D6.5 STANDARDIZATION, EXPLOITATION, AND SUSTAINABILITY FINAL ROADMAP

Final Version

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Abstract	This document highlights the standardization activities carried out with the support of the 6G-NTN project. It provides a high-level development and deployment plan for the system and considerations for the exploitation plan. Sustainability aspects of 6G-NTN are also addressed covering the environmental footprint and handprint of 6G-NTN-based systems.
Keywords	Standardization, Exploitation, Sustainability

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EXECUTIVE SUMMARY

This document highlights the standardization activities carried out in the framework of the 6G-NTN project.

A development and deployment plan for 6G-NTN-based satellite networks is provided that 5G-NTN-based Space segment can 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 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 TN and NTN 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).

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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
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 provides a comprehensive overview of the standardization, exploitation, and sustainability activities carried out during the 6G-NTN project. It documents how the project's technical outcomes were aligned with relevant standardization and pre-standardization initiatives, translated into exploitable assets, and structured to ensure long-term sustainability and impact beyond the project's duration.

Activities related to exploitation and sustainability were led by Task 6.4, which focused on identifying exploitation pathways, assessing long-term impact, and implementing strategies to secure the continued use of project results. Task 6.3 addressed standardization and pre-standardization, contributing to relevant standards bodies and initiatives to facilitate the adoption of the project's innovations within the 6G Non-Terrestrial Networks (NTN) ecosystem. This deliverable consolidates the outputs of both tasks, providing a complete record of the project's work in these areas.

2 STANDARDIZATION

2.1 Recall of the Project's Standardization Task and Objectives

This task 6.3 was focused 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:

- Promoted a new study item on NTN for 6G 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, high accuracy and reliable positioning methods, spectrum sharing enablers (NTN/NTN and NTN/TN co-existence analysis), monitoring/control enablers for AI driven RAN.
- Coordinated with the SSIG - Satellite Standardization 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 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.
- Identified the 3GPP technical specifications (*e.g.,* related to 3GPP RAN WG1, WG2, WG3, WG4) that needs to be adapted to support the proposed techniques.
- Prepared/promoted technical contributions demonstrating 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 Rel-20 study item.
- Coordinated with relevant stakeholders from mobile, satellite and vertical industries having interest in NTN standardization in 3GPP.
- Contributed to ETSI for the development on a harmonized standard for ultra-small aperture terminals operating in Q/V band.
- Prepared 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.

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

6G-NTN Project Coordinator Alessandro Vanelli-Coralli and 6G-NTN Technical Manager Nicolas Chuberre have been instrumental in the organization 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 across the world and was the first of its kind to allow exchange of ideas on NTN in the context of 6G.

It has been an opportunity, for the 6G-NTN project 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 standardization have been discussed in both 3GPP and ETSI context.

During the conference, a white paper "Vision on Non-Terrestrial Networks in 6G system (or IMT-2030), Use Cases, Requirements, and Possible Standardization approach: A Perspective from the 6G-NTN Project" has been published, 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 the paper at:

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

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 organized : 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). Over 20 questions were raised by the audience.

- 225 viewed the webinar live
- 98 viewed the webinar on-demand until 23/05/2024
- Total number of pre-registrations: 476
- There have 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 webinars organized on other 6G related topics; the rating of the webinar received so far by attendees was **5 out of 5** !

2.2.3 3GPP

Leveraging project outcomes, Thales successfully contributed to 3GPP

- to promote some NTN related features in the work plan of the 5G-Advanced track as well as the 6G track
- to study and define some NTN related features in relevant study/work items of the 5G-Advanced track, as well as the 6G track

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

Here under are the list of relevant NTN related study/work items the project contributed to establish and to execute:

TABLE 1: LIST OF RELEVANT 3GPP NTN RELATED STUDY/WORK ITEMS FOR THE PROJECT

Std projects	3GPP tDoC	Target completion	Scope (NTN related)	Outcomes
Rel-20 Study on GNSS resilient NR-NTN operation (5G-Advanced)	RP-251863	June 2026	Assess impact on initial access and connected mode procedures for NR-NTN	TR 38.8xx
Rel-20 SA1-led Study on 6G use cases and service requirements	SP-241391	March 2026	Proposal of NTN related use cases for at least ubiquitous coverage but also system operations (Last use cases can be introduced in August meeting)	TR 22.870
Rel-20 SA2-led Study on Architecture for 6G System	SP-250806	[Dec 2026]	• WT#2: Study migration and interworking, including ○ How to support interworking between 6GS and 4G/5G NTN/satellite access that use EPS/5GS • WT#7: Study how to support 6G RAT for NTN, based on RAN decision, and support service continuity aspects. ○ NOTE 8: The detailed scope for WT#7 will be coordinated and aligned with RAN	TR 23.801-01
Rel-20 RAN-led Study on 6G Scenarios and requirements - part 1 & 2	RP-2 50810	June 2026	Performance Requirements Deployment scenarios Functional Requirements *j) Aim at a harmonized 6G Radio design for TN and NTN, including their integration*	TR 38.914
Rel-20 RAN1-led Study on 6G Radio	RP-251881	March 2027	Radio interface and radio access aspects	TR 38.9XX, 38.8xx

2.2.3.1 3GPP Rel-20 SA1-led study item on 6G use cases and service requirements

Note that SA1 working group is responsible for the definition of service requirements.

- Promotion of NTN for the study item

Firstly, at the Stage 1 Workshop on IMT-2030 Use Cases, 8-10th May 2024 in Rotterdam/The Netherlands which agenda and the list of documents presented can be found at https://www.3gpp.org/ftp/workshop/2024-05-08_3GPP_Stage1_IMT2030_UC_WS,

- an 6G-NTN contribution has been introduced in the 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.
- 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: the views presented by Nicolas Chuberre during this panel didn't necessarily represent the views of other 6G-NTN partners.

Secondly, 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 contribution from Thales did not necessarily reflect the views of other 6G-NTN partners.

Contribution to the study item

Leveraging 6G-NTN project outcomes, Thales prepared and submitted numerous contributions to SA1 which led to the adoption of the following use cases related to NTN highlighted with bold characters in the 3GPP Technical Report TR 22.870:

- 5 System and Operational Aspects
  - 5.6 Sustainability and Energy Efficiency
    - **5.6.x Use case on "Energy efficiency of 6G system with multiple access networks (TN and NTN)"**
  - 5.8 Device Support
    - **5.8.x Diversity of UEs for satellite access**
- 8. Ubiquitous connectivity
  - **8.1 Use case on Ubiquitous and Resilient Network**
  - 8.2 Use case on enhanced user experience with sparse LEO satellite deployment

- **8.3 Use case on "service continuity for wearable mobile devices"**
- 8.4 Use case on resilient positioning in satellite networks
- **8.5 Use case on "Disaster relief"**
- **8.6 Use case on "low-energy positioning in satellite networks"**
- **8.7 Use case on Global mobile video**
- 8.8 Use case on low-altitude logistics supported by NTN
- 8.9. Use case on hybrid TN and NTN positioning
- 8.10 Use case on hybrid NTN and GNSS positioning

List of contributions submitted to SA1 on 6G use cases (targeting the 3GPP TR 22.870) are

- S1-242017 "Views on Rel-20 6G study item's areas of interest" submitted by Thales, TNO, Airbus, SES, EchoStar to SA1#107 in August 2024 under agenda item: 8.2 "6G area of interest contributions"
- S1-244020 "NTN related 6G System and Operational aspect" submitted by Thales to SA1#108 in November 2024 under agenda item 8.1.1 System and Operation Aspects (FS_6G-REQ)
- S1-244015 "Use Case on "Resilient and quasi seamless service continuity for wearable devices"" submitted by Thales to SA1#108 in November 2024 under agenda item 8.1.3 Ubiquitous Connectivity (FS_6G-REQ)
- S1-244019 "Use Case on "Disaster relief"" submitted by Thales, TNO, Firstnet, Mitre to SA1#108 in November 2024 under agenda item 8.1.3 Ubiquitous Connectivity (FS_6G-REQ)
- S1-244214 "New use case on low-energy positioning in satellite networks" submitted by Thales, ESA, Novamint, SyncTechno Inc., ETRI, Softil, NICT, Sateliot, Airbus to SA1#108 in November 2024 under agenda item 8.1.3 Ubiquitous Connectivity (FS_6G-REQ)
- S1-250275 "Use Case on "Disaster relief" - Updates" submitted by Thales, ESA, Novamint to SA1#109 in February 2025 under agenda item 8.1.4 Ubiquitous Connectivity (FS_6G-REQ)
- S1-250141 "Diversity of devices for NTN in 6G" submitted by Thales, Novamint to SA1#109 in February 2025 under agenda item 8.1.1 System and Operation Aspects (FS_6G-REQ)
- S1-250144 "Use case on low-energy positioning in satellite networks – Updates" submitted by Thales, ESA, Novamint to SA1#109 in February 2025 under agenda item 8.1.3 Ubiquitous Connectivity (FS_6G-REQ)

- S1-250142 “Resiliency to failure with NTN in 6G” submitted by Thales, Novamint to SA1#109 in February 2025 under agenda item 8.1.1 System and Operation Aspects (FS_6G-REQ)
- S1-250143 “6G NTN resiliency to GNSS unavailability” submitted by Thales, Novamint to SA1#109 in February 2025 under agenda item 8.1.1 System and Operation Aspects (FS_6G-REQ)
- S1-250023 “Energy efficiency of 6G with multi radio access technologies (NTN and TN)” submitted by Thales, Novamint to SA1#109 in February 2025 under agenda item 8.1.1 System and Operation Aspects (FS_6G-REQ)
- S1-252054 “Energy efficiency of 6G with multi radio access technologies (NTN and TN)” submitted by Thales, Novamint to SA1#110 in May 2025 under agenda item 8.1.2 System and Operation Aspects (FS_6G_REQ)
- S1-252055 “6G NTN resiliency to GNSS unavailability” submitted by Thales, Novamint to SA1#110 in May 2025 under agenda item 8.1.2 System and Operation Aspects (FS_6G_REQ)
- S1-252056 “Use Case on “Disaster relief” – Updates” submitted by Thales, ESA, Novamint to SA1#110 in May 2025 under agenda item 8.1.5 Ubiquitous Connectivity (FS_6G_REQ)
- S1-252057 Diversity of devices for NTN in 6G submitted by Thales, Novamint to SA1#110 in May 2025 under agenda item 8.1.1 System and Operation Aspects (FS_6G_REQ)
- S1-252058 “Resiliency to network nodes failure in 6G” submitted by Thales, Novamint to SA1#110 in May 2025 under agenda item 8.1.1 System and Operation Aspects (FS_6G_REQ)
- S1-252298 “Updated UC "service continuity for wearable mobile devices"” submitted by Thales to SA1#110 in May 2025 under agenda item 8.1.5 Ubiquitous coverage (FS_6G_REQ)
- S1-252296 “Use case on low-energy positioning in satellite networks – Updates”, submitted by ESA, Thales, Novamint, Airbus to SA1#110 in May 2025 under agenda item 8.1.5 Ubiquitous coverage (FS_6G_REQ)
- S1-253017 “UC 8.5 Disaster Relief – Updates” submitted by Thales, Novamint, MITRE, Firstnet, TNO to SA1#111 in August 2025 under agenda item 8.1.5 Ubiquitous coverage (FS_6G_REQ)
- S1-253016 “UC 5.8.2 Use case on energy efficiency of 6G system with multiple access networks (TN and NTN) – UPDATES”, submitted by Thales, Novamint, to SA1#111 in August 2025 under agenda item 8.1.2 System and Operation Aspects (FS_6G_REQ)
- S1-253019 “Multi-tenant 6G satellite access”, submitted by Thales, Novamint, to SA1#111 in August 2025 under agenda item 8.1.2 System and Operation Aspects (FS_6G_REQ)

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- S1-253015 "Energy efficient 6G coverage", submitted by Thales, Novamint, to SA1#111 in August 2025 under agenda item 8.1.2 System and Operation Aspects (FS_6G_REQ)
- S1-253020 "UC - Diversity of UEs for satellite access –UPDATES", submitted by Thales, Novamint, to SA1#111 in August 2025 under agenda item 8.1.2 System and Operation Aspects (FS_6G_REQ)
- S1-253018 "New UC - Resiliency with NTN" , submitted by Thales, Novamint, to SA1#111 in August 2025 under agenda item 8.1.2 System and Operation Aspects (FS_6G_REQ)
- S1-253306 "Correction of editorial issue in use case on low-energy positioning in satellite networks", submitted by Thales, Novamint, to SA1#111 in August 2025 under agenda item 8.1.5 Ubiquitous coverage (FS_6G_REQ)
- S1-254433 pCR Pseudo-CR on Annex related to satellite/NTN Novamint, Thales, TNO, ESA, SoftBank Corp.
- S1-254407 pCR Updated use case 8.7 on low-power positioning Nokia, AT&T, ESA, Thales, Novamint, Airbus
- S1-254406 pCR New use case on Event-based Inter-PLMN Coordination LG Uplus, SK Telecom, Thales, Novamint
- S1-254393 pCR Resubmission of use case on High-altitude UAV supervision TNO, Airbus, ESA, Fraunhofer, Thales, Novamint
- S1-254392 pCR Resubmission of a use case on Satellite based Sensing of space objects TNO, Airbus, ESA, Fraunhofer, Thales, Novamint
- S1-254382 pCR Use Case on Enhanced Multi-Access Connectivity NICT, Deutsche Telekom, Thales, Novamint, NEC, TNO, Sharp, Eutelsat, EDF, Viasat, ESA, SES, Airbus, Netherlands Police, Hispasat, JSAT, Philips, Terrestar, Gilat, SyncTechno Inc., EchoStar, Boost Mobile Network, Lockheed Martin, Skylo
- S1-254350 pCR New Use Case on critical communication infrastructure during a power outage situation KPN, TNO, Telefonica, Philips, Thales
- S1-254337 pCR UC 5.8.2 Use case on energy efficiency of 6G system with multiple Thales, Novamint
- S1-254284 pCR Resubmission of use case on NTN based Atmospheric monitoring and weather alerts TNO, Airbus, ESA, Fraunhofer, Thales, Novamint
- S1-254283 pCR Resubmission of use case on NTN based detection of ships in the open sea TNO, Airbus, ESA, Fraunhofer, Thales, Novamint
- S1-254282 pCR Resubmission of use case on NTN based high-altitude UAV supervision TNO, Airbus, ESA, Fraunhofer, Thales, Novamint
- S1-254281 pCR Resubmission of a use case on NTN based Sensing of space debris TNO, Airbus, ESA, Fraunhofer, Thales, Novamint
- S1-254280 pCR Pseudo-CR on Annex related to satellite/NTN Novamint, Thales, TNO, ESA

- S1-254278 pCR New use case on event-based inter-operator reselection coordination LG Uplus, SK Telecom, Thales, Novamint
- S1-254214 pCR Pseudo-CR on Annex related to satellite/NTN NOVAMINT, Thales, TNO, ESA
- S1-254080 pCR UC - 5.10.2 Diversity of UEs for satellite access - UPDATES THALES
- S1-254076 pCR Updated use case 8.7 on low-power positioning Nokia, AT&T, ESA, Thales, Novamint, Airbus
- S1-254032 pCR Use Case on Enhanced Multi-Access Connectivity NICT, Deutsche Telekom, Thales, Novamint, NEC
- S1-254021 pCR UC 5.8.2 Use case on energy efficiency of 6G system with multiple access networks (TN and NTN) - UPDATES THALES

2.2.3.2 Rel-20 SA2-led Study on Architecture for 6G System

Note that SA2 WG is responsible for the definition of the system architecture.

- **Promotion of NTN for the study item**

Leveraging 6G-NTN project outcomes, Thales prepared and submitted a contribution (S2-2504855) together with Echostar, calling for the creation of a Rel-20 6G study item addressing the support of 6G RAT for NTN use cases.

1. Investigate adaptation and evolution of the core network to support the 6G RAT including NTN capabilities.
2. Study enhancements for seamless service continuity between terrestrial and satellite networks.
3. Study the interworking mechanisms between 6G NTN and existing NTN networks.
4. Study the interworking mechanisms between 6G NTN and 5G/4G terrestrial networks.
5. Study how to utilize 6G NTN as a key enabler for critical 6G use cases requiring ubiquitous coverage, network resiliency and sustainability, integrated sensing.
6. Leveraging existing multi orbit solutions developed in 5G and study how to extend it in the 6G context.
7. Enhancements to embark Core Network NFs onboard satellites.

8. Support of broadcast and multicast services over 6G NTN.
9. Study on how 6G NTN can support Positioning Navigation and Tracking.

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

As a result, the study item was agreed in June 2025 with NTN-related objectives recalled here under:

- WT#2: Study migration and interworking, including
  - How to support interworking between 6GS and 4G/5G NTN/satellite access that use EPS/5GS.
- WT#7: Study how to support 6G RAT for NTN, based on RAN decision, and support service continuity aspects.

NOTE 8: The detailed scope for WT#7 will be coordinated and aligned with RAN

Contribution to the study item

- S2-2506226 "6G system architecture to support of NTN", submitted by Thales, Novamint, ST Engineering iDirect, to SA2#171 in August 2025 under agenda item 20.6.1 FS_6G_ARC
- S2-2511254 pCR [WT#7]: Work task and key issue for 6G satellite access. CATT, Ericsson, OPPO, LGE, NTT DOCOMO, Skylo Technologies, NEC, Novamint, Thales, TNO, EchoStar, Inmarsat, Viasat, Sateliot, Airbus, Eutelsat, Vivo, Spreadtrum, CSCN, MediaTek Inc., China Unicom, China Telecom, China Mobile, ZTE corporation, Xiaomi, QC, N
- S2-2509940 pCR [WT#7] Work task and key issue for 6G satellite access. NEC, Thales

2.2.3.3 3GPP Rel-20 RAN-led study on 6G scenarios and requirements - part 1 & 2

Note that TSG-RAN is responsible for the definition of the Radio access network and the radio protocol.

- **Promotion of NTN for the study item**

Leveraging 6G-NTN project outcomes, Thales prepared and submitted two contributions, calling for the creation of a Rel-20 6G study item as part of the TSG-wide 6G Workshop stage 2 in Incheon/Korea (10-11th March 2025):

- 6GWS-250027 proposing that:
  - The study on 6G scenarios and requirements shall consider satellite-based access.
  - NTN radio specifics in terms of extended/variable propagation delay/Doppler shift, radio cells (earth moving/fixed), channel model(s), propagation impairments, spectrum, and support of simultaneous multi-satellite connectivity shall be taken into account from day one (i.e. study phase in Rel-20 and normative phase in Rel-21) for the definition of the 6G Radio interface.
  - RAN to discuss the introduction of additional NTN-related features in Rel-20/21 and/or beyond.
- 6GWS-250040 requesting
  - TSG-RAN to take into account the above recommendations for the definition of the 6G radio interface/access technology.
  - TSG-RAN to consider in priority the following recommendations (see chapter “Radio link characteristics”) for the definition of the 6G radio Interface/access technology as part of Rel-20 study / Rel-21 work items:

GNSS independent operation with GSO and NGSO space segment	Satellite service allocated spectrum
Low multi path propagation	Satellite propagation impairments
Extended coverage	Enhanced error floor without HARQ

  - TSG-RAN to further discuss in which release(s) of 6G the other recommendations should be addressed

Efficient grant free access protocol	4G NB-IoT NTN, 5G NR NTN and 6G radio access coexistence in same beams
TN/NTN mobility	Multi connectivity/carrier aggregation
Extension of satellite footprint	GNSS free Positioning Navigation and Timing
On board power constraints	Enhanced network verified UE location service
Flexible RAN functional split	Broadcasting service
Enhanced security	UE with directive antenna

Note: These Thales contributions did not necessarily reflect the views of other 6G-NTN partners.

As a result, the study item was agreed in March 2025 with NTN related objectives recalled here under:

- Develop 3GPP requirements for 6G Radio for these practical deployment scenarios to ensure substantial gains in all relevant bands: overall performance, user experience, TCO reduction including at least:
    - Aim at a harmonized 6G Radio design for TN and NTN, including their integration

Contribution to the study item

Leveraging 6G-NTN project outcomes, Thales prepared and submitted one contribution in June 2025 (RP-250880 Practical NTN related deployment scenarios) requesting that:

- The 6G radio interface/access shall be defined to support all the practical NTN deployment scenarios described in terms of orbits, and related service link characteristics in the table within clause 3.1 of RP-250880)
- The 6G radio interface/access shall be defined to support all the NTN payload types in the table within clause 3.3 of RP-250880)
- The 6G radio interface/access shall be defined to support all the NTN capable UE types in the table within clause 3.5 of RP-250880)
- The 6G radio interface/access shall be defined to support all the duplex mode at UE and network level in the table within clause 3.5 of RP-250880)
- The 6G radio interface/access shall be defined to support TN/NTN mobility considering the different UE architecture described in the table within clause 4.1 of RP-250880)
- The 6G radio interface/access shall be defined to support TN/NTN multi connectivity with simultaneous traffic flow in both legs
- The 6G radio interface/access shall be defined to provide high-accuracy and resilient positioning without GNSS service

In addition, Thales also submitted the following contributions:

- RP-251949 “3GPP specific requirements on NTN”, submitted by Ericsson, CHTTL, CMCC, ESA, FirstNet, KT Corp., Nokia, T-Mobile USA, Telstra to RAN#109 in Beijing/China in September 2025 under agenda item 8.2.1.4

- RP-251935 “Text proposal for TR 38.914 for NTN deployment scenarios”, submitted by Thales, ESA, Airbus DS, Fraunhofer IIS, Fraunhofer HHI, Eutelsat, Iridium, Gatehouse Satcom, TNO, Novamint, ST Engineering iDirect to RAN#109 in Beijing/China in September 2025 under agenda item 8.2.1.1 Deployment scenarios

- RP-251936 “Text proposal for TR 38.914 for NTN performance requirements” , submitted by Thales, ESA, Airbus DS, Fraunhofer IIS, Fraunhofer HHI, Eutelsat, Iridium, Gatehouse Satcom, TNO, Novamint, ST Engineering iDirect to RAN#109 in Beijing/China in September 2025 under agenda item 8.2.1.2 Key performance indicators

- RP-252147 “Architecture/migration requirements for NTN” submitted by Thales, ESA, Airbus DS, Fraunhofer IIS, Fraunhofer HHI, Eutelsat, Iridium, Gatehouse Satcom, Novamint, Echostar, ST Engineering iDirect to RAN#109 in Beijing/China in September 2025 under agenda item 8.2.1.3 Requirements for architecture and migration

- RP-251982 “New and existing services for NTN” submitted by Thales, ESA, Airbus DS, Fraunhofer IIS, Fraunhofer HHI, Eutelsat, Iridium, Gatehouse Satcom, TNO, Novamint, ST Engineering iDirect to RAN#109 in Beijing/China in September 2025 under agenda item 8.2.1.4 Requirements of new and existing services

- RP-253091 “3GPP specific requirements on NTN”, submitted by Ericsson, CHTTL, CMCC, ESA, FirstNet, KT Corp., Nokia, T-Mobile USA, Telstra to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.4

- RP-253215 discussion NTN preferred/priority mode for 6G KT Corp., Thales, Iridium, Viasat to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.3.3 Other operational requirements

- RP-253206 discussion NTN specific proposals related to co-existence between NB-IoT NTN and 6GR NTN ViaSat Satellite Holdings Ltd, Novamint, Airbus, Sateliot, Gatehouse Satcom, ESA, EchoStar, Thales, Iridium, Skylo, Terrestar to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.3.3 Other operational requirements

- RP-253205 discussion NTN specific proposals related to updates to architecture and migration clause ViaSat Satellite Holdings Ltd, Novamint, Airbus, Sateliot, Gatehouse Satcom, ESA, ST Engineering iDirect, EchoStar, Thales, Skylo, Terrestar to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.2 Architecture and migration

- RP-253102 discussion New and existing services for NTN THALES, Sateliot, Iridium, Fraunhofer IIS, Fraunhofer HHI, Novamint, Gatehouse Satcom, Airbus, ESA, Amazon to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.4 Requirements of new and existing services

- RP-253101 discussion TP on Other operational requirements for NTN THALES, Sateliot, Viasat, ST Engineering iDirect, Novamint, Fraunhofer IIS, Fraunhofer HHI, EchoStar, Gatehouse Satcom, Airbus, SES, ESA, Hispasat to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.3.3 Other operational requirements

- RP-253100 discussion TP on NTN devices THALES, Sateliot, Iridium, Viasat, ST Engineering iDirect, Novamint, Eutelsat, TNO, EchoStar, Airbus, Gatehouse Satcom, ESA to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.3.2 Devices

- RP-253097 discussion TP on Spectrum around 6GHz THALES, Airbus, SES, Hispasat available Decision RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.3.1 Spectrum

- RP-253096 discussion TP on Spectrum for NTN THALES, Iridium, Viasat, ST Engineering iDirect, Novamint, Fraunhofer IIS, Fraunhofer HHI, Eutelsat, EchoStar, Gatehouse Satcom, Airbus, SES, ESA, Hispasat, Sateliot to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.3.1 Spectrum
- RP-253095 discussion TP on on NTN performance requirements THALES, Novamint, TNO, Viasat, Sateliot, Fraunhofer IIS, Fraunhofer HHI, Eutelsat, Gatehouse Satcom, Airbus ST Engineering iDirect, SES, ESA, EchoStar to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.1 Performances
- RP-253089 discussion Requirements for supporting aerial UEs in 6G Ericsson, Airbus, AT&T, BDBOS, CATT, CHTTL, China Telecom, CMCC, DISA, Erillisverkot, FirstNet, Fujitsu, Intel, KDDI, KT Corp., Motorola Solutions, NIST, Nkom, NTT DOCOMO, SK Telecom, Softil, Spark, Spreadtrum, SyncTechno Inc, Telstra, Thales, The Netherlands Police, Verizon, Vodafone to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.4 Requirements of new and existing services
- RP-253088 discussion Resiliency requirements in 6G Ericsson, Airbus, BDBOS, Deutsche Telekom, DISA, Erillisverkot, FirstNet, LGUplus, Motorola Solutions, Nkom, Nokia, Softil, SyncTechno Inc, Telstra, Thales, The Netherlands Police, T-Mobile USA, Verizon to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.3.3 Other operational requirements
- RP-253087 discussion TP on Architecture/migration requirements for NTN THALES, Sateliot, Iridium, Viasat, ST Engineering iDirect, Novamint, Airbus, Fraunhofer IIS, Fraunhofer HHI, Eutelsat, TNO, EchoStar, Gatehous Satcom, SES, ESA, Hispasat, Amazon to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.2 Architecture and migration
- RP-253086 discussion TP on NTN deployment scenarios THALES, TNO, Iridium, BMW, Bosch, Airbus, Eutelsat, Novamint, Toyota, ESA CATT, CSCN, LG Electronics, Sharp, EchoStar to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.0 Deployment scenarios
- RP-253042 discussion Requirements for Vehicular Device Types BMW AG, Robert Bosch GmbH, Volkswagen AG, Toyota ITC, Aumovio, SES S.A., Fraunhofer IIS, BYD, Thales, Airbus to RAN#110 in Baltimore/USA in December 2025 under agenda item 8.2.1.3.2 Devices

2.2.3.4 3GPP Rel-20 RAN1-led study item on 6G radio

Note that RAN1 working group is responsible for the definition of the physical layer.

- **Promotion of NTN for the study item**

Leveraging 6G-NTN project outcomes, Thales prepared and submitted a contribution (RP-251001) calling for the creation of a Rel-20 6G study item and requesting:

- to study in priority the following NTN capabilities for the 6G RAT as part of the Rel-20
    - NTN resiliency to GNSS service
    - PAPR requirements for NTN downlink transmission
    - Flexible frame structure
    - Extended coverage
    - Flexible duplex mode support at UE level
    - Support of HD-FDD at Network side
    - Mitigate specific NTN Propagation impairments
    - Operation at low error rate
    - Massive messaging capability
    - Extension of satellite footprint
    - Positioning Navigation and Timing
    - Enhanced network verified UE location service

- to study, in priority, the following NTN capabilities for the 6G RAT as part of the Rel-21 or beyond
    - Quasi seamless TN/NTN mobility in connected mode
    - 6G NTN coexistence with IoT-NTN or NR-NTN in same beam
    - Multi connectivity/carrier aggregation
    - RAT energy consumption determination for one-to-many service
    - Distributed MIMO across several satellites

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

Contribution to the study item

- R1-2506327 “Overview of 6GR air interface”, submitted by Thales, Eutelsat Group, Airbus, ESA, EchoStar, Viasat to RAN1#122 in Bengalore/India in August 2025 under agenda item 11.1
- R1-2507602 discussion Positioning, Navigation and Timing (PNT) in 6G NTN-TN harmonization Airbus, ESA, Fraunhofer IIS, Thales, Iridium to RAN1#122-bis in Prague/Czech Republik in October 2025 under agenda item 11.1
- R1-2507571 discussion Satellite Access Node Characteristics for the Evaluation Assumptions for 6GR air interface ESA, Thales, Viasat to RAN1#122-bis in Prague/Czech Republik in October 2025 under agenda item 11.2
- R1-2507509 discussion Discussion on 6GR channel coding ETRI, ESA, Thales to RAN1#122-bis in Prague/Czech Republik in October 2025 under agenda item 11.4.1

- R1-2507343 discussion Overview of 6GR air interface THALES, Airbus, ESA, EchoStar, Eutelsat Group, Novamint, TNO, Fraunhofer IIS, Iridium to RAN1#122-bis in Prague/Czech Republik in October 2025 under agenda item 11.1
- R1-2506905 discussion Discussion on waveform for 6GR air interface THALES, University of Bologna, CTTC, DLR, ESA to RAN1#122-bis in Prague/Czech Republik in October 2025 under agenda item 11.3
- R1-2509303 discussion Discussion on DL DFT-s-OFDM for 6GR LG Electronics, CATT, Thales, Lenovo, IITH, WiSig to RAN1#123 in Dallas/USA in November 2025 under agenda item 11.3.1
- R1-2509055 discussion NTN Characteristics for the Evaluation Assumptions for 6GR air interface ESA, Thales, Viasat, Eutelsat, Airbus, SES, Hispasat to RAN1#123 in Dallas/USA in November 2025 under agenda item 11.2
- R1-2508975 discussion Discussion on 6GR channel coding ETRI, ESA, Thales to RAN1#123 in Dallas/USA in November 2025 under agenda item 11.4.1
- R1-2508873 discussion Positioning, Navigation and Timing (PNT) in 6G NTN-TN harmonization Airbus, ESA, Fraunhofer IIS, Thales, Iridium, Novamint, Sateliot to RAN1#123 in Dallas/USA in November 2025 under agenda item 11.1
- R1-2508472 discussion Overview of 6GR air interface THALES to RAN1#123 in Dallas/USA in November 2025 under agenda item 11.1
- R1-2508471 discussion Discussion on waveform for 6GR air interface THALES to RAN1#123 in Dallas/USA in November 2025 under agenda item 11.3.1
- R2-2507647 discussion 6G Mobility aspects for NTN THALES, Airbus, Echostar, Novamint, Fraunhofer IIS to RAN2#131bis in Prague/Czech Republik in October 2025 under agenda item 10.4
- R2-2507646 discussion 6G Control Plane design aspects for NTN THALES, Airbus, Echostar, Novamint, Fraunhofer IIS to RAN2#131bis in Prague/Czech Republik in October 2025 under agenda item 10.3.2
- R2-2507645 discussion 6G User Plane design aspects for NTN THALES, Airbus, Echostar, Novamint, Fraunhofer IIS to RAN2#131bis in Prague/Czech Republik in October 2025 under agenda item 10.3.1
- R2-2507644 discussion 6G Radio Access Technology general aspects for NTN THALES, Airbus, Echostar, Novamint, Fraunhofer IIS to RAN2#131bis in Prague/Czech Republik in October 2025 under agenda item 10.2
- R2-2508814 discussion 6G TN/NTN Integration THALES, TNO, Airbus, ESA, Novamint, EchoStar to RAN2#132 in Dallas/USA in November 2025 under agenda item 10.2.2

- R3-257193 discussion 6G RAN internal functional split and interfaces for NTN THALES, Echostar to RAN3#129-bisin Prague/Czech Republik in October 2025 under agenda item 10.4
- R3-257192 discussion 6G RAN overall architecture for NTN THALES, Echostar to RAN3#129-bisin Prague/Czech Republik in October 2025 under agenda item 10.2.1
- R3-258643 pCR Discussion on 6G RAN functional split Samsung, Verizon, NTT DoCoMo, Rakuten, Qualcomm, China Unicom, FiberCop, Jio Platforms, NEC, Google, T-Mobile USA, Fujitsu, Thales, Mavenir, Boost Mobile, Tejas Networks, Charter, Sony, CATT, Lenovo to RAN3#130 in Dallas/USA in November 2025 under agenda item 10.4
- R3-258565 discussion 6G RAN internal functional split for NTN THALES, ESA, EchoStar, Lockheed Martin, Novamint to RAN3#130 in Dallas/USA in November 2025 under agenda item 10.4
- R4-2520747 other Views on NTN SAN RF requirements impact in 6G ViaSat Satellite Holdings Ltd, Thuraya, Thales, Terrestar to RAN4#117 in Dallas/USA in November 2025 under agenda item 8.4.2

2.2.3.5 3GPP Rel-19 RAN2-led NR-NTN-ph3 work item

Several project partners among which Thales, Ericsson, Telit, and Qualcomm have promoted successfully the support of regenerative payload in the Rel-19 work plan of 5G-Advanced (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.

2.2.4 ITU-R WP4B

The overall work plan, timeline, process and deliverables for the future development of satellite IMT-2030 is described in Annex 3 to Document 4B/139, 27 May 2025.

The project has successfully contributed to:

- WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT NEW REPORT ON DEVELOPMENT AND TECHNOLOGY TRENDS FOR THE SATELLITE COMPONENT OF IMT TOWARDS 2030 AND BEYOND
  - see Thales' contributions in 4B/133 to WP4B meeting #56 (1^{st} – 6^{th} May 2025 in Shanghai/China and in 4B/179 to WP4B meeting #57 22 – 28^{th} October 2025

  - latest draft of the document can be found in Annex 3 to Document 4B/186, 31 October 2025
- WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT NEW ITU-R REPORT ON A FRAMEWORK FOR SATELLITE RADIO INTERFACE(S) OF IMT-2030
  - see Thales' contributions in 4B/180 to WP4B meeting #57 22 – 28th October 2025
  - latest draft of the document can be found in Annex 1 to Document 4B/186, 31 October 2025
- WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT NEW REPORT ITU-R M.[IMT-2030-SATELLITEREQ-EVAL-SUB] on Technical performance requirements, evaluation methodology, and submission templates for the satellite radio interface(s) of IMT-2030
  - see Ericsson's contributions in 4B/171 to WP4B meeting #57 22 – 28th October 2025
  - latest draft of the document can be found in Annex 2 to Document 4B/186, 31 October 2025

2.3 Ecosystem Building

2.3.1 Satellite Standardization Interest Group (SSIG)

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

This SSIG was established on 8 January 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

Furthermore, 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.

2.3.2 NTN Forum

Under Thales Alenia Space initiative and ESA, the “NTN forum” has been created with the objective to provide a collaborative platform for all relevant stakeholders to foster collective actions towards the harmonious, non-discriminatory and market-driven development and implementation of NTN solutions – for 5G and 6G systems and related services.

https://connectivity.esa.int/the-non-terrestrial-networks-forum

It entails 4 working groups:

- WG#1: Pre-standardization
- WG#2: Consolidation of vertical needs
- WG#3: Experimentation
- WG#4: Devices

Currently, there are more than 250 organizations from 41 countries that are members of the forum.

Partners of the 6G-NTN project have used this “NTN forum” and especially the WG#1 to promote views on NTN especially wrt 3GPP workplan on 6G.

Co-funded by the European Union

3 EXPLOITATION

3.1 Overall

The project has demonstrated the added value of a NTN as native component of the 6G system. Indeed, NTN 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 ensuring 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 NTN component is expected to address consumer, enterprise and vertical market segments:

TABLE 2: 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 capable 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 Common 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 of “service“ satellites, operating respectively in FR1 and FR2 bands. This concept allows to maximize 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 has identified how they plan to exploit the project outcomes.

3.2 High-Level Development Plan

Let us recall, the timeline for the roll-out of the different 5G-NTN solutions/deployment scenarios here under:

TABLE 3: LIST OF NTN DEPLOYMENT SCENARIOS

NTN Deployment scenarios	A	B	C	D	E	F
Service	Messaging, voice, narrowband data			Broadband		

NTN Deployment scenarios	A	B	C	D	E	F
NTN Radio Access Technology	IoT-NTN	IoT-NTN	IoT-NTN	NR-NTN	NR-NTN	NR-NTN
Orbit	GSO	NGSO	NGSO	NGSO	GSO	NGSO
Duplex mode	FDD	FDD	TDD	FDD	FDD	FDD
Payload	Transparent	Transparent/Regenerative			Transparent	Regenerative
Bands	Below 7.125 GHz (e.g. L/S bands)				Above 10 GHz (e.g. Ku/Ka band)	
Targeted devices	Internet of Things & Smartphones (D2D)			Smartphones	Fixed and Mobile VSAT	
Potential SNOs	*Viasat/Inmarsat* *Ligado* *TerreStar Solutions* *Thuraya*	*Sateliot* *OQT* *OmniSpace*	*Iridium*	*SpaceX, MSS-A*	*Hispasat* *Intelsat, JSAT, KTSAT, Ovzon* *Eutelsat Group*	*SpaceRISE* *Eutelsat Group*

In the figure below, an approximate timeline is provided for the solution development for each NTN scenarios.

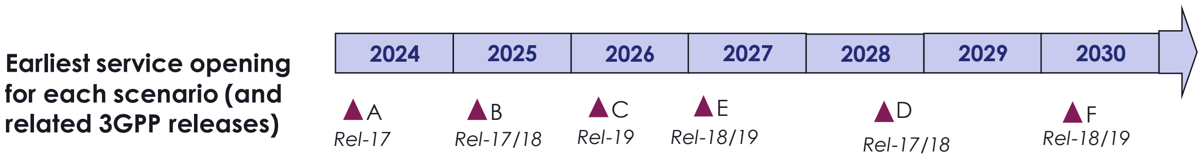

FIGURE 1: TIMELINE FOR THE ROLL-OUT OF 5G-NTN SOLUTIONS (BASED ON INDUSTRIAL SOURCES)

Observation: 5G-NTN solutions are expected to be deployed by 2030

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

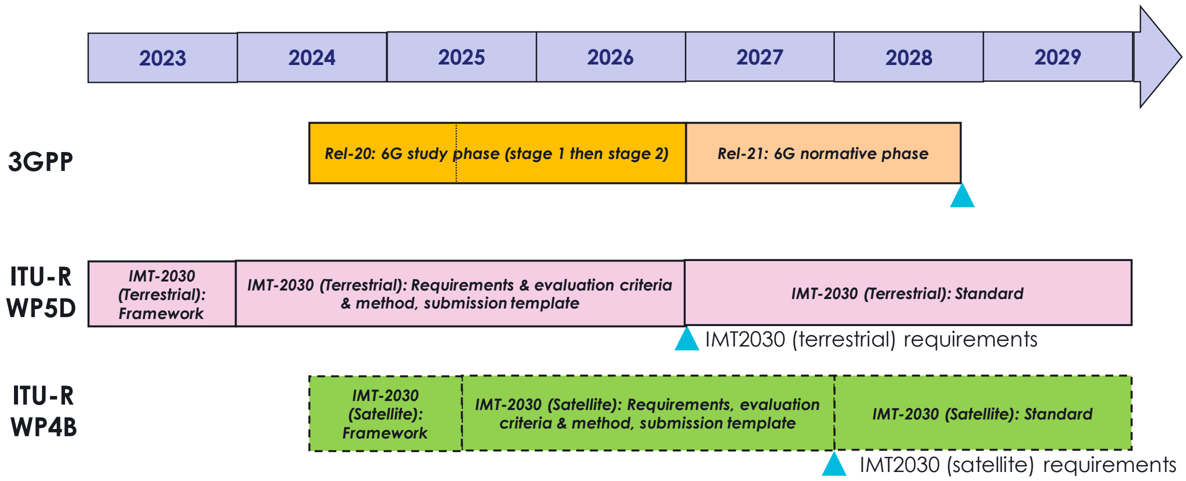

FIGURE 2: 6G NTN IN 3GPP AND ITU-R ROADMAP

The first version of 6G standard (3GPP Release-21) will be available end of 2028. Assuming about three years of development for the 6G technology (terminal's chipset and RF front-end, gNB, core network functions, etc.), it is likely that the first commercial services will be open end of 2031 with terrestrial networks.

Observation: 6G-TN-based service is expected to be available end of 2031

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/optimized.

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

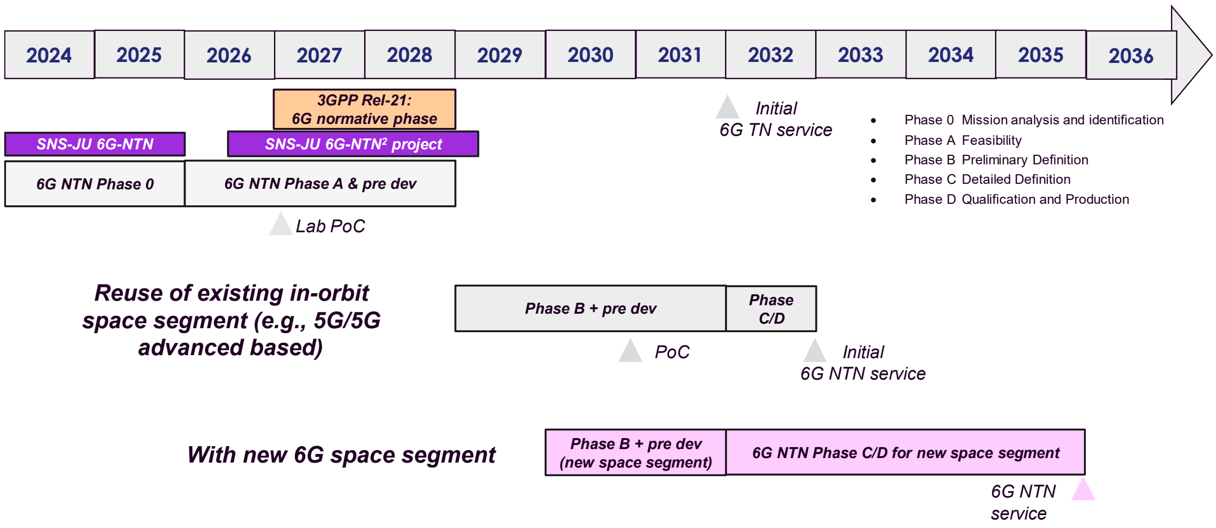

FIGURE 3: PROPOSED OVERALL DEVELOPMENT PLAN OF 6G-NTN SOLUTIONS

Proposal: To target a service roll-out for 6G-NTN respectively end of 2032 over existing space segment and end 2035 with a new space segment.

According to ESA (https://www.esa.int/Science_Exploration/Space_Science/Building_and_testing_spacecraft), the lifetime cycles associated to 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: Utilization
- Phase F: Disposal

3.3 Detailed Development Plan

6G-NTN solutions require to develop a number of sub-systems and related parts. Some parts may be common with the parts of 6G-TN solutions. Others may be common with the ones developed for legacy SatCom systems. The table below identified the different parts to be developed for 6G-NTN solution and highlight synergies with 6G-TN parts.

TABLE 4: 6G-NTN BUILDING BLOCKS

6G-NTN Sub-systems	Parts	Synergies with 6G-TN parts	Comments
Terminal level	Modem	High	The objective will be to re-use 'as is' 6G chipsets developed for 6G-TN user equipment
	Antenna	For FR1 6G-NTN, the synergies are high	FR1: re-use the RF front –end developed for 6G-TN UE FR2: develop specific phased array antenna
Ground network	Tracking antenna system at gateway level for the feeder links	None	However, there are high synergies with the gateway's antenna of legacy satcom systems
	NTN control center	Low	A common framework for Artificial Intelligence driven Radio Resource Management algorithm may be envisaged but the operational constraints as well as are very different
	Network management center	High	The main challenge in 6G-NTN context is to dynamically orchestrate the Virtual Network Functions on board the NGSO/GSO satellites
Space segment (Service/Feeder NGSO and GSO satellites)	Phased array antenna operating in FR1 or FR2	None	These are very specific developments
	On board modems	Medium	Given the specific space environmental conditions, the design constraints may be different
	On board storage/computing resources to embark virtual network functions	Medium	Given the specific space environmental conditions, the design constraints may be different
	Inter satellite links	None	New standard is needed for 100 Gbps optical links
	Customized platforms	None	Platforms optimized for the launch strategy may be needed

6G-NTN Sub-systems	Parts	Synergies with 6G-TN parts	Comments
Software products for ground or space segment	Core/RAN/transport network functions	Medium	When embarked on board a satellite, development constraints may be very different from the one of 6G TN
	End to end routing in the mega constellation	None	Given the predictable dynamicity of the network topology, this requires a specific development

The space segment represents the most complex development and it is estimated that at least three years are necessary to develop the most complex parts in the list above.

All these parts could be developed by SMEs while assembled and deployed by satellite primes.

Note, however, that the on board phased array antenna operating in FR1 or FR2 may be best provided by satellite primes.

The support of institutions is highly recommended especially for the most critical parts such as platforms, on board products as well as terminal's phased array antenna.

3.4 Industrial Stakeholders

3.4.1 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 2.23 billion euros in 2024, and has around 8,100 employees in seven 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 direct connectivity to smartphones or 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 centers. The outcomes will also be used in the planning for the design and development of future products at payload, platform and ground segment level to prepare for the design/development/deployment of future space network infrastructures based on 6G.

3.4.2 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

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

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

3.4.3 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.

3.4.4 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.

3.4.5 Greenerwave

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

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

3.4.6 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 operation of satellite and terrestrial wireless/mobile 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. Standardization input is prepared accordingly for the 6G Releases coming up.

3.4.7 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 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.

3.5 Academics and Research Centers Stakeholders

3.5.1 University of Bologna

Expertise: The University of Bologna (UNIBO) is known as the oldest University of the western world. It is organized 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.

3.5.2 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.

3.5.3 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.

3.6 Consultancies

3.6.1 Martel (MAR)

Expertise: Martel (MAR) is an innovative SME with 30 years of experience in European Commission-funded projects. The company has a dedicated R&D department (Martel Lab) and a strategic media division (Martel Media). MAR specializes in 5G/6G, Non-Terrestrial Networks (NTN), AI, Cloud-Edge computing, and network virtualization. Notably, MAR coordinates the SNS-JU project 6G4Society, embedding societal values and sustainability Key Value Indicators (KVIs) into technical development. To ensure strategic alignment, MAR's CTO serves on the one6G Association Board, linking R&D outcomes to industry standardization. Additionally, the EC Innovation Radar has recognized MAR as a "Key Innovator" for its contributions to Open Source MANO and AI platforms.

Exploitation: Within the 6G-NTN project, MAR leads the development of an open-source, AI-powered forecasting framework for proactive Cloud-Native Network Function (CNF) orchestration. This solution leverages machine learning to predict satellite node resource usage (CPU, RAM), minimizing cold-start delays and optimizing energy efficiency in resource-constrained NTN environments. Presented at major venues like EuCNC 2025, this key asset has strengthened MAR's position in 5G/6G telecommunications, IoT, and AI solutions. It will be further demonstrated at the upcoming ETSI SNS4SNS event in February 2026. Furthermore, by providing project management support and leading communication and dissemination activities, MAR has enhanced its service portfolio in innovation management, consulting, and media services for the R&D&I sector.

3.6.2 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 gained in 6G-NTN 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.

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 minimize 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 is 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 (Footprint)

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 NTN 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 conducting 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 analyses 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-funded 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 5: OUTCOMES OF THE LIFE CYCLE ANALYSIS ON SATELLITE COMMUNICATION SYSTEMS

<table>
<tr><th>The different phases of the life cycle of a satellite network</th><th>Findings</th></tr>
<tr><td>General</td><td>Climate Change, Acidification, Water resources depletion, Ozone depletion, Mineral resources depletion are different aspects to be considered for the environmental impact</td></tr>
<tr><td>Phase A: Feasibility</td><td rowspan="2">For a constellation, the impact of these phases is quasi-independent on the number of satellites</td></tr>
<tr><td>Phase B: Preliminary definition</td></tr>
<tr><td>Phase C: Detailed definition</td><td rowspan="3">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</td></tr>
<tr><td>Phase D: Qualification and production</td></tr>
<tr><td>Phase E1: Launch and commissioning</td></tr>
<tr><td>Phase E2: Utilization</td><td>Most of the impact comes from the energy consumption of User Equipment</td></tr>
</table>

4.2.2 Energy efficiency – Products

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

TABLE 6: 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 orbits/altitudes in terms of sizing as well as impact on the terminal in order to understand the benefits & costs of each orbit in terms of environmental impact.

TABLE 7: 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 around the globe depends on the altitude and the minimum elevation angle under which the terminal “sees” the satellite

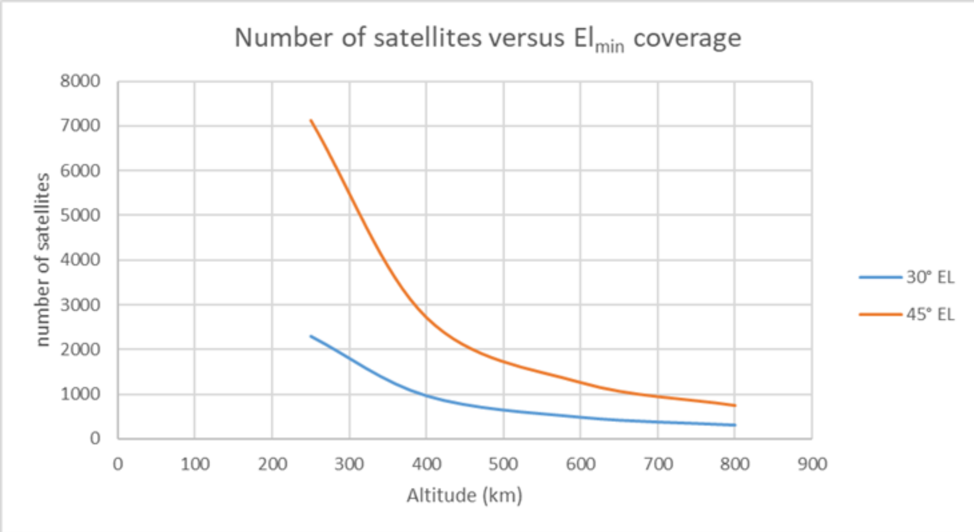

FIGURE 4 : NUMBER OF SATELLITES REQUIRED IN A NGSO CONSTELLATION DEPENDING ON ITS ALTITUDE (200 - 800 KM) AND THE MINIMUM ELEVATION

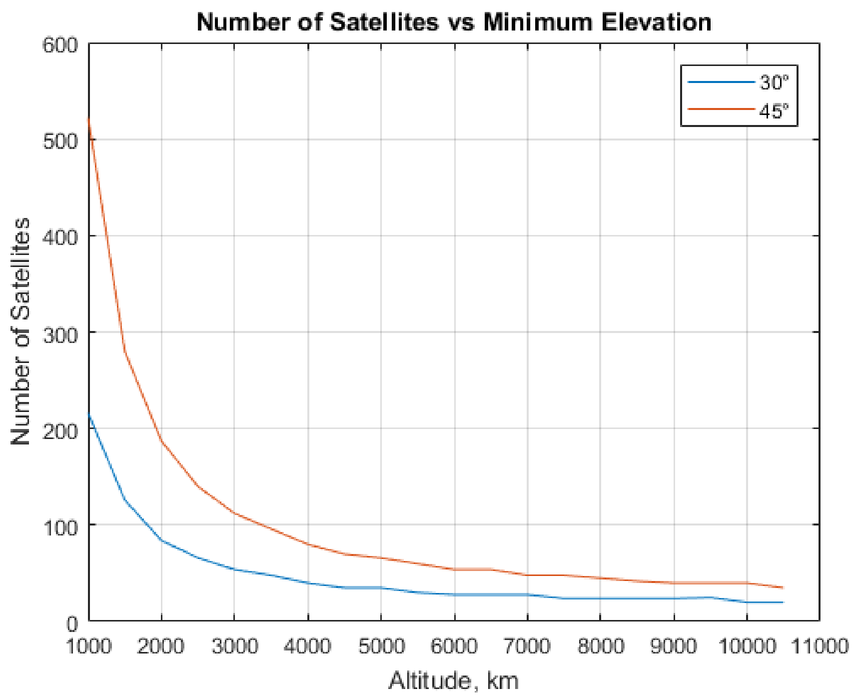

FIGURE 5 : NUMBER OF SATELLITES REQUIRED IN A NGSO CONSTELLATION DEPENDING ON ITS ALTITUDE (1000 – 11000 KM) AND THE MINIMUM ELEVATION

TABLE 8: 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.

TABLE 9: CHARACTERISTICS OF THE DIFFERENT TYPES OF HAPS

HAPS type	**Balloons**	**Airplane**	**Airship**
Example	*Loon/google*	*Zephyr*	*Stratobus*
Service coverage	Earth moving footprint (unpredictable)	Earth moving footprint (predictable)	Quasi earth fixed footprint
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 rationale in Table 6).

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 range 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 Amplifiers 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, one 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 NTN layers (i.e. HAPS, LEO/MEO/GEO).

4.2.3.1 Space segment

4.2.3.1.1 Combination of satellites from different altitudes for a given service

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

The maximum distance between satellite and the User Equipment depends on the altitude of the satellite and the minimum elevation. Hence, GSO or MEO satellites will be penalized compared to LEO in terms of

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

TABLE 10: ADDITIONAL FREE SPACE LOSS ATTENUATION BETWEEN GSO AND MEO VERSUS LEO

Satellite altitude	**km**	**600**	**8500**	**35786**
Distance UE-satellite at 30° min elevation	km	1075,2	10625.7	38611,7
Attenuation due to distance	dB	60,6	80,5	91,7
Relative attenuation Wrt LEO@600 km	dB	-	+19,9	+11,2

Such attenuation may be partly compensated with larger antenna size on board, however, the antenna size will be constrained by the fairing of the launcher and the capability to deploy the antenna in orbit. Hence, for a given terminal, the achievable data rate will be smaller as the altitude of the satellite increases.

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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 sizes of beams resulting in at least 2 layers of beams, which respective footprints 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 beam.
- 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 satellites will increasingly embark regenerative payloads, 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 centers. The contribution of the latter 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 maximum transmit power and the number of gateways to be deployed.

The required number of gateways depends on whether the space segment is transparent or regenerative with ISL. In the latter, 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 of emergency communications.

In a worst case, one can assume that the latter 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 optimized 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 part and the modem part.

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

Furthermore, the higher the number of 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 of the VSAT in idle mode by off-loading common signaling to GSO resource. Hence when in idle mode, the terminal has to track the GSO satellite which is relatively static instead of tracking the NGSO satellites in motion.

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 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 NGSO or GSO satellite)
    - $P_{UE\text{-}idle}$ [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, Authorization, 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).

3. **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.

4. **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, industrialization, and decarbonization 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 11: 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 authorization 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 specialized 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 localizing 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 characterizes this issue, its root causes, key metrics for related space sustainability, and the European opportunity to lead in sustainability endeavors connected to space-related 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 minimizing 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 emphasizes 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 minimize

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** establishes the Copernicus Earth observation program, 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 minimizing space debris. The key provisions of both instruments are outlined in the previous sub-section 4.2.2.

4.2.5.2 Characterization 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 maneuverability; and
- Space utilization: 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: minimizes 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 constellations 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 is 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.

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

4.2.7 EMF exposure

As stated by the World Health Organization 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, and
- smartphone devices which may be held near the ear of the user.

In the latter case, the operation of a smartphone in a NTN 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 than for UE operating in terrestrial networks.

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.

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4.3 NTN Contribution to the Sustainability of 6G (Footprint)

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 hard 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 with the coverage area.

While NTN will not reduce the footprint carbon of 6G, it will undoubtedly enable sustainable development of the 6G system by:

- Fostering the development of the economy in areas away from the overcrowded/highly polluted cities
- Balancing 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
- Assessing the 6G service demand and decide where the 6G TN component shall be deployed in priority

4.3.2 Off-loading of signaling and traffic

It may be beneficial to off-load part of the traffic and signaling 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.

Moreover, it should take into account the size of the targeted audience for the traffic and common signaling 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 further optimized 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.

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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 schemes 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 6G-NTN Contribution to the Sustainability of the Society (Handprint)

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 of 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 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 NTN.

Regarding the infrastructure quality with 6G, in terms of bridging digital divide in the context of the above issues and beyond, several important points shall be noted.

- 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 analyzed 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 summarize, 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 optimize routing and traffic management. One of the main ways doing this is through **broadband connectivity to drones** (or UxV). Drones may refer to 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 also encompass 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 optimized routing of vehicles and vessels. This reduces fuel consumption by minimizing 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 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 **optimizing flight path**. NTNs have 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**. For example, airlines can use real-time satellite data to adjust flight routes dynamically to avoid adverse weather conditions and optimize 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 **optimized 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 **optimize 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 fertilization**, not only **minimizing energy use**, but also **maximizing yield**.[20]

To summarize, 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 optimization. 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 optimizing 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 NTN in the context of 6G.

Let us distinguish two types of NTN:

- 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 in [21]).

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 sets high constraints on the antenna on board GSO and possibly on board MEO.

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 minimum elevation angle. However, this is not sustainable friendly given that launch and satellite production account 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 provides global service continuity.

4.5.1.3 System level

Use of smart routing techniques to transfer the traffic between the NTN and TN components according to energy consumption with objective to optimize the overall 6G system energy consumption.

Enablers for the spectrum re-use between the NTN and TN 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 devices 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. minimum elevation angle should be greater than 30° or even 45°).

At equivalent performances, a lower complexity antenna (e.g. through adoption of half duplex mode) would 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 Life Cycle Assessment. 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 layers of space segment can be used to maximize 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 optimize the energy consumption of terminals 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 minimum 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 footprint.

4.5.2.3 System level

Use of smart routing techniques to transfer the traffic between the different NTN layers according to the QoS requirements and the energy consumption.

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

4.6 Contribution to the SNS-JU's Task Force Sustainability

6G-NTN contributed to the sustainability report of the SNS sustainability task force published in June 2025. The report is based on a questionnaire of 67 questions covering sustainability targets, sustainability methodologies, trade-offs, implementation considerations, and how the project contributes to the sustainability task force.

As outlined in the report, the transition demands require a holistic approach: balancing architectural trade-offs (e.g. centralized vs distributed systems), optimizing energy-intensive components like Radio Units, and integrating renewable energy sources. Among the 67 contributing projects, 6G-NTN plays a pivotal role in advancing sustainable connectivity solutions, likely addressing challenges such as power-efficient satellite/airborne infrastructure, resilient backhaul, and modular design to minimize IT footpring. The project's alignment with SNS JU's broader goals, including co-optimization of performance and sustainability, adherence to standardized methodologies (e.g., Life Cycle Assessment), and collaboration with bodies like ETSI, underscores its contribution to shaping a green, inclusive, and high-performance 6G ecosystem. However, the report also identifies persistent gaps, such as the need for unified sustainability metrics and stronger policy engagement, which 6G-NTN and peer projects must collectively address to meet the EU's 2030 climate and digital sovereignty targets.

4.7 TOWARDS A SUSTAINABLE 6G-NTN

4.7.1 NSGO constellation sustainability: Design trade-offs

In this chapter, we shall focus the analysis on the design of the NGSO space segment. For 6G satellite networks, the most impactful parameter in terms of sustainability relates to the total mass to be launched in space.

Assuming a given operating frequency which depends on the mission, and the targeted user requirements, the design and sizing of the space segment shall optimize the necessary energy to deploy the overall mass of space segment to be launched. The energy required for the launch is proportional to the space segment sizing (number of satellites x satellite mass) and to the orbit altitude.

The set of user requirements not only defines the targeted service requirements (data rate, maximum latency) but also the targeted user terminals as well as the targeted capacity and service/radio link availability.

Typically, both maximum latency and the minimum elevation angle (minimum angle under which a terminal can operate with a satellite) constrain the maximum altitude of the constellation.

The targeted terminals may also impact the minimum elevation angle:

- For direct to smartphone devices (typically operating in FR1 bands), the space segment shall be able to serve at least the same smartphones in terms of antenna gain, Tx power and receiver sensitivity as the ones targeted by the cellular network infrastructure. Any improvement on these RF parameters will allow to increase the capacity and data rate capabilities.
- For broadband connectivity to vehicle mounted devices (typically operating in bands above 10 GHz), the space segment shall be able to serve terminals with an antenna able to track the motions of the NGSO satellite and compensate for the motion of the vehicle. The antenna of the terminal shall be sufficiently small (e.g. max 20 cm diameter) to be installed on a vehicle. Such antenna is most likely be based on phased array technology. The larger the scan angle supported, the higher the complexity of the antenna. Since the complexity of the antenna directly impacts the cost of the terminal, it will also affect the affordability of the service and hence the system sustainability.

Once the maximum altitude and the minimum elevation angle are set, the sizing of the space segment will depend on:

- The mass of the satellite
  - relates to the satellite power and antenna size. It can be reduced by selecting a low altitude and a high minimum elevation angle which minimizes the propagation loss to be overcome.
- The number of necessary satellites

- to provide the required coverage. The larger the on-board antenna size, the smaller the footprint of beams generated and hence the smaller the instantaneous coverage that can be provided by one satellite.
- to ensure service continuity in any point of a targeted service coverage. The number of satellites can be reduced when selecting a higher altitude and a lower minimum elevation angle.

As seen above: both altitude and minimum elevation angle have an opposite effect on the sizing of the space segment. Therefore, there should be an optimum of space segment sizing and hence an optimum in terms of energy required to deploy it.

The target life time of each satellite also impact the sustainability of the system. The higher the life time, the less energy is needed to deploy the space segment.

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5 CONCLUSION

This document highlights the standardization activities carried out with the support of the 6G-NTN project. The numerous contributions and achievements across various SDOs demonstrate the project's leadership in advancing the standardization of NTN for 6G.

In addition, preliminary development and deployment plans for 6G-NTN satellite networks have been initiated. These plans consider the potential to leverage and refurbish the 5G-NTN space segment as a foundation for rolling out initial 6G-NTN satellite networks, facilitating a smooth transition and early deployment of the next-generation system.

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 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 offloading of signaling and traffic between TN and NTN 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).

Finally, an analysis has been conducted demonstrating that the space segment, particularly NGSO constellations, can be designed to optimize sustainability outcomes, minimizing negative impacts while maximizing societal and environmental benefits.

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