with this informal group to invite several of satellite communication industry stakeholders provide their views during the ETSI conference on NTN in 6G.

This SSIG was established on January 8th, 2018 as a special interest group for standardization moderated by Nicolas Chuberre from Thales Alenia Space France and sponsored by the European Space Agency (ESA). It now gathers more than 60 satellite stakeholders worldwide, most of which are now 3GPP members. The SSIG is a platform through which a broad range of stakeholders can exchange information on satellite-related standardization activities for the integration of satellites into the evolving 3GPP ecosystem to promote mutual understanding and collective effectiveness in pursuit of the vision . The SSIG can also provide a platform/forum to garner support from individual participating organizations for specific actions they wish to pursue (in line with the vision).

See https://connectivity.esa.int/projects/helena-highly-skilled-satellite-community-members-drive-3gpp-nonterrestrial-network-standardization

Further more, Thales shared with SSIG members, its SA1 contribution calling for the creation of a Rel-20 6G study item focusing on “ubiquitous and resilient connectivity” use case family and successfully collected more supporting companies.

2.3 PLANS UNTIL END OF THE PROJECT

2.3.1 3GPP SA1 activities

There is an opportunity to continue to leverage 6G-NTN outcomes and contributes to 3GPP SA1 with the objective of

- Having a 6G study item approved in the Rel-20 addressing use cases related to NTN capabilities (3GPP SA1#107 meeting, 19th-23rd August 2024 in Maastricht/The Netherlands)
- Defining/analysing most relevant NTN related use cases (investigated in the 6G-NTN project) as part of the approved Rel-20 6G study in order to identify the necessary service requirements.

This SA1 led 6G study item will develop a technical report which is expected to be finalized in March 2026.

As part of this study item, NTN related use cases (including service requirements) leveraging especially, the work carried out in the WP2 of 6G-NTN project, can be proposed.

Before the SA1#107 meeting, Thales will propose a draft contribution to the 6G-NTN consortium offering an opportunity for taking into account other views and possibly gather their support.

Once the study items are approved, Thales will invite interested partners to discuss a possible work plan to contribute to the study item.

Note: This does not prevent each 6G-NTN partner, to contribute independently according to its own 6G strategy.

2.3.2 3GPP TSG-wide 6G Workshop stage 2 in Incheon/Korea (10-11th March 2025)

During this TSG workshop, companies are invited to provide

- Stage 1 presentations of 6G UCs/concepts; status of SA1 6G TR
- Stage 2 presentation of companies’ ideas on 6G system architecture and radio access networks concepts

Rel-20 Stage 2 study items on 6G at SA2 and RAN level are expected to be approved and start at TSG#108 in June 2025 (see SP-240432/RP-240823).

These SA2 and RAN led 6G study items will each develop a technical report which are expected to be finalized in respectively March and June 2027.

As part of the project, there is an opportunity to 1/ influence the scope of these study items and then 2/ contribute to their execution once they are approved.

Leveraging the 6G-NTN project outcomes, Thales plans to initiate a draft contribution for this stage 2 workshop. The contribution may address different topics investigated in the project among which

- GNSS free operation
- Seamless service continuity between NTN/TN
- Compact and self-tracking FPA for vehicle/UxV mounted devices
- Reliable, high accuracy and low latency determination of UE location
- UE – NTN – UE mesh connectivity (without feeder)
- Autonomous private network (NTN+TN) operation over a specific area
- Smart NTN/TN combination for sustainability and resilience
- Multi-tenant non-terrestrial network infrastructure
- NTN/TN Spectrum coexistence optimization

Thales will propose an initial draft by end of December 2024, to the 6G-NTN consortium offering an opportunity to all partners to take into account their views and possibly gather their support.

Once the study items are approved, Thales will invite interested partners to discuss a possible work plan to contribute to the study items.

2.3.3 Creation of an “NTN forum”

Under ESA initiative and with the support of Thales Alenia Space, a “NTN forum” will likely be created with the objective to gather all stakeholders having interest in NTN solutions.

Partners of the 6G-NTN project may use this “NTN forum” to promote their views on NTN in 6G for example in the perspective of the 3GPP TSG-wide 6G Workshop stage 2 in March 2025 in Incheon/Korea.

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3 EXPLOITATION

3.1 OVERALL

The project is currently demonstrating the added value of a non-terrestrial network as native component of the 6G system. Indeed, non-terrestrial networks are expected to contribute to address the “connecting the unconnected”, “security and resilience” and possibly to the “sustainability” overarching aspects of the IMT-2030.

This requires to ensure that

- the specific characteristics (delay, Doppler, spectrum, etc.), of the NTN component are considered since the inception of the development of the specifications of the 6G systems at both radio interface and architecture level;
- an economic sustainability of such a system under the constraint to provide affordable services to the end users.

Such non-terrestrial network component is expected to address consumer, enterprise and vertical market segments:

Table 1: Non-Terrestrial Networks’ targeted market segment

Market segment	**Consumer**	**Enterprise**	**Verticals**
Description	connectivity to smartphones or wearable devices & cars Need for guaranteed coverage By 2030, at least 7.5% of the total number of mobile subscribers (5.2Bn) expected to be NTN 5% of the new cars (~75 million per year) are expected to be NTN capable	Need for services in rural areas or less developed areas and moving platforms Unique UE for both NTN/TN Similar use cases to today (e.g. media & entertainment) As the technology becomes cheaper and compact and easier to access, the adoption is expected to rise.	Utilities, agriculture, governmental users Specific requirements: e.g. autonomy, security Several 100 K of users are expected to require satellite connectivity

As part of the project,

- the design principles of a satellite network component based on a three layer space segment (GSO, NGSO and HAPS) have been defined and consolidated. The NGSO constellation is made of two types of satellites interconnected via Inter Satellite Link: A "feeder satellite" which may serve a set of "service satellite" operating in different frequency bands. There can be different types "service" satellite, operating respectively in FR1 and FR2 bands. This concept allows to maximise the throughput per service satellite while the "feeder" satellite allows to embark, routing and edge computing resources for the support of added value services (e.g. mesh connectivity, advanced navigation)
- the features enabling the 6G radio interface and the related system/radio access network architectures to be NTN friendly have been identified/evaluated
- the feasibility of key technologies such as the self-tracking phased array antenna for vehicle/drone mounted user equipment operating in FR2 have been assessed

This opens up new business opportunities for the development/manufacturing and deployment of this satellite network infrastructure and the related ground network component and user terminals as well as new areas for research as well as education of future engineers.

In the following, each project partner have identified how they plan to exploit the project outcomes.

3.2 PRELIMINARY DEVELOPMENT PLAN

The following chart depicts the possible roadmap of 6G-NTN related activities in ITU-R and 3GPP:

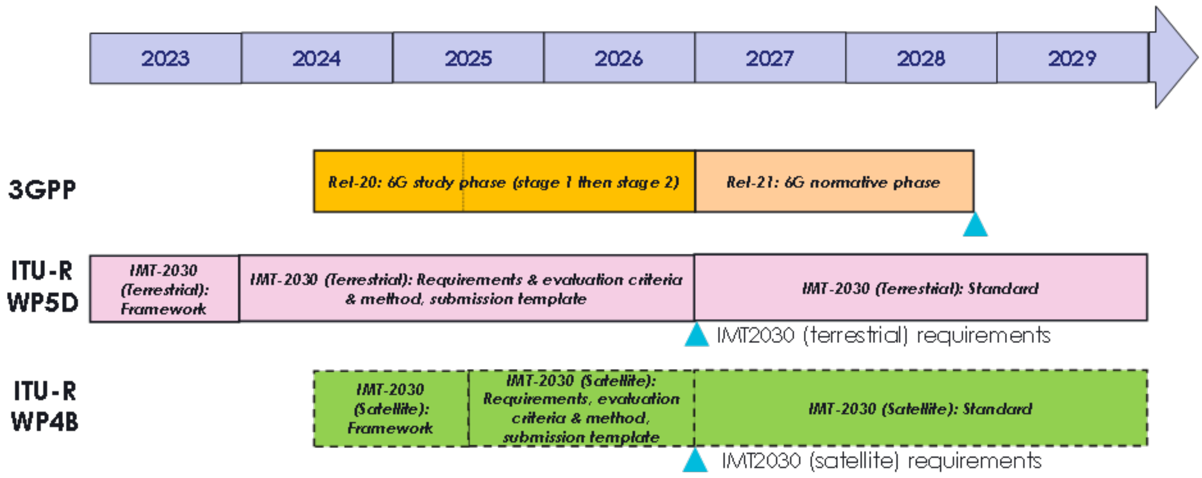

FIGURE 1: 6G'SNTN IN 3GPP AND ITUR ROADMAP

In line with the above, an overall development plan is provided according to ESA (https://www.esa.int/Science_Exploration/Space_Science/Building_and_testing_spacecraft), the lifetime cycles associated to the Building and testing spacecraft are depicted below

- Phase 0: Mission analysis and identification
- Phase A: Feasibility
- Phase B: Preliminary Definition
- Phase C: Detailed Definition
- Phase D: Qualification and Production
- Phase E: Utilisation
- Phase F: Disposal

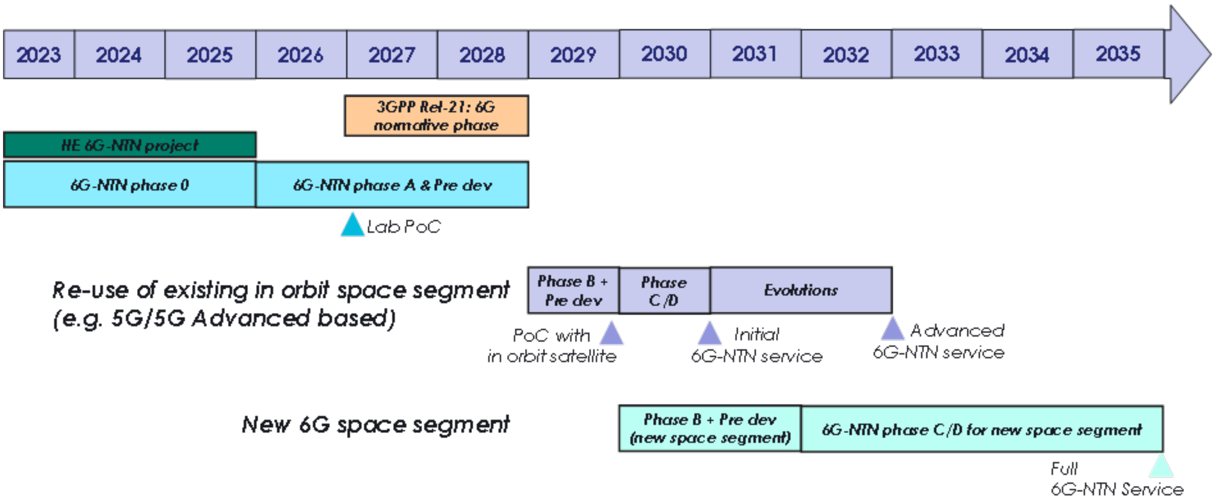

FIGURE 2: POSSIBLE 6G'S NTN OVERALL DEVELOPMENT PLAN

This above mentioned schedule takes into account the possible time line for 5G-NTN solutions roll-out here under depicted:

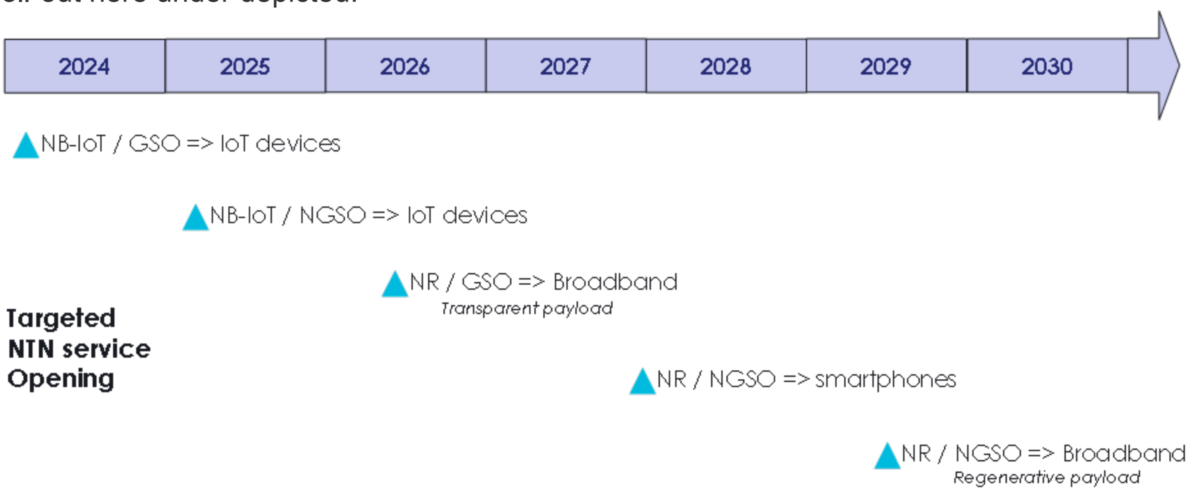

FIGURE 3: TENTATIVE TIME LINE FOR 5G-NTN SOLUTIONS ROLL OUT (BASED ON INDUSTRIAL SOURCES)

The 6G-NTN system architecture and radio interface will be subject to research and development in parallel with the standardisation activities up to the end of 2029.

We shall distinguish between 6G-NTN services being rolled out respectively on existing space segment (e.g. 5G/5G advanced friendly) and 6G-NTN services being rolled on a new space segment specifically being designed/optimised.

This phased approach will allow to offer new 6G-NTN service capability much earlier that with the deployment of a new space segment.

This will require to develop the following sub-systems:

- Terminal level:
  - Modems,
  - phased array antenna
- Ground network
  - Tracking antenna system at gateway level for the feeder links
  - NTN control center implementing Artificial Intelligence driven Radio Resource Management.
  - Network management center dynamically orchestrating the Virtual Network Functions on board the NGSO/GSO satellites
- Space segment
  - Service NGSO satellites: Phased array antenna operating in FR1 or FR2, Inter satellite links
  - Feeder NGSO satellites: Modems, Virtual network function framework, Inter satellite links
  - GSO satellites: Modems, Virtual network function framework
- Software products for ground or space segment
  - RAN controller including resource control (e.g. Control Unit)
  - Selected core/ran/transport network functions.
  - End to end routing

By the end of the project, for each of the above products or sub-systems, the plan will further details in terms of development phases and milestones.

- The possible industry stakeholders types that can develop (some may be SMEs).
- The possible institutional frameworks that could support part of the plan.

3.3 INDUSTRY STAKEHOLDERS

3.3.1 Thales Alenia Space (France and UK)

Expertise: Thales Alenia Space (TAS), a joint venture between Thales (67%) and Leonardo S.p.A (33%), is a key European player in space telecommunications, navigation, Earth observation, exploration and orbital infrastructures. The company posted consolidated revenues approximately of 2.15 billion euros in 2021, and has around 8,900 employees in ten countries. Thales Alenia Space is one of the world's leading manufacturers of communications satellites, platforms and payloads, which account for 45% of its business. The company offers a complete range of solutions, from high-performance components to turnkey systems. The Spacebus family of geostationary platforms meets the needs of operators from around the world, and payloads designed and built by Thales Alenia Space have proven their performance, reliability and competitiveness on satellites made by all leading manufacturers. Within Thales Alenia Space group, Thales Alenia Space -France (TASF) is the lead competence centre for telecom systems, payloads and antennas as well as GSO (geostationary Synchronous Orbit) satellites platform design and development: GSO systems based on its Spacebus platform family or Space Inspire product, high-performance payloads and electronics equipment including antennas, Non GSO constellations: Iridium NEXT, Globalstar 2nd generation and O3B constellations, representing more than 150 satellites ordered, Defense systems: French Syracuse Tele communication systems. Furthermore, Thales Alenia Space is currently developing a High Altitude Platform called Stratobus1 as well as location system solutions for vertical market applications. For the 5 last years, Thales Alenia Space – France has been driving the standardization in 3GPP and ETSI on 5G NTN topic thanks to a significant effort in R&D.

Exploitation: TAS plans to use the project outcomes to design/size future satellite networks aiming at providing broadband services to vehicle and drone mounted terminals, with the ambition to capture contracts in the development/deployment of the space infrastructure and the related control centres. The outcomes will also be used in the planning for the development of future products/solutions to prepare for the future systems.

3.3.2 Thales SIX

Expertise: THALES SIX FRANCE (TH-SIX) is a major subsidiary of the THALES Group. THALES is the European technology leader in providing safety and security, 40% in transport and aerospace, and 60% in Security and Defence. In 6G-NTN, TH-SIX is represented as world leader in critical information systems and secure communications, which addresses every activity related to telecommunications from systems down to components: radio communications, flexible waveform design, IP networks, orchestration, cyber security, mission critical applications and satellite communication. TH-SIX is the first world company on the market in the systems and professional military equipment of communications. TH-SIX contributes to the success of EU funded research projects for more than 10 years. TH-SIX has strong expertise in the domain of cyber security, E2E orchestration solutions and Radio Access Network (RAN) for 4G/5G, while actively contributing to Service and System Aspects (SA) studies for the next 6G communications. TH-SIX is involved in different standardization groups such as 3GPP RAN/SA-Plenaries, RAN1/RAN2, currently with 5G NTN contributions in RAN4.

Exploitation: THALES SIX (TH-SIX) aims at reaching the technical, regulatory and standard enablers for the 6G-NTN component to be integrated as part of 6G for extended coverage, resiliency and sustainability. Based on a novel multi-orbit network architecture envisaged as natively part of 6G systems combined with smaller terminal form factor concept, 6G-NTN component can offer new service capabilities and increased performances (such as data rate, latency, position accuracy and reliability) to meet the needed requirements of vertical stakeholders as well as (mass-market) consumers. Therefore, 6G-NTN can contribute to define a flexible waveform optimized for both terrestrial and non-terrestrial network components considering the operational constraints (e.g., impairments due to RF, propagation, Doppler shift and delay), interference management and spectrum sharing in order to best support the targeted services. In order to make this happen, it is important to consider the introduction of new 6G satellite frequency bands for future satellite deployments and further actively contribute at standardisation level (mainly 3GPP) to help driving 5G activity towards 6G. On the other hand, dynamic orchestration of VNF, smart routing and edge-based service provisioning in a dynamic network topology will introduce a novel approach to deploy different services with respect the cyber security aspects. Moreover, complementary analysis of the

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[1] https://www.thalesgroup.com/en/worldwide/space/case-study/stratobus-halfway-between-drone-and-satellite

regulatory framework to identify design elements and potential needs for regulatory changes are currently considered.

3.3.3 Ericsson (Sweden and France)

Expertise: Ericsson (ERIS, ERIF) is the global leader in RAN and Core networks. Ericsson conducts research and drives the standardization and development of new sustainable solutions, targeting market needs for telecommunication services as well as vertical industries such as manufacturing, media, automotive and transport.

Exploitation: As global leaders in RAN and Core networks, ERIS and ERIF will use the project results to better understand technical and commercial implications of providing NTN services in different frequency bands than currently standardized, as well as the use cases such services will enable in the future. Additionally, Ericsson intends to understand the necessary coordination of NTN networks towards existing and future 5G & 6G TN networks. Furthermore, the results of the 6G-NTN project may be used as guidance for planning upcoming standardization activities in 3GPP and elsewhere.

3.3.4 Qualcomm

Expertise: Qualcomm is the world’s leading wireless technology innovator, inventing the technologies that underpin and ensure ever-improving speed, security and latency-free wireless connectivity that is contributing to the digital transformation of economies. Its fundamental innovations and products used in mobile devices and other wireless inventions allow the development of the mobile ecosystem (smartphones, tablets, computers, XR, etc.) and its expansion into new industries (industry of the future, automotive, drones, etc.). The company has several R&D centers in France with more than 180 employees.

Exploitation: Qualcomm foresees that the outcome from the project will become valuable cellular industrial landscape and market analysis material to help shaping up 6G-NTN vision and 6G-NTN strategy in coordination with other 6G standard/working groups such as NextG-Alliance, 3GPP, ETSI etc.

3.3.5 Greenerwave

Expertise: Greenerwave is active in the development of novel Flat Panel Antenna.

Exploitation: It ambitions to propose FPA adapted to the 6G-NTN requirements and hence capturing part of the market.

3.3.6 Telit

Expertise: Telit Cinterion is an IoT device and service provider. The company helps businesses integrate, activate, and operate devices in today’s hyperconnected world. It is very experienced in guiding enterprises through the process of deploying IoT, based on more than 30 years of experience.

Telit Cinterion offers modules, platforms, cellular IoT plans and custom designed devices and services. The company recently announced NTN-TN IoT modules for telematics, tracking and trace and other IoT applications. Telit Cinterion is involved in the definition of use cases in the NTN space, including those related to market requirements for 6G NTN. For the project, the company provides expertise in terminals and its influence as active member of various global standards bodies including the 3GPP and others where we are involved in technical sustainability and also on environmental and societal sustainability.

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Exploitation: As the next-generation NTN solution, 6G NTN will support enhanced services and new use cases.

Telit Cinterion is an innovative IoT communication solution provider committed to contributing to the evolution of technology and standards. NTN and its evolution in the context of the 6G NTN project, provide a connectivity overlay, increasing the resilience of connections, providing coverage in uncovered areas. The company recognizes the benefits of standardized technologies for global connectivity and believes the NTN and TN NTN promise for seamless connectivity in context of 6G and is therefore committed to contributing to the 6G NTN technical evolution. The project outcome and the standardized 6G NTN solutions thereof will be used in the planning for the development of future terminals/solutions supporting NTN for various verticals and use cases.

3.3.7 SES

Expertise: SES is a leading satellite network operator and has significant expertise in satellite communication systems. While wireless communications has been a key competence for the elaboration of the communication services, up to now mainly DVB based standards have been used and proprietary systems developed jointly with partners. Since a few years SES is building up the 3GPP experience with a dedicated team within the System Engineering team at SES Engineering. The participation in 3GPP meetings and the contribution to the NTN topic have let to a basis experience in 5G-NTN that can be complemented with the satellite communication experience.

Exploitation: The 6G-NTN as next generation NTN solution aims to provide a basis for an integrated operations of satellite and terrestrial wireless network with new use cases and services. SES is evaluating to integrate 3GPP 5G/6G NTN networks as a product in its future product portfolio for services that target mobile networks. For the convergence of Satellite Network Operators (SNO) and Mobile Network Operators (MNO), SES is preparing to provide the satellite communication basis for a joint service offering to direct-to-device (D2D) services. Different initiatives are ongoing in this respect, in particular targeting the usage of the identified frequency bands, C-band in particular but also in mmWave bands, Ka-band and Ku-band. The 6G-NTN solutions are therefore used as a basis for the definition of integrated satellite terrestrial services. Standardisation input is prepared accordingly for the 6G Releases coming up.

3.3.8 Orange

Expertise: ORA is one of the world’s leading telecommunications operators with sales of 42 billion euros in 2020 and 142,000 employees worldwide on 31 December 2020, including 82,000 employees in France. The Group has a total customer base of 259 million customers worldwide by 31 December 2020, including 214 million mobile customers and 22 million fixed broadband customers. The Group is present in 26 countries. ORA is also a leading provider of global IT and telecommunication services to multinational companies, under the brand ORA Business Services. ORA’s researchers explore technological breakthroughs, new uses and innovative business models. ORA Innovation invents the technologies required to deploy the networks and services of the future in a world that is fully Digital and Human. ORA contributors in the 6G-NTN are Researchers on evolutions of RAN (such as O-RAN), end-to-end architectures, and NTN/HAPS. Satellite activities at Orange apply currently to residential connectivity for remote villages/houses, IP/VPN for remote enterprises, maritime connectivity brokering, and interconnexion links, based on GEO and MEO satellites.

Exploitation: ORA will exploit the results of 6G-NTN to increase its knowledge on the strategic opportunity to add complementarity between TN and NTN in its portfolio and thereby, to strengthen offers for Verticals and possibly mass-market (in case of D2D extension). Results

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of this project are used as guidance for standardization activities, in liaison with 3GPP and IETF delegates, to define service and system requirements. They also raise the challenges and needs to integrate NTN system in a traditional TN Architecture.

3.4 ACADEMICS AND RESEARCH CENTRES STAKEHOLDERS

3.4.1 University of Bologna

Expertise: The University of Bologna (UNIBO) is known as the oldest University of the western world. It is organised in a multi-campus structure with 5 operating sites (Bologna, Cesena, Forl., Ravenna, and Rimini) and, since 1998, also permanent headquarters in Buenos Aires. UNIBO is member of the major European Networks and stakeholders' thematic groups, including the 5GPPP the Public Private Partnership (PPP), the 6G Infrastructure Association (6G IA), and the Networld2020 European Technology Platforms (ETP). UniBo is a full member of ETSI and of 3GPP. The activities of the University of Bologna are conducted within the Department Electrical, Electronic, and Information Engineering "Guglielmo Marconi" (DEI). Within DEI, the Digicomm Group, led by Prof. Alessandro Vanelli-Coralli, focuses its research activities on Wireless Communication Systems with specific emphasis on Satellite and Terrestrial integration, addressing the development of new algorithms, performance analysis, knowledge transfer, and support to standardization (DVB, ETSI, O'RAN, and 3GPP participation as external consultants of SDO members). The Digicomm group has coordinated several ESA and EC projects. Currently, it leads the H2020 Dynasat RIA and the ESA Innovative Techniques and Technologies for B5G Satcom study.

Exploitation: The project outcomes will be leveraged in three primary areas as outlined by its mandate: research, teaching, and knowledge transfer. Specifically, the advancements achieved by the 6G NTN project will enable the team to identify and develop new research fields, enhance teaching materials to improve the employability of UNIBO graduates, and facilitate knowledge transfer to local, national, and European companies. This will contribute to the competitiveness of the European industry and SMEs in the evolving sector of Terrestrial and Satellite integrations for B5G systems.

3.4.2 CTTC

Expertise: The Centre Tecnologic de Telecomunicacions de Catalunya (CTTC) was founded in December 2001 and is a private non-profit R&D centre with substantial funding support from the autonomous government of Catalonia (Generalitat de Catalunya) along with research and development partnership with industry. The main objectives of CTTC are to conduct research in communications technologies and geomatics; to participate in research and development competitive projects, mainly developing or applying communication technologies; to develop tools and solutions based on geomatics, communication networks, systems and technologies; to provide training and support to graduate students and post-docs in the scope of its R&D activities. CTTC has wide experience in the participation and coordination of research projects funded by EC under HE JU-SNS, H2020-ICT, FP7, FP6, ENIAC, ARTEMIS and EUREKA programs, by ESA and by Spanish national programs. CTTC has also a wide portfolio of direct industrial contracts. After its reorganization in 2022, Space and Resilient Communications and Systems (SRCOM) research unit inherits satellite communication activities performed by the research centre in the last 15 years. These include leading the largest ESA funded project on low-TRL satellite communications (SatNEx IV and V) and more than 10 technology transfer contracts with major vendors and operators.

Exploitation: CTTC's participation in this project is expected to stimulate several technology transfers and IPR generation activities, which are at the true core of its mission. From participation in 6G-NTN, CTTC staff will acquire new knowledge in enhancing the capabilities of existing 6G RICs. CTTC exploitation strategy is based on the rule of protect or publish, i.e. to publish any new acquired knowledge which is not protected or planned to be used in commercial exploration. Moreover, as a member of 6G-IA CTTC will exploit the project's results to the 6G industrial community in Europe.

3.4.3 DLR

Expertise: DLR is the national aeronautics and space research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. DLR has 30 locations in Germany and offices in Brussels, Paris, Tokyo and Washington D.C. In the fiscal year 2020, DLR's budget for research and operations was 1261 million-euro, 44 percent of which was third-party funding acquired through competitive tendering. The space budget managed by DLR amounted to 1552 million euro (excluding EUMETSAT). Of this, the German contribution to financing the European Space Agency (ESA) was 945 million euros. Consequently, the ESA share accounted for 61 percent of the total space budget. Around 305 million euros were allocated to the National Space Programme, which accounts for a share of 20 percent. For the research and technology sector, the total amount was around 301 million euros. The research space sector thus accounted for 19 percent of the total space budget. The DLR Projektträger funding was 2240 million euros and the Project Management Agency for Aeronautics Research and Technology had a budget of 202 million euros.

DLR's identity is that of a research institution focused on scientific excellence. The DLR Institute of Communications and Navigation is dedicated to mission-oriented research in selected areas of communications and navigation. Its work ranges from the theoretical foundations to the demonstration of new procedures and systems in a real environment and is embedded in DLR's Space, Aeronautics, Transport, Security and Digitalization programmes. The Institute currently employs around 230 staff, including 200 scientists at the locations Oberpfaffenhofen and Neustrelitz.

The Satellite Networks department plays since many years a leading role in Europe in the conception and investigation of novel system concepts, transmission techniques, protocols and applications for Satellite Communications.

Exploitation: As no-profit research institution, ETSI, 3GPP and 6G-IA member**, DLR** aims to support the take-off of NTN mostly through IPR generation. This shall lead to the acquisition of further projects in the area aiming at a higher TRL of the developed technological solutions and ultimately at technology transfer to industry.

3.5 CONSULTANCIES

3.5.1 Martel (MAR)

Expertise: MAR is a dynamic and innovative SME with over 25 years of experience in European Commission-funded projects. MAR has been involved in more than 40 H2020 projects and six recently funded Horizon Europe projects, including various RIAs, IAs, and CSAs in the 5G, Satellite, Next Generation Internet, Cloud, and IoT domains.

Currently, MAR coordinates the Next Generation Internet Outreach Office and two CSAs supporting European cloud computing initiatives (HCLOUD and HUB4CLOUD). MAR also supports the Next Generation IoT research ecosystem through the EU-IOT CSA and the work on the OpenContinuum CSA, which aims to create an open ecosystem for European strategic autonomy and interoperability across the computing continuum industry. Additionally, MAR is involved in the Horizon Europe 6GSTART CSA, which supports SNS JU, where MAR leads dissemination and coordination efforts.

Moreover, MAR is coordinating the CSA 6G4SOCIETY, which aims to ensure that societal and sustainable values are properly embedded into the development of 6G technology, bringing a sociological perspective to technological development. The project engages key stakeholders from the private and public sectors, as well as European citizens at large, to ensure correct and clear information about the expected impacts of 6G technology.

Exploitation: MAR aims to consolidate its expertise and strengthen its position in telecommunications, IoT, and AI solutions for 5G/6G by further integrating its proficiency in cloud-native architectures, edge computing, and service orchestration software for telecommunication infrastructure. By leading dissemination and exploitation activities, MAR is enhancing its knowledge base and offering innovation management, consulting, and media services in the R&D&I sector, with a particular emphasis on 5G/6G.

The exposure gained through these dissemination, communication, and technical activities is positioning MAR as a key facilitator for the adoption of project results by industries and research and innovation stakeholders. Specifically, in collaboration with the 6G4Society CSA, MAR is fostering partnerships focused on Key Value Indicators (KVIs) and sustainability in 6G connectivity. This collaboration aims to strengthen the sustainability objectives of both initiatives and promote the overall sustainability of 6G technology.

3.5.2 Digital for Planet (D4P)

Expertise: D4P is a non-profit organization dedicated to supporting the design, development, and adoption of innovative digital technologies, systems, and solutions. Its mission is to empower individuals, communities, and both public and private organizations to effectively address significant social, economic, and environmental challenges. D4P prioritizes the development of sustainable, open, inclusive, trustworthy, verifiable, and ethical digital technologies and solutions, promoting their widespread adoption across various sectors. Its efforts align with the European Green Deal objectives and the United Nations Sustainable Development Goals, fostering environmental awareness and sustainable development.

D4P cultivates an open network of experts and organizations, supporting research, innovation, and policy-driven initiatives. The association organizes events, webinars, surveys, and expert sessions focused on themes and topics related to the development and adoption of green and sustainable digital technologies.

Exploitation: D4P is committed to driving the green and digital transition. By focusing on defining use cases and requirements, D4P aims to highlight and investigate sustainability aspects within the scope of 6G-NTN. Its communication and community-building efforts have established a strong platform for engaging and uniting stakeholders around the twin transition of digital and environmental sustainability.

The activities and experience in the 6G-NTN arena are enhancing D4P’s visibility and credibility within both, scientific and industrial communities. This paves the way for new business opportunities. Through these efforts, D4P continues to support and promote the adoption of sustainable digital technologies, fostering a collaborative environment for stakeholders dedicated to a greener future.

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In particular, as the Work Package leader for Public Engagement and Communication in the CSA 6G4Society initiative, D4P is actively fostering collaborations with partners and civil society focused on sustainability in 6G connectivity and the acceptance from end users.

4 SUSTAINABILITY

4.1 GENERAL ASPECTS OF SUSTAINABILITY IN TELECOM

As the world prepares for 6G deployment, sustainability concerns are paramount. Key issues include:

(i) Environmental footprint: the production and disposal of electronic equipment for 6G networks contribute immensely to e-waste and resource depletion. Additionally, the energy demands of 6G infrastructure are expected to significantly increase carbon emissions, exacerbating climate change.

What naturally follows from the environmental footprint of 6G are **(ii) resource and energy consumption** and **(iii) energy efficiency**. Regarding the former, 6G will require advanced materials and rare earth elements, whose extraction and processing have significant environmental impacts, including habitat destruction, water pollution, and high energy use. Moreover, NTNs require significant energy for launch and maintenance. Energy efficiency, in its turn, implies that monitoring and then decreasing concerned energy consumption through e.g. using renewable energy sources and developing energy-efficient methodologies and technologies are essential to minimise telecom's and, thereby, NTNs carbon footprint.

As follows from the above, these three stakes/requirements are the most crucial in the context of sustainability. We therefore address relevant carbon footprint, energy consumption, and energy efficiency.

What's also important are regulatory and compliance challenges: navigating global and EU sustainability regulations and standards will be essential for 6G deployment, presenting both challenges and opportunities for innovation. Digital, social and economic equity is crucial and includes ensuring equitable distribution of 6G benefits to avoid widening, and also trying to narrow, the digital divide. Sustainable practices must include efforts to bridge this gap. We develop on relevant regulatory framework and on digital divide and equity.

In the following, we will put an emphasis on the following points: environmental footprint; energy consumption measurement and reduction; operational efficiency; renewable energy integration; policy and regulatory compliance; waste management; and various broader sustainability and equity aspects.

This study aims to consider the environmental impact of 6G-NTN deployment while ensuring support for increased data traffic and connected devices, as well as less digitally divided society. This is in line with global and EU sustainability goals, creating a sustainable and resilient network infrastructure.

4.2 A SUSTAINABLE NTN IN 6G (FOOT PRINT)

One of the key aspects of sustainability in telecom is the energy efficiency. As stated by the International Energy Agency (IEA)[1], the "Efficient energy use, or energy efficiency, is the process of reducing the amount of energy required to provide products and services".

In this regard, the importance of lowering the energy consumption in the non-terrestrial network component is of paramount importance, and this is for several reasons:

Sustainability goals: lowering energy consumption can reduce the environmental impact.

Network performance: energy consumption directly impacts network performance. Monitoring energy usage helps identify and resolve issues (e.g. availability and reliability) that affect performance, ensuring optimal network operation.

Regulatory compliance: many countries and regions have strict energy efficiency regulations, including the EU Green Deal.[2] Measuring energy consumption helps operators comply with these regulations and avoid penalties.

Other sustainability aspects for the NTN component are:

- Use of scarce and hazardous material
- Space debris management and end-of-life disposal
- Impact on EMF exposure

4.2.1 Recall of previous Life Cycle Assessment

If the concern of environmental impact has already reached the space sector for years, it is also now understood, under the urgency dictated by climate change, how critical is this impact of the design of large-scale satellite system.

This requires to conduct Life Cycle Assessment on satellite communication networks. The European Space Agency has developed a handbook for LCA on space systems which should be considered.

➲ ESA LCA HANDBOOK, 22/09/2021

(https://indico.esa.int/event/321/contributions/6391/attachments/4380/6604/CSID2021_ESA_LCA_Handbook.pdf)

While LCA is out of the scope of 6G-NTN project, it is worth referring to two analysis carried out on satellite networks:

➲ GSO broadband network: ETSI TR 103353 “Satellite Earth Stations and Systems (SES); Environmental impact of satellite broadband network; Full LCA (Life Cycle Assessment)”, 2016 (https://portal.etsi.org/webapp/ewp/copy_file.asp?Action_type=&Action_nb=&Wki_Id=45973)

- Also to be considered ETSI, « ETSI TR 103 352: Satellite Earth stations and Systems (SES); Energy efficiency of satellite broadband network ». 2016.

➲ NGSO broadband network: European commission‘s Dynasat project (Topic SPACE-29-TEC-2020) deliverable D6.8 (“Market analysis, exploitation and sustainability”) - ANNEX “Simplified Life Cycle Assessment for DYNASAT“, Thales Alenia Space, 26/03/2023

- Note that this document is not publicly available (see https://www.dynasat.eu/public-deliverables/)

Comparison of GSO and several NGSO broadband networks:

"Lean networks for resilient connected uses", Digital infrastructures adapted to the dual carbon constraint, March 2024, https://theshiftproject.org/wp-content/uploads/2024/04/The-Shift-Project-Lean-networks-for-resilient-connected-uses-Final-report-March-2024.pdf

"Satellite networks: climate footprint and place in the digital system", Theshiftproject at BEREC's Satellite Workshop, May 22th, 2024, https://www.berec.europa.eu/system/files/2024-05/10.%20TheShiftProject.pdf

Although the scope and approach of both LCAs differ from one another, a number of findings can be mentioned:

Table 1: Outcomes of the life cycle analysis on satellite communication systems

The different phases of the life cycle of a satellite network	Findings
General	Climate Change, Acidification, Water resources depletion, Ozone depletion, Mineral resources depletion are different aspects to be considered for the environmental impact
Phase A: Feasibility	For a constellation, the impact of these phases is quasi-independent on the number of satellites
Phase B: Preliminary definition	
Phase C: Detailed definition	The environmental impact of manufacturing and launch of the space segment highly relates to the number and weight of satellites. The environmental impact related to the manufacturing of user equipment is also critical given the number of terminals to be deployed
Phase D: Qualification and production	
Phase E1: Launch and commissioning	
Phase E2: Utilisation	Most of the impact comes from the energy consumption of User Equipment

4.2.2 Energy efficiency – Products

Here the energy it takes to develop and deploy a product should be taken into account.

Table 1: Considerations on the energy consumption of space, ground and user segments during different life cycle phases

	Ground segment (Gateway, network equipment (part of RAN and Core)	Space segment	User segment (User Equipment)

Development phase (manufacturing)	Apart from the gateway (antenna and RF front-end), the rest is similar to the mobile network and hence same sustainability enablers apply	This is specific and **shall be considered in the study**	Smartphones: same sustainability enablers as for mobile system apply VSAT terminal: one should distinguish between the antenna and the modem and **shall be considered in the study**
Deployment phase	same sustainability enablers as for mobile system apply	This is specific and **shall be considered in the study.** It refers to mainly the transportation of the satellites towards the launch pad and launch of the space segment	Smartphones: same sustainability enablers as for mobile system apply VSAT terminal: The mounting on vehicle, transportation platform … is specific and **shall be considered in the study**

4.2.2.1 Space segment

The space segment is solar powered, its sustainability impact is addressed separately. The mass of the satellite will depend mainly on the aggregated output power, the output back-off and the amount of processing. This impacts the number of launches needed for a given orbit.

4.2.2.1.1 Characteristics/sizing considerations of each orbit/altitudes

Let us compare the different orbit/altitude in terms of sizing as well as impact on the terminal in order to understand the benefits & costs or each orbit in terms of environmental impact.

TABLE 1: SPACE SEGMENT SIZING AND TERMINAL COMPLEXITY VERSUS ORBIT

Orbit type	GEO	MEO	LEO	HAPS
Altitude	35786 km	7000 – 20000 km	500 – 1500 km	~20 km
Potential coverage	Up to World coverage between [-70°; +70°] latitudes	Up to Global coverage	Up to Global coverage	200 km field of view per HAPS

Round Trip delay due to propagation	<600 ms	<150 ms	<50 ms	< 5 ms
Typical space segment sizing for service continuity (at least one satellite in visibility) without spares	3-4 satellites and 10° min elevation	24-28 satellites at 8500 km and 30° min elevation	448 satellites at 600 km and 30° min elevation	Lacunar
Typical average power payload/mass of satellites	15 – 20 KW/3 – 4 tons	3-4 kW/3-4 tons	1 kW/1 ton	Typically up to several kW for Airship
Typical number of satellites per launch (NOTE1)	Up to 2	Up to 6 (satellite with electrical propulsion) @ 8000 km	Up to 20 (@600 km), 10 (@800 km)	1 but self-raising
Typical design lifetime of satellites	Up to 15 years	Up to 12 years	Up to 7 years	Up to one year for Airship
NOTE 1: The same launcher, i.e. Falcon 9, is considered for the comparison				

The sizing of the space segment to ensure service continuity with at least one satellite in visibility everywhere in the globe depends on the altitude and the min elevation angle under which the terminal “sees” the satellite

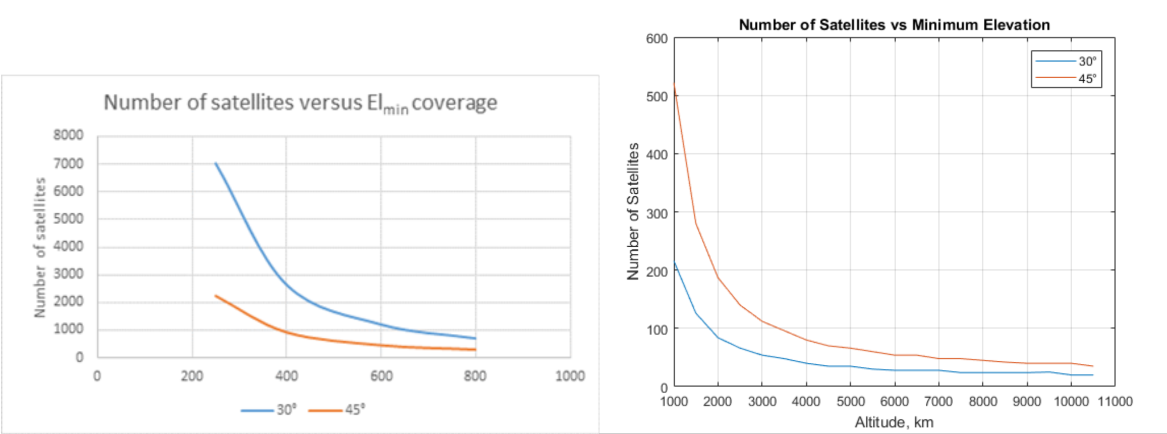

FIGURE 4 NUMBER OF SATELLITES REQUIRED IN A NGSO CONSTELLATION DEPENDING ON ITS ALTITUDE AND THE MIN ELEVATION

TABLE 2: NUMBER OF SATELLITES REQUIRED IN A NGSO CONSTELLATION DEPENDING ON ITS ALTITUDE AND THE MIN ELEVATION

1 Sat visible, 10s min handover				
Elevation	**250km**	**400km**	**600km**	**800km**
10	360	180	104	72
20	984	432	228	144
30	2244	920	448	286
40	4794	1856	874	527
45	7015	2652	1222	720
50	10434	3818	1710	1008

	Total		**# Planes**		**# Sats per Plane**	
	Min User Elevation, °					
Altitude, km	**30**	**45**	**30**	**45**	**30**	**45**
1000	216	522	12	18	18	29
1500	126	280	9	14	14	20
2000	84	187	7	11	12	17
2500	66	140	6	10	11	14
3000	54	112	6	8	9	14
3500	48	96	6	8	8	12
4000	40	80	5	8	8	10
4500	35	70	5	7	7	10
5000	35	66	5	6	7	11
5500	30	60	5	6	6	10
6000	28	54	4	6	7	9
6500	28	54	4	6	7	9
7000	28	48	4	6	7	8
7500	24	48	4	6	6	8
8000	24	45	4	5	6	9
8500	24	42	4	6	6	7
9000	24	40	4	5	6	8
9500	25	40	5	5	5	8
10000	20	40	4	5	5	8
10500	20	35	4	5	5	7

Note 2: The sizing of the HAPS segment will depend on the type of the High Altitude Platform System.

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TABLE 3: CHARACTERISTICS OF THE DIFFERENT TYPES OF HAPS

HAPS type	**Balloons**	**Airplane**	**Airship**
Example	*Loon/google*	*Zephyr*	*Stratobus*
Service coverage	Earth moving foot print (un predictable)	Earth moving foot print (predictable)	Quasi earth fixed foot print
Payload power	Up to several tens of Watts	Up to several hundred of Watts	Typically up to several kW
Duration of operation without refill	Several days	Up to one month	Up to one year

4.2.2.2 Ground segment

Not considered (see rational in the first table of the sub chapter)

4.2.2.3 User equipment

The energy efficiency for product development is linked to the specifications and relevance of the device's technologies, particularly for the automatic tracking antenna. Specifically, we need to consider the following main points :

Angular scanning capability

Number of simultaneous beams : We must determine the optimal number of simultaneous beams to maximize performance.

Minimum required EIRP and G/T performance characteristics: The antenna must meet minimum specifications in terms of Effective Isotropic Radiated Power (EIRP) and Gain over Temperature (G/T).

To achieve reduced consumption and low losses, we need to be in the optimal performance area of the antenna. Here are our improvement strategies:

Limit angular scanning: by increasing the minimum elevation that the antenna must achieve, we can reduce angular scanning and optimize the number of elements needed to achieve EIRP and G/T performance.

Use half-duplex mode : Operating in half-duplex mode reduces the complexity of the Beamforming Network (BFN) and, consequently, its power consumption. One beam for transmission (Tx) and two beams for reception (Rx) are recommended.

Optimize components: By using efficient High Power Amplifiers (HPA) and low noise LNA and reducing interconnections—especially by developing very compact flat panels—we can minimize losses associated with component and BFN routing.

These development approaches will reduce the antenna size and device complexity. Finally, a product that is both energy-efficient in manufacture and use.

4.2.3 Energy efficiency – services

In the context of radio communications, it shall take into account the energy consumption of the different parts of the system (network and user equipment) as well as the service performance of the system such as throughput (cell or user level), simultaneous number of users served and targeted service area.

For mobile systems[3], three possible metrics are suggested to characterize the energy efficiency:

- successfully transferred data volume per unit time over consumed power (εI);
- area unit over consumed power (εA);
- number of users over consumed power (εS).

A number of metrics should be defined that will allow a fair comparison between NTN and terrestrial network components in the context of 6G mobile system.

- As per an ETSI report[4], two energy efficiency metrics have already been defined for GSO based broadband network:
- The energy per bit $ECI_{E/B}$ can be calculated by dividing the total power consumed by the satellite network by the total throughput of the satellite on the downlink.

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

- The power per unit area $ECI_{P/A}$ can be calculated by dividing the total power consumed by the satellite network by the total coverage area for the satellite network in km^2.

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

With

- T_{SN} satellite network throughput;
- A_{SN} satellite coverage area;
- P_{SN} satellite network consumption (including ground segment and user equipment while the space segment contribution can be considered negligible).

$P_{SN} = P_G + (P_{UE} \times N_{UE})$

where: P_G is the average power consumption of the ground segment (gateway, Radio Access Network (if transparent payload), Core Network + NTN centre);
P_{UE} is the average power consumption of a User Equipment
N_{UE} is the number of User Equipment supported.

Such existing NTN related metrics should be leveraged in the context of 6G. However, they may have to refined and adapted to take into account the transmission mode (unicast/multicast/broadcast) and the different non-terrestrial network layers (i.e. HAPS, LEO/MEO/GEO).

4.2.3.1 Space segment

4.2.3.1.1 Combination of satellites from different altitude for a given service

We shall assume a given terminal type able to operate with satellite and HAPS at different altitudes.

The max distance between satellite and the User Equipment depends on the altitude of the satellite and the min elevation. Hence GSO or MEO satellites will be penalised compared to LEO in terms of

- Quality of service due to higher latency
- max data rate (UL and DL) it can offer per terminals, since the free space loss is much higher as depicted in the table below:

TABLE 4: ADDITIONAL FREE SPACE LOSS ATTENUATION BETWEEN GSO AND MEO VERSUS LEO

Satellite altitude	km	600	8500	35786
Approx distance UE-satellite at 30° min elevation	km	1200,00	17000,00	71572,00
Attenuation due to distance	dB	61,6	84,6	97,1
Relative attenuation Wrt LEO@600 km	dB	-	+23,0	+35,5

Such attenuation may be partly compensated with higher antenna size on board, however, the antenna size will be constraint by the fairing of the space rocket and the capability to deploy in orbit the antenna (in FR1 only). Hence the following table summarises the type of services that can be provide from satellite and HAPS depending on the orbit/altitude.

TABLE 5: TYPE OF SERVICES SUPPORTED BY SATELLITE AT DIFFERENT ALTITUDES FOR A GIVEN TARGETED TERMINAL TYPES

Targeted Terminal type \ Orbit type	Frequency range	GEO	MEO	LEO	HAPS
Devices with omni directional antenna	FR1	• Broadcast service • Narrowband service	• Broadcast/Multicast service • Narrowband service • Network based location (but requires 3 satellites in visibility)	• Wideband service • Broadcast/ Multicast service	• Broadband service
Devices with directive antenna (tracking)	Above 10 GHz	• Broadband service • Broadcast service	• Broadband service • Network based location (but requires 3 satellites in visibility)	• Broadband service	• Broadband service

4.2.3.1.2 Beam pattern/size

In some legacy satellite systems, (e.g. L band GEO system from Inmarsat), the space segment is generating various size of beams resulting in at least 2 layers of beams, which respective foot print are superposed on the ground.

The intent is to use the larger beams for broadcast traffic (e.g. to convey contents targeting large audience) and common signaling (e.g. for the network entry) while using the smaller beams for the unicast traffic.

- This prevents to replicate the broadcast traffic in each small beams.
- It allows to stop transmitting in the small beams where there is no traffic while using the large beams as “keep (the network) alive beams” for the zero load condition.

In a multi-layer system, one could envisage to generate large beams from GSO while generating smaller beams from NGSO.

4.2.3.1.3 On board processing

As satellite will increasingly embark regenerative payload, it is of prime importance to select energy efficient radio interface, especially optimizing the processing of the demodulation/decoding. The selection in 3GPP of a 6G waveform should take into account the required processing/channel bandwidth and for a given spectral efficiency.

4.2.3.2 Ground segment

One should focus on the NTN specific parts of the ground segment which are the gateways and the NTN control centres. The contribution of the later can be considered as negligible compared to the gateways since it is mainly a computing resource.

The power consumed by the ground segment depends largely on the max transmit power and the number of gateways to be deployed.

The required number of gateway depends on whether the space segment is transparent or regenerative with ISL. In the later, the required number of gateways may be reduced significantly especially if the feeder link throughput is high.

However, it also depends on the regulations given that countries may require at least one gateway in their territory to be able to do locally the lawful intercept and the handling emergency communications.

In a worst case, one can assume that the later regulatory constraint will prevail and hence the required number of gateways for a global network may represent several hundreds, with each Gateway able to operate with the different “layers” (i.e. orbit/altitude) of the space segment. In that case the feeder link bandwidth may be optimised along with the transmit power, hence reducing the power consumption. Typically one gateway will be able to serve a set of several beams.

4.2.3.3 User equipment

4.2.3.3.1 Smartphones

The sustainability enablers should be the same as for the smartphones operating with the terrestrial network component of 6G.

What is at stake is to limit as much as possible the energy consumption thanks to energy saving techniques.

4.2.3.3.2 VSAT terminal

For such devices, we should distinguish between the self-tracking and directive antenna and the modem parts.

Let us focus our analysis on the antenna which shall always (idle and connected mode) track the serving satellite(s). It is expected that the energy consumption relates to the motion of the satellites to track as well as the relative motion of the terminal wrt satellites.

Furthermore, the higher the radiating elements, the higher the energy consumption.

For example the antenna/RF of the Starlink terminal consumes in average 50-70 Watts[5] which is relatively high.

One could envisage to reduce the energy consumption in idle mode by either stopping the tracking of satellites by off-loading common signalling to GSO resources

4.2.3.3.3 Proposed new energy efficient metrics

Hence we propose 4 metrics

- Connected mode: Energy per bit transmitted
  - Downlink: Power consumption of the ground segment part serving a given beam over the beam throughput
    - E.g. P_G [W] / (Number of satellites x Number of beams per satellite x Max throughput in a beam [Mbps])
  - Uplink: Power consumption of the UE in idle mode over the max UL data rate
    - E.g. $P_{UE\text{-}connected}$ [W] / Max data rate per user [kbps]
- Idle mode: Energy to support network entry
  - At network level: Energy needed to transmit the common signaling (including SSB) over a given area
    - E.g. (P_G [W] / Beam area) x (SSB duration / SSB max periodicity)
  - at user equipment level: Power consumption of the terminal in idle mode (mainly the power to continuously track the serving satellite in motion)
    - $P_{UE\text{-}idle}$ [W]

Where

$P_{UE\text{-}idle}$ is the average power consumption of a User Equipment in idle mode

$P_{UE\text{-}connected}$ is the average power consumption of a User Equipment in connected mode

4.2.4 Hazardous and scarce materials

This section proceeds as follows: subsection 1 briefly outlines the most relevant EU legislation and policies (hereinafter, 'EU policy context') currently applicable to hazardous and scarce materials with relation to our project. Subsection 2 critically analyses the stakes, challenges, and opportunities of the interface of the updated EU policy context with broader sustainability aspects of our project. Subsection 3 concludes.

4.2.4.1 Updated list of the requirements and applicable policies / legislation in the EU

4.2.4.1.1 Hazardous chemical substances

The use of hazardous chemical substances in Telecom and SatCom systems is regulated by several key EU legislative pieces:

1. **REACH (EC 1907/2006)**: This regulation is on chemicals and their safe use, dealing with the Registration, Evaluation, Authorisation, and Restriction of Chemical substances. It aims to improve the protection of human health and the environment through better and earlier identification of the intrinsic properties of chemical substances, enhancing innovation and competitiveness of the EU chemicals industry.

2. **RoHS (2011/65/EU):** The Restriction of Hazardous Substances Directive limits the use of six hazardous materials in the manufacture of various types of electrical and electronic equipment (EEE). The directive specifies maximum concentrations in homogeneous materials for substances like lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB), and polybrominated diphenyl ethers (PBDE).

   Directive (EU) 2017/2102: An amendment to the RoHS Directive, broadening the scope of the restrictions to include all electrical and electronic equipment, cables, and spare parts, with some exemptions for specific applications, including certain categories of large-scale stationary industrial tools and fixed installations.

3. **ECHA's SCIP Database** (Substances of Concern in articles as such or in complex objects (i.e. products)): As of January 2021, under the **Waste Framework Directive (2008/98/EC)**, any supplier of articles containing substances of very high concern (SVHC) on the **REACH Candidate List above** 0.1% w/w must submit information to the SCIP database. This aims to ensure that information about substances of concern is available throughout the whole lifecycle of products and materials, including the waste stage.

4.2.4.1.2 Scarce materials

Material scarcity and critical raw materials are significant concerns for the EU:

1. **The European Green Deal (2019):** The Green Deal aims to transform the EU into a modern, resource-efficient, and competitive economy, including enhancing the circular and sustainable economy, which impacts the use and recycling of critical raw materials, reducing EU dependency on scarce resources. Regarding the relevant EU policy context, the Green Deal prompted the creation of two policy initiatives as follows:
2. **Critical Raw Materials Resilience Action Plan (2020)**: The European Commission's Action Plan on Critical Raw Materials outlines measures to reduce dependency on third countries, diversify supply from both primary and secondary sources, improve resource efficiency, and promote responsible and sustainable sourcing worldwide.
3. Notably, the list of most critical raw materials at EU level is reflected in the **Critical Raw Materials Resilience report (2020)**: this report, among many other things, has an important chapter (Chapter 2) on **supply and sustainability challenges**. In a nutshell, this chapter highlights a better management and sustainability of raw materials as a must for the EU. The related strategic planning aligns with the EU's goal of achieving a digital and climate-neutral economy by 2050 and enhances its global influence, as per the Green Deal, cited earlier. A foresight report published with this Communication[6] complements the criticality assessment, projecting the demand for raw materials up to 2050 for strategic technologies and sectors. For instance, the EU's demand for **lithium** and **cobalt** (both elements being crucial for the industry ecosystems of **Aerospace/ defence**, **Digital**, and **Electronics**, see Annex 2 of the Communication of the Report) could increase up to 60 times by 2050. Demand for these and other rare earths (e.g. **bauxite**, **beryllium**, etc., see Annex 2 for the full list) used in digital technologies may grow tenfold. Note that global demand for raw materials, driven by population growth, industrialisation, and decarbonisation efforts, exacerbated by the COVID-19 crisis, drive significant increases in

demand for metals and minerals, which overall could more than double by 2060 (the World Bank and OECD forecasts). Those factors highlight the vulnerability of supply chains, prompting a need for the EU to improve the resilience of critical supply chains, reduce import dependence, enhance resource efficiency, and increase supply capacity within the EU to ensure a **sustainable and secure transition to clean energy**.

4.2.4.2 Sustainability aspects: stakes, challenges, and opportunities

4.2.4.2.1 Impact reduction opportunities – quantified where possible

Hazardous chemical substances

REACH creates obsolescence issues for all impacted Articles, Preparations, or Substances (APS) used during/for the manufacturing of SatCom systems. The space industry has identified numerous materials and chemical substances used in the assembly of the space segment or during the manufacturing process that may impact APS. Some critical substances include:

Table 1:Chemical substances used during space system development subject to APS

ECHA list	Chemical substances	REACH Sunset date
Annex XIV	Bis (2-ethyl(hexyl)phtalate) (DEHP)	February 2015
Annex XIV	Dibutyl phthalate	February 2015
Annex XIV	Trichloroethylene	April 2016
Annex XIV	Chrome-VI based substances	September 2017
Candidate List	Hydrazine (fuel for Spacecraft)	-
Candidate List	Potassium hydroxyoctaoxodizincatedichromate	-
Candidate List	Methanol	-
Candidate List	1-methyl-2-pyrrolidone (RF absorbing material)	-
Candidate List	Dimethylformamide (in manufacturing process to unglue)	-
Candidate List	N,N-dimethylacetamide	-
Candidate List	N,N-dimethylformamide	-

RoHS directives restrict the use of lead in the manufacture of various types of electronic and electrical equipment (EEE), specifying maximum concentrations in homogeneous materials. However, certain exemptions allow its use in specific SatCom infrastructure.

Scarce materials

Gallium and germanium are critical elements for SatCom due to their applications in microwave devices and solar panels, respectively. Other materials such as neodymium, tantalum, and indium have specific uses but limited alternatives.

4.2.4.2.2 Cleaner technology options

Hazardous chemical substance

Space manufacturers and agencies are addressing REACH obsolescence issues by:

- Using qualified or developing alternatives;

- Seeking authorisation for space-related applications; and
- Exploring exemptions from REACH for space industry applications.

In the ground segment, similar activities are undertaken by SatCom system vendors following ICT industry actions.

Scarce materials

Efforts are ongoing to replace critical materials in the space segment, including:

- Gallium: potential alternatives include GaN over SiC substrate, SiGe on SiC substrate, and InP semiconductors.
- Germanium: graphene and carbon nanotubes are considered for future photovoltaic cells, and flexible, light Kapton layers for sun shields.
- Tantalum: alternatives include niobium capacitors and avoiding sourcing from conflict regions.
- Indium: removed from soldering techniques but still used in solar panel junctions.

4.2.4.2.3 Conclusion and a way forward

This section highlights the necessity to address hazardous chemical substances and scarce materials in SatCom systems, driven by a recent wave of stringent EU policies. It underscores ongoing efforts to find viable alternatives, which incur significant costs, and necessitate investment, cooperation, and technological innovation. More specifically, what needs to be addressed as soon as possible is:

- A lack of investments at the EU level in highly specialised applications and related research;
- Leveraging European R&D for sourcing outside China (the source No.1 or No.2 of several materials relevant for the SatCom industry cited in this section and the 2020 Critical Raw Materials Report (see its Annex 2)) and other extra-European suppliers, especially critical countries, such as Congo DR (the source of more than 50% of EU imports of cobalt), and/or localising supply chains.
- Finding alternatives for substances banned under the current EU policy context applicable to the relevant materials.

4.2.5 Waste potential and handling

This sub-section addresses mainly the space debris issue. It first identifies the relevant regulations in France, which has been the first country to tackle the problem and at European level.

It then characterises this issue, its root causes, key metrics for related space sustainability, and the European opportunity to lead in sustainability endeavours connected to space-relating waste.

It also refers to specific contributions from E-Space to mitigate the problem. The sub-section closes with a particular analysis of French law relating to space operations, and an outline of relevant EU framework in this regard.

4.2.5.1 Relevant regulations for the space debris issue

French space law (loi spatiale)

LOI n° 2008-518 du 3 juin 2008 relative aux opérations spatiales, hereinafter 'French space law' or 'space law', is focused on space debris and waste management within the scope of space activities.[7] Below is a brief analysis of the law:

1. Scope and objectives (Arts. 1 and 2 of space law). The law primarily addresses the regulation of space operations to ensure the long-term sustainability of space activities by minimising space debris generation. It sets forth requirements for space operators to manage waste and debris generated by their activities.
2. Operator responsibilities (Arts. 12-20; see also Arts. 2, 5-8). Covered operators are required to implement measures to reduce the creation of space debris throughout the lifecycle of space objects, from launch to disposal. The law binds operators to provide detailed plans for the mitigation of space debris, including end-of-life disposal plans for satellites and other space objects.
3. Compliance and monitoring (Arts. 4-8). Concerned operators must comply with technical standards and guidelines set by relevant authorities, such as the French Space Agency (CNES). Regular monitoring and reporting are required to ensure adherence to these standards. Operators must provide data and evidence of compliance as requested by regulatory bodies.
4. Sanctions for non-compliance (Arts. 9-11). Space law includes penalties and sanctions under French administrative and criminal law in cases where operators fail to meet the required standards for space debris mitigation. These penalties can include fines and other administrative actions to enforce compliance.
5. International cooperation (see Arts.12, 14, 22, 24). Notably, French space law emphasises the importance of international collaboration in managing space debris, aligning with international guidelines and best practices. France's commitments under various applicable international agreements are reinforced, promoting global efforts to address space debris issues.
6. Technical standards and guidelines (see e.g. Art.21). Specific technical guidelines are provided for the design, operation, and disposal of space objects to minimise debris generation. The law encourages the use of innovative technologies and best practices in debris mitigation efforts.

All in all, French space law is part of France's broader commitment to ensuring the responsible use of outer space and protecting the space environment for future generations. The comprehensive approach includes strict regulatory requirements, continuous monitoring, and active participation in European and international initiatives aimed at reducing space debris.

EU most relevant framework

Note that, at the supranational level, the EU has two main instruments to address directly the space sustainability, and, in particular, the debris management. **Copernicus Regulation e**stablishes the Copernicus Earth observation programme, which provides valuable data for environmental monitoring and disaster management. **European Code of Conduct for Space Debris Mitigation is a** non-binding code, endorsed by the ESA and EU member states, and provides guidelines for minimising space debris. The key provisions of both instruments are outlined in the previous sub-section 4.2.2.

4.2.5.2 Characterisation of the space debris issue

Scoping space debris

The severity of space debris currently produces the ecological and socio-economic impacts and the threat to the future of space exploration, as well as to Earth's environment and broader sustainability.[8] The two most critical impacts are:

- Economic impact: space debris can cause costly damages to current spacecraft, increase the cost of new satellites, and impede the ability to launch new systems; and
- Kessler effect: in-space collisions are expected to rise, leading to a cascading effect where space becomes increasingly hazardous due to debris.[9]

There is thus a pressing need of rethinking spacecraft design to minimize these risks.

Root causes

The key root causes of the space debris problem are identified as follows:

- Existing debris: there are over one million debris objects between 1 and 10 cm, 36,500 objects 10 cm and larger, and more than 10,000 metric tons of debris in orbit (as per the presentation by Greg Wyler at the 1st ESA Workshop on Satcom in Very Low Earth Orbit (VLEO) on November 4, 2022); and
- Regulatory gaps: a current lack of global minimal regulations has led to a 'Wild West' scenario in Low Earth Orbit (LEO), with minimal regard for long-term safety and sustainability (as per Wyler's, 4 November 2022, cited above).

Key metrics for space sustainability

The concept of orbital carrying capacity highlights critical metrics such as:

- Collision probability: factors include satellite cross-sectional area, mass, number of objects, and manoeuvrability; and
- Space utilisation: ensuring equitable access to space necessitates understanding and managing these metrics.

4.2.5.3 Proposed approaches to space safety and space debris-related sustainability

To mitigate the debris problem, for instance, Greg Wyler of E-Space proposes several design principles for satellites[10]:

1. Small cross-sectional area: minimises collision probability.
2. Low mass: reduces the likelihood of creating debris upon collision.
3. No component release: prevents additional debris generation.
4. Fail-safe deorbiting: ensures satellites deorbit automatically in case of failure.
5. Complete burn-up: satellites should burn up upon re-entry, leaving no debris.
6. Debris capture and deorbit: satellites should be capable of capturing components from collided objects and sacrificially deorbiting.

4.2.6 Migration aspects between 5G-NTN and 6G-NTN

Most likely the earliest 5G-NTN based LEO constellation will be deployed and operational in 2027/28. Assuming a 7 years lifetime, such constellation should be up and running until 2034/35 while the 6G is expected to be deployed from 2030 onwards.

Since the objective is to deploy 6G-NTN service in the same time frame as the 6G TN component, it is desirable that 6G-NTN can be deployed leveraging 5G-NTN based LEO constellation infrastructure. This would prevent the deployment of an extra constellation (6G-NTN specific) and hence significant increase of space objects and risk of additional debris in the long term.

Conversely, 6G-NTN based LEO constellation are expected to replace progressively the 5G-NTN ones from 2034/35 onwards. It would be beneficial to be able to continue to support 5G-NTN capable UE which may be mounted for a long usage on vehicle, transportation platforms.

Therefore, it is recommended that the 6G NTN be designed to support some Backward compatibility between 6G-NTN and 5G-NTN to be able to extend the lifetime of both the 5G-NTN infra and UE.

Enabling the implementation of 6G-NTN upgrades onto the LEO based 5G satellite network infrastructure. This should be possible since the 5G-NTN infra should be mostly transparent payload

Enabling 6G-NTN radio protocol to support 5G-NTN capable UE.

4.2.7 EMF exposure

As stated by the World Health Organisation in https://www.who.int/health-topics/electromagnetic-fields#tab=tab_1, "*Electromagnetic fields (EMF) of all frequencies represent one of the most common and fastest growing environmental influences, about which anxiety and speculation are spreading. All populations are now exposed to varying degrees of EMF, and the levels will continue to increase as technology advances.*"

Most of the EMF exposure that individuals experience comes from their mobile phones and is directly proportional to its transmitted power :

"*Mobile phones are low-powered radiofrequency transmitters, operating at frequencies between 450 and 2700 MHz with peak powers in the range of 0.1 to 2 watts. The handset only transmits power when it is turned on. The power (and hence the radiofrequency exposure to a user) falls off rapidly with increasing distance from the handset. A person using a mobile phone 30–40 cm away from their body – for example when text messaging, accessing the Internet, or using a "hands free" device – will therefore have a much lower exposure to radiofrequency fields than someone holding the handset against their head.*"

"*Radiofrequency exposure limits for mobile phone users are given in terms of **Specific Absorption Rate (SAR)** – the rate of radiofrequency energy absorption per unit mass of the body. Currently, two international bodies[11],[12] have developed exposure guidelines for workers and for the general public, except patients undergoing medical diagnosis or treatment. These guidelines are based on a detailed assessment of the available scientific evidence.*"

In the case of NTN, one should distinguish between

devices with directive antenna for which issues are limited as long as the users don't stand in from of the antenna aperture.

Smartphone devices which may be hold near the ear of the user

In the latter case, the operation of a smartphone in a Non-Terrestrial Network differs from the operation in a terrestrial network, by the average transmit power. In NTN, a UE is quasi always transmitting at higher power whenever data is transmitted.

For terrestrial network, it has been estimated[13] that in rural environments, the 95th percentile time-averaged output power values were found to be 2.2% of the maximum available power for LTE UE. This corresponds to ~1 dB less compared to max transmit power.

Given that EMF has a cumulative effect, the SAR limit for UE operating in NTN should hence be 1 dB lower that for UE operating in Terrestrial Network.

The CENELEC specifies SAR limits within the EU, following IEC standards. For mobile phones, and other such hand-held devices, the SAR limit is 2 W/kg averaged over the 10 g of tissue absorbing the most signal (IEC 62209-1).

Hence for smartphones UE operating in NTN, the SAR limit should be reduced to 1.95 W/kg.

4.3 NTN CONTRIBUTION TO A SUSTAINABLE 6G (FOOT PRINT)

4.3.1 Impact on energy consumption

The demand in connectivity at global level is driven partly by some unconnected consumers (the digital divide challenge) and partly by verticals which also operate in areas beyond the current terrestrial mobile system coverage.

Addressing this traffic demand with terrestrial network would require a large number (millions) of base stations as well as a dense fiber networks leading to a high carbon footprint given that the Radio Access Network accounts about 73% of a terrestrial mobile network's energy consumption and 80% of its carbon footprint. Furthermore, most of the currently unconnected areas feature a low densely populated areas where profitability is harsh to achieve. Hence it is beneficial to consider the deployment of a NTN component with fixed investment instead of a TN component which investment increases exponentially with the coverage area.

While NTN will not reduce the foot-print carbon of 6G, it will undoubtedly enable sustainable development of the 6G system.

Foster the development of the economy in areas away from the overcrowded/highly polluted cities

Balance the traffic between NTN and TN with an objective to optimize the overall energy consumption of the 6G system, for example with the energy shut down or reduction of under-used Base stations during the periods of day with low traffic demand.

Detect the 6G service demand and assess where the 6G TN component shall be deployed in priority

4.3.2 Off-loading of signalling and traffic

It may be beneficial to off load part of the traffic and signalling onto the NTN component in order to improve the overall energy consumption of the 6G system.

This would require to develop smart routing techniques which will take into account not only the QoS characteristics but also the energy efficiency metrics associated to NTN and TN component.

More-over, it should take into account the size of the targeted audience for the traffic and common signalling which may be best off loaded to broadcast service over the largest area.

4.3.3 Optimum spectrum usage between NTN and TN

Spectrum is a scarce resource and with the ever-increasing traffic demand, its usage shall be always further optimised while ensuring the necessary QoS.

So far, the spectrum has been segmented in frequency bands each assigned to a specific service (e.g. mobile and satellite services). With the unification of both TN and NTN component in the 6G system, the frontier between such services is becoming increasingly blurred.

Besides, the use of a given frequency band across a geographical area may not be uniform in

- Time: with a varying spectrum usage over a 24h period
- and space: resulting in local hot spots over urban areas and low usage in the rest of the area.

With the capability to operate jointly both TN and NTN components in 6G, it will be possible to consider innovative scheme enabling smart spectrum coexistence between both types of services, up to possible sharing of the same frequency band under specific operational conditions.

This does not preclude to maintain exclusive allocations of selected frequency bands to each services.

4.4 HANDPRINT OF NTN IN 6G: IMPACT ON SOCIETY

4.4.1 Impact on digital divide

The digital divide is defined as ‘the gap between those who have affordable access, skills, and support to effectively engage online and those who do not’.[14] In other words, the digital divide means more than just access to the internet or mobile devices. It actually includes disparities in:

1. Affordability
2. digital literacy
3. infrastructure quality
4. content access.

Essentially, we are addressing Digital (In)Equality. The lack of digital equality significantly affects state and citizen engagement in the digital economy and overall sustainable development of society.

For our project, the above points 1 (affordability) and 3 (infrastructure quality) are the most relevant.

Affordability in the context of digital divide refers to whether individuals and communities can financially access digital technologies and hardware. It is about the initial cost of devices, but also about ongoing expenses such as internet subscriptions, software, and maintenance. Thus, infrastructure goes hand in hand with affordability and accessibility. Affordability is one of the gaps we need to bridge to achieve digital inclusion. Indeed, affordability has huge impact on education, but also on healthcare, remote working, job opportunities and new market/business opportunities.

But the most important aspect of digital divide for our project is **infrastructure quality.** High-quality infrastructure ensures that digital services are inclusive, reliable, fast, and accessible to all segments of the population, thus helping to bridge the gap of affordable and accessible connectivity.

The key aspects of infrastructure quality in the context of our project are:

Internet speed and latency: for example, in poorer countries and regions, internet speeds are often slower, and latency is higher compared to developed countries. This can hinder activities that require real-time data transfer, such as remote work, education, telemedicine, etc. 6G promises significantly higher speeds (up to 100 times faster than 5G) and ultra-low latency, enabling real-time applications even in regions that currently experience poor network performance.

Reliability and resilience: for example, the regions prone to natural disasters may experience frequent disruptions in their digital infrastructure, affecting communication and emergency response efforts. 6G networks are designed to be highly resilient, with self-healing capabilities and the use of AI for predictive maintenance. This ensures continuous service availability even during adverse conditions.

And, most importantly, the aspect of network coverage, implying problems at the duality urban vs. rural Areas: very often, including in the richest countries of Western Europe, urban areas tend to have robust network coverage with high-speed internet, while rural and remote areas often suffer from poor connectivity. This disparity limits the economic and educational opportunities for residents in underserved regions. 6G interface itself, which (unlike 5G where digital divide was about connectivity vs. non-connectivity issues) aims to provide ubiquitous connectivity, including coverage in hard-to-reach areas through technologies like NTNs, thanks to such as HAPS discussed earlier in this study.

Regarding the interface of infrastructure quality with 6G, in terms of bridging digital divide in the context of the above issues and beyond, it several important points. Firstly, 6G will **leverage advanced technologies** such as terahertz communication and intelligent surfaces to provide seamless connectivity. This means a truly enhanced connectivity and that even remote areas will have access to high-speed internet, reducing geographic disparities. Secondly, by integrating NTNs, 6G will ensure **global coverage**, including areas where terrestrial infrastructure is challenging to deploy. For instance, satellites and HAPS will offer connectivity in remote and rural regions, enhancing infrastructure quality.

Thirdly, and importantly, it means **higher capacity and lower latency**, namely, 6G networks will offer unprecedented data transfer rates and minimal latency, supporting applications that require instantaneous communication. This will benefit sectors like healthcare (telemedicine), education (virtual classrooms), and business (remote work), thereby **narrowing the digital divide**.

Last, but definitely not least, it will bring about **more sustainable and energy-efficient networks**. Sustainability is a core aspect of 6G development. On the other hand, recall that in Section 4.1 we highlighted and analysed the most relevant aspects of telecom’s carbon and broader environmental footprint, energy consumption issues, and, thereby a need for an enhanced energy efficiency. By focusing on energy-efficient network designs and renewable energy integration, 6G is sustainable by design and will reduce the environmental impact of digital infrastructure, making it more sustainable and reliable in the long term.

For example, one key current challenge is an inconsistent and inadequate network infrastructure in urban areas that can hamper the deployment of smart city technologies. 6G will support massive IoT deployments, enabling real-time data collection and processing for smart traffic management and energy-efficient buildings, thus enhancing energy efficiency.

To summarise, infrastructure quality is a pivotal element in overcoming the digital divide. The advent of 6G promises to significantly enhance digital infrastructure by providing high-speed, low-latency, reliable, and sustainable connectivity in Europe. This will ensure that all regions, regardless of their geographic or socio-economic status, can benefit from the sustainable digital transformation, fostering greater equity and inclusion in the digital age.

4.4.2 Impact on transportation sectors

As we underlined earlier in this document, NTNs are integral to the deployment of 6G and play a significant role in enhancing connectivity, particularly in remote and underserved areas. They thus offer several advantages for reducing energy consumption across various sectors, including transportation aspects in aeronautics, maritime, and agriculture. Since one of our main focuses in Section 4 is **energy consumption** and, thereby, **energy efficiency,** in this section we thus consider only NTNs benefits regarding energy consumption and efficiency, and the aspects directly related to them. We are aware of such other revolutionary concepts as, for example, the indoor farming based on advanced digital and communication services in agriculture,[15] but they seem to be beyond the scope of the present section.

In general, in transportation, NTNs have the potential to optimise routing and traffic management. One of the main ways doing this is through **broadband connectivity to drones** (or UxV). Drones are uncrewed aerial vehicles (UAVs) that vary in size and flying capabilities, including range, endurance, and maximum payload. Depending on their category, flying drones can operate at altitudes ranging from a few meters to several thousand meters. NTN connectivity is essential for drones with medium (tens of kilometres) to long (hundreds of kilometres) range or endurance. These drones can perform various missions such as high-definition video observation for situational awareness and relaying local telecommunication traffic. Drones can refer to uncrewed maritime ships or land vehicles. NTN connectivity can support remote piloting for these vehicles, provided it ensures high reliability and low latency. This is particularly important for **agricultural vehicles** in **enclosed areas**.[16]

Another important feature for all three sectors concerned is **high speed broadband connectivity to transportation platforms**. NTNs can provide real-time data on traffic conditions and weather, allowing for optimised routing of vehicles and vessels. This reduces fuel consumption by minimising idle time and avoiding congested routes. For example, satellites can deliver precise GPS data for navigation systems, helping those who drive/navigate to choose the most efficient paths and reduce travel time and fuel usage. Another example is the fleet management, when NTNs can help enabling continuous monitoring and management of vehicle fleets. This helps in maintaining optimal driving practices and scheduling maintenance to **prevent inefficient energy consumption**. HAPS can oversee large areas, providing connectivity and data to logistics companies for better fleet management and reduced operational costs.[17]

In **aeronautics**, NTNs can enhance efficiency through **optimising flight path**. NTNs has the capacity to provide comprehensive atmospheric data and satellite-based navigation aids that help in **plotting the most efficient flight paths**, **reducing fuel consumption and emissions**.

Co-funded by the European Union

For example, airlines can use real-time satellite data to adjust flight routes dynamically to avoid adverse weather conditions and optimise energy efficiency.

NTNs can also contribute to **remote monitoring and maintenance**. Namely, NTNs can facilitate continuous monitoring of aircraft systems, enabling **predictive maintenance** and **reducing the need for energy-intensive repairs**. For instance, UAVs equipped with sensors can inspect aircraft for maintenance issues, ensuring timely interventions and improving energy efficiency.[18]

Regarding **maritime** sector, quite similarly to aeronautics, NTNs can make navigation more efficient by providing ships with accurate navigational data and weather forecasts, allowing for **optimised routing and reduced energy consumption**. For example, satellite communications **enable ships to navigate the most efficient routes**, avoiding storms and reducing travel distances. Moreover, in terms of fleet and cargo management, NTNs allow for real-time tracking and management of maritime fleets and cargo, **enhancing logistics and reducing unnecessary fuel use**. For instance, HAPS can monitor large ocean areas, providing data for efficient route planning and fuel management for shipping companies.

For **agriculture**, NTNs will act through quite the same workings as for the two previous sectors, and can play an important role especially in (i) **digital farming** and (i) **precision agriculture**.[19]

Regarding the former, NTNs support the operation of autonomous automated agricultural machinery, which can **optimise farming processes** and **reduce energy consumption**. This can be implemented through UAVs and HAPS providing connectivity and data for autonomous tractors and harvesters, enabling them to **operate more efficiently** and **reduce fuel use**.

In precision agriculture, NTNs enable precise monitoring of crop conditions and soil health through satellite imagery and UAVs. This supports **efficient use of resources** like water and fertilizers, reducing energy consumption. That is, satellites can monitor crop health and provide data for **targeted irrigation and fertilisation**, not only **minimising energy use**, but also **maximising yield**.[20]

To summarise, the benefits of NTNs in reducing energy consumption across the three sectors are: (i) global coverage; (ii) real-time data; (iii) predictive maintenance; and resource optimisation. All in all, NTNs are critical in enabling more efficient and sustainable operations especially in terms of transport, be it in aeronautics, maritime, or agriculture sectors. By providing real-time data, global coverage, and enhanced monitoring capabilities, NTNs help in optimising resource use, reducing energy consumption, and **ultimately supporting environmental sustainability goals**. As 6G technology evolves, the role of NTNs in these sectors will become even more pronounced, driving further advancements in energy efficiency and operational effectiveness.

4.5 DESIGN PRINCIPLES FOR A SUSTAINABLE FRIENDLY 6G-NTN

The challenges are to reduce the environmental footprint while improving the performances of non-terrestrial network in the context of 6G.

Let us distinguish two types of non-terrestrial networks:

The network providing connectivity to smartphones and operating in FR1 bands

The network providing connectivity to terminals with directive and self-tracking antenna and operating (VSAT) in above 10 GHz bands

4.5.1 NTN for the connectivity of smartphones

Compared to 5G-NTN, the objective is to improve the throughput and extend the coverage to harsh radio environments for instance, to support messaging services in indoor conditions.

4.5.1.1 Terminal level

Any improvement in terms of sensitivity and antenna gain will be beneficial for the link budget and hence the system performance. With an increased antenna gain, and at equivalent performances, the UE will consume less energy, which would increase the sustainability as the terminal segment is an important part of satellite communication system's carbon footprint (See LCA analysis).

Such improvements in terms of UE characteristics may be at the expense of a reasonable price increase.

4.5.1.2 Space segment level

The link budget is highly constrained. This excludes GSO space segment and would lead to MEO with extremely large deployable antenna.

As per LEO and for a given frequency band, an increase of the system performance would require a larger on board antenna aperture

more satellites in the constellation to ensure higher elevation angle. However, this is not sustainable friendly given that launch and satellite production accounts to the majority of the satellite system's carbon footprint according to Theshiftproject's LCA.

A third approach would be to design a flexible space segment able to increase the throughput in some areas at the expense of others.

HAPS may be considered to address locally a hot spot of traffic, complementing the LEO space segment which provide global service continuity

4.5.1.3 System level

Use of smart routing techniques to transfer the traffic between the non-terrestrial and terrestrial network components according to energy consumption with objective to optimise the overall 6G system energy consumption.

Enablers for the spectrum re-use between the non-terrestrial network and terrestrial network components through AI driven radio resource management.

4.5.2 NTN for the connectivity of VSAT

Compared to 5G-NTN, the objective is to improve the throughput and be able to address smaller device that can be mounted onto vehicles and drones

4.5.2.1 Terminal level

Great care shall be taken to reduce the terminal's complexity and the energy consumption (product and service) of the self-tracking / flat panel antenna through smaller aperture (e.g. < 20 cm and lower) with less radiating elements, lower transmit power, reduced scanning angle (i.e. Min elevation angle should be greater than 30° or even 45°).

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At equivalent performances, a lower complexity antenna will contribute to reduce the carbon footprint of the terminal production phase which accounts to 10-15% of the satellite system's carbon footprint according to Theshiftproject's LCA the modem through adoption of half duplex mode. One beam for transmission (Tx) and two beams for reception (Rx) are recommended.

Reducing the antenna aperture to < 20 cm will allow mounting compatibility on smaller platforms such as vehicles and drones.

4.5.2.2 Space segment level

As seen earlier, a trade-off should be carried out between "NGSO only" versus multi-layer "NGSO+GSO" space segment design.

There are two aspects that could favour the multi-layer design:

Resiliency: Having two layer of space segment can be used to maximise the inherent resiliency of the satellite network with respect to the failure of a given satellite node, since the number of access option is at least double if both layers provide the same coverage.

Sustainability: Phase C/D: The total mass of satellites to be launched may be higher but the extended lifetime of GSO satellites may partly compensate it

Phase E: Can the broadcast capacity of GSO be exploited to off load traffic (e.g. audience driven content) and common signalling? Can the GSO resource be exploited to optimise the energy consumption of terminal and reduce the energy needed for the tracking of satellite in motion ?

In such multi-layer (NGSO/GSO) satellite networks:

GSO would provide

- broadcast services for the distribution of large audience content and the idle mode common signalling as part of the network entry procedure
- broadband services for back-up
- NGSO would provide
- high speed broadband services
- Network based location service

4.5.2.2.1 Design recommendations

NGSO @ relatively low altitude (e.g. LEO) to support low latency: Optimum constellation design to be found: between the support of high elevation angle to support reduced complexity self-tracking antenna and a reduced total mass to be launched

NGSO @ relatively high altitude (e.g. MEO) to ensure multiple satellite in visibility. It may generate large beams for broadcast and smaller beams for broadband

GSO able to generate a flexible beam Pattern: large beams for broadcast and smaller beams for broadband

Regenerative payloads with the support of Inter Satellite Links and edge computing/storage resources may be considered to reduce the ground segment foot print.

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4.5.2.3 System level

Use of smart routing techniques to transfer the traffic between the different non-terrestrial network layers according to the QoS requirements and the energy consumption

Enablers for the spectrum re-use across the non-terrestrial network layers through AI driven radio resource management.

4.6 WAY FORWARD ON THE SUSTAINABILITY FOR THE NTN COMPONENT IN 6G

4.6.1 Refinement of sustainability related requirements identified in 6G-NTN D2.3

Based on the above, the sustainability related requirements identified in 6G-NTN D2.3 will be reviewed in the next phase of the project, with the refinement of Key performance indicators and Key Value Indicators enabling to undertake some quantitative analysis on selected aspects.

The sustainability friendly design principles of the NTN component of 6G will be refined accordingly.

4.6.2 Part of SNS-JU's TF sustainability

The project will continue to take part in the SNS-JU task force to take into account he guidance and feedbacks and promote new KPIs and KVIs towards other projects

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5 CONCLUSIONS

In this document we have highlighted the standardisation activities carried out with the support of the 6G-NTN project. Given that the standardisation of 6G (study and normative phase) have not yet started in 3GPP, it relates to pre standardisation effort. The work plan at 3GPP of the project is also provided. The status of the achievements will be provided in the next version of the document.

We have also initiated some development and deployment plan for 6G-NTN based satellite networks assuming that 5G-NTN based Space segment could be refurbished to roll out some initial 6G-NTN satellite network. This plan will be consolidated in view of the other WP outcomes in the next version of the document.

When considering the sustainability aspect, this covers the environmental footprint and handprint of 6G-NTN based systems

- In terms of footprint, one should distinguish between the
  - The intrinsic footprint of the NTN component in 6G with the following aspects to be considered: energy efficiency, EMF exposure, Hazard and scarce material consumption, Waste potential handling, and the migration between 5G-NTN and 6G-NTN,
  - The potential contribution of NTN component to the footprint of 6G thanks to smart off-loading of signalling and traffic between terrestrial and non-terrestrial networks and enablers for optimum spectrum usage between TN and NTN,
- The handprint of NTN component in 6G includes the impact on society with a focus on the Impact of digital divide and the Impact on the transportation sector (i.e. aeronautical, maritime, railway, land vehicle).
  - This enables to set some sustainable friendly design principles

This initial study will be complemented in the next version of the document with some quantitative assessment.

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