D7.4: Dissemination, Communication Report and Exploitation Final Report

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Abstract	This document describes the 5G-STARDUST communication and impact creation activities carried out during the second half of the project, and the final Exploitation plan devised. Thanks to a close monitoring of KPIs and achievements, this document provides an overview on the continuation of the activities implemented and conducted based on the strategy and plans outlined in D7.1 and D7.2.
Keywords	Dissemination, Communication, Liaisons, Community Building, Impact, Exploitation.

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DISCLAIMER

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Classified S-UE/ EU-S	*EU SECRET under the Commission Decision* *No2015/ 444*	

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

DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

DATA: Data sets, microdata, etc.

DMP: Data management plan

ETHICS: Deliverables related to ethics issues.

SECURITY: Deliverables related to security issues

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

EXECUTIVE SUMMARY

5G-STARDUST's Work Package 7 (WP7), is the main vehicle for dissemination, communication, exploitation, and impact creation within the project. As such, it defines all the required actions to ensure that the project's work, solutions, and results are disseminated, demonstrated, and communicated among the appropriate stakeholders at the right venues to timely impact, improve, and drive innovation management activities. It also orchestrates the project's liaisons and standardisation activities (which are detailed in the separate documents D7.3 and D7.5) and entices 5G-STARDUST's specific work towards exploitation and sustainability plans. This deliverable describes how the project has continued to follow, in the second half of its run, a comprehensive and effective approach to dissemination, communication, community building activities, and towards the finalisation of an exploitation strategy, following up on what envisioned in D7.1 (Dissemination and Communication Plan) and D7.2, the predecessor of the current document.

During the second half of the project, the consortium has harvested fruitful results from a wide range of dissemination promotion and engagement activities. The different communication channels and dissemination tools identified at the beginning of the project were used in order to promote the main news, activities and results of 5G-STARDUST. The key results are listed as follows:

- 5G-STARDUST has participated in or was involved in the organisation of **47 total events** for the reporting period, presenting itself to relevant stakeholders.
- **18 scientific publications** have been published or submitted, presenting 5G-STARDUST's progress.
- In total, 5G-STARDUST has widely promoted its results and activities to **more than 120,000 stakeholders**; including subscribers to social media channels, events, website visitors and through exposure on other relevant initiatives and projects, such as the European Smart Networks and Services Joint Undertaking (SNS JU).
- 5G-STARDUST was featured in **3 additional news articles** on specialised press publications.
- Over **9,000 unique visitors** browsed through the 5G-STARDUST website.
- 5G-STARDUST and its individual partners **organised and co-organised a total of 7 events**, often in close collaboration with related EU-funded projects within the overall SNS JU context.
- Finalisation of the devised **Exploitation and Sustainability plan** contained in the present document.

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ABBREVIATIONS

SNS JU	European Smart Networks and Services Joint Undertaking
TN	Terrestrial Networks
NTN	Non-Terrestrial Networks
GDPR	General Data Protection Regulation
AI/ML	Artificial Intelligence/Machine Learning
IoT	Internet of Things
GEO	Geostationary Equatorial Orbit
LEO	Low Earth Orbit
D2D	Device-to-Device
E2E	End-to-End
MNO	Mobile Network Operator
SNO	Satellite Network Operator
PLMN	Public Land Mobile Network
3GPP	3rd Generation Partnership Project
O-RAN	Open Radio Access Network
CU/DU	Centralized Unit / Distributed Unit
COTS	Commercial Off-the-Shelf
IPR	Intellectual Property Rights
KER	Key Exploitable Results

1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

D7.4 serves on the purpose of a dissemination, communication report for activities for the second half of the project, providing details on the dissemination and communication activities performed during the period July 2024 - December 2025. As such, the document also presents plans for the aftermath of the project and takes stock of actions conducted and their ultimate impact. Additionally, information on the final exploitation plan is presented.

In addition to reporting the dissemination and communication activities carried out during the second half of the project, this deliverable introduces the final exploitation and sustainability perspective of 5G-STARDUST. It outlines how the project's most relevant results may evolve beyond the research phase, with a particular focus on their potential for post-project uptake, market relevance, and long-term impact. The approach is structured around the project's prioritized Key Exploitable Results (KERs), identified and refined with the support of the Horizon Results Booster service.

1.2 DOCUMENT COMPOSITION

The sections of the D7.4 are arranged as follows, following this introductory **Section 1:**

- **Section 2** recaps objectives and stakeholders, then depicting outreach and impact creation activities and tools used during the first half of the project (M18-M36);
- **Section 3** focuses on the liaisons and cluster activities with other initiatives, with emphasis on SNS JU;
- **Section 4** focuses on the assessment of the activities' results;
- **Section 5** breaks down the project's final exploitation and sustainability plan;
- **Section 6** outlines plans for activities following the end of the project;
- **Section 7** draws conclusions on the overall conducted activities – and the connected results.

2 COMMUNICATION AND DISSEMINATION ACTIVITIES M18-M39

2.1 OBJECTIVES AND STAKEHOLDERS

5G-STARDUST's mission is to design, develop and demonstrate a deeper integration of Terrestrial Networks (TN) and Non-Terrestrial Networks (NTN) in order to deliver a fully integrated 5G-NTN autonomous system with novel self-adapting end-to-end connectivity models for enabling ubiquitous radio access. This would address – as key points to be mentioned - the needs and demand for cost-effective connectivity in un(der)served areas; adaptation to diverse verticals' requirements and to time-varying network operations (e.g., data traffic loads and topology changes); cost-effective and scalable integration of satellite with terrestrial infrastructures to efficiently manage the deployment and operation of massive capacity networks.

Outreach and impact creation activities are central to follow these overall 5G-STARDUST goals. They are being closely monitored and coordinated to ensure a broad visibility and an effective engagement of all targeted stakeholders in the networking domain (such as researchers, industry, operators, and end-users). These actions are coordinated by Martel with active contributions from all consortium partners, following the objectives below (as previously listed in D7.2):

- Ensure 5G-STARDUST's broad visibility by spreading knowledge about the project and its results, as well as establishing a distinctive and recognizable identity that will support exploitation and sustainability efforts.
- Reach, stimulate and engage a critical mass of relevant stakeholders to ensure that the results of the project are effectively showcased, leading to validation, improvement and possibly further adoption of the developed technologies and concepts, especially towards target vertical sectors.
- Facilitate exploitation of the project's outcomes and promote the development of innovative solutions based on the 5G-STARDUST methodology and concepts.
- Continuing to ensure close coordination with fellow SNS JU projects – and other relevant initiatives in the networking/telecommunications industry.

2.2 ONLINE DISSEMINATION

2.2.1 Website

Launched at the beginning of the project (M2), the 5G-STARDUST website (www.5g-stardust.eu) has been acting as an information hub presenting the project's goals, activities, and achievements. To this purpose, content has been constantly updated and featured as follows:

- General information about the project, its vision and objectives
- Introduction of the consortium
- News items, press releases, press clipping and newsletter sub-sections

- List of relevant events
- A repository of resources, such as publications, presentations/talks, promotional materials, videos, and public deliverables
- Contact information and links to social media accounts
- An acknowledgment to SNS JU and a page dedicated to the initiative, offering a brief overview and links to fellow projects at work under the SNS umbrella

The website is being periodically updated according to the progress of the project – counting **27 news articles published** in total, offering insight on the consortium, its activity and the ecosystem they operate within. At the end of the project (end of March 2026), the website counts over **9,000 unique visitors**, who generated over **20,000 page views** on an **average visit duration of 2'13"**. Drilling down into specific pages, the most popular pages - alongside the homepage – are the events' page (for a total of over 2,000 views) and the news' page, counting a total of 1,758 views.

The figures below provide the aforementioned plus some additional details: Figure 1 (Traffic overview and visit duration), Figure 2 (Top visited pages) and Figure 3 (Visits per country).

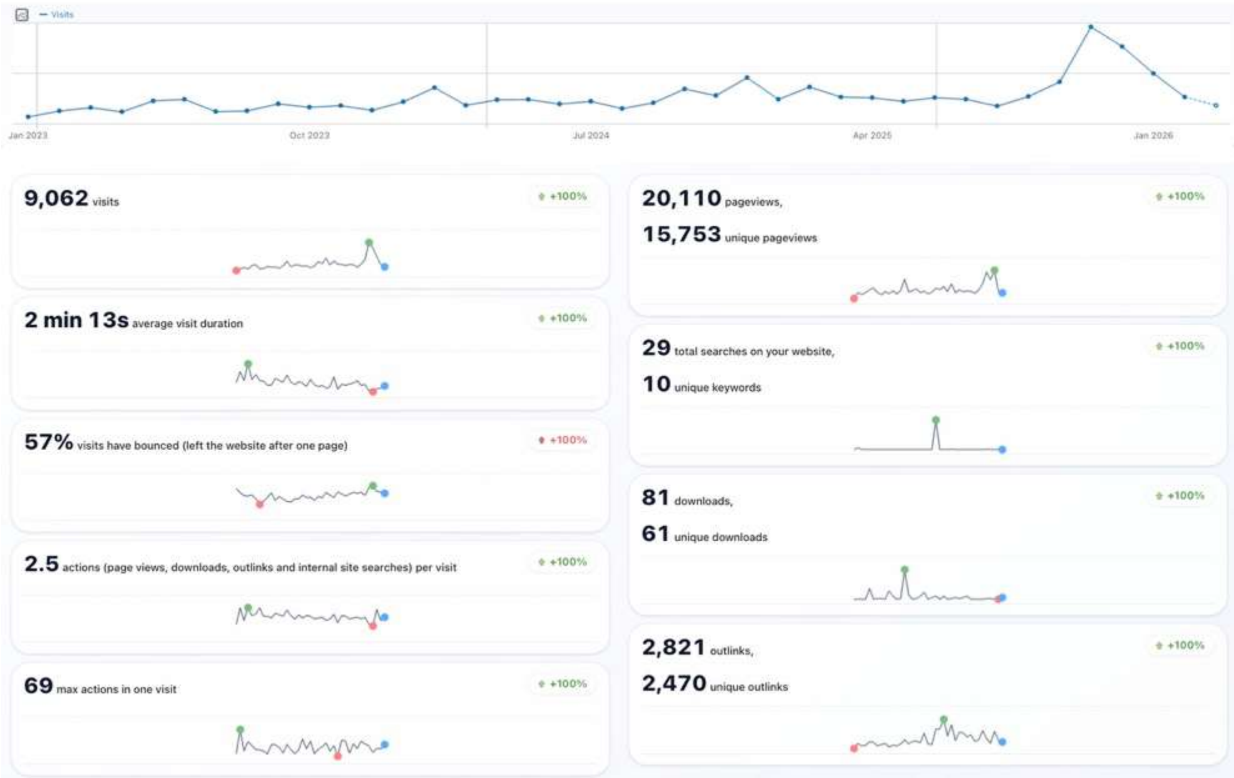

Figure 1: 5G-STARDUST website – Traffic overview and visit duration

PAGE URL	PAGEVIEWS	UNIQUE PAGEVIEWS	BOUNCE RATE	AVG. TIME O...
/index	7,268	35.5% 5,594	53%	00:00:47
event	2,116	10.2% 1,602	57%	00:01:17
news-articles	1,758	8.2% 1,298	62%	00:00:19
deliverables	1,085	5.7% 903	68%	00:01:37
about-the-project	1,081	5% 784	50%	00:01:06
events	789	3.8% 592	63%	00:00:45
consortium	661	3.5% 557	48%	00:01:14
presentations	627	3.3% 526	74%	00:01:34
2023	666	3.2% 504	57%	00:01:32
scientific-publications	569	3.1% 496	63%	00:01:09

Figure 2: 5G-STARDUST website – Top visited pages

COUNTRY	VISITS
United States	1,652
Switzerland	1,112
Germany	847
France	690
Spain	659

Figure 3: 5G-STARDUST website – Visits per country

All information and e-mails collected are protected under the General Data Protection Regulation (GDPR). Contact is and will continue to only be made with people who have submitted inquiries. Similarly, the newsletters are and will continue to be sent out only to individuals who have explicitly requested to receive them. Any person who has subscribed can request for their e-mail address to be removed from the list. The website provides information on the data kept and how they are used in alignment with the GDPR under the Privacy Policy link (footer of the webpage).

As previously stated in D7.2, any additional information on the project website can be found in Section 3.2 of D7.1.

2.2.2 Social Media channels

5G-STARDUST continued to be present on social media channels, regularly promoting the project activities and output while encouraging a wider promotion of the networking solutions at the core of its work. The project can ultimately count a fair follower/visitor base on several social media channels, namely Twitter/X, LinkedIn, and YouTube, which are all linked to the project's website.

Twitter/X

5G-STARDUST uses Twitter/X as a social network to cover real-time news/announcements, cross-share relevant and interesting initiatives, and to establish meaningful connections with targeted groups of stakeholders, including policy makers, industry, and the general public. So far, the project's account (https://x.com/5G_Stardust) has reached **214 followers** (including project partners, similar projects, interested stakeholders, etc.). In total, around 120 tweets have been posted. The project also follows 56 accounts on the platform: mostly projects and initiatives in similar fields or of similar nature in which partners have been involved or have been connected to.

Figure 4: 5G-STARDUST Twitter/X page

LinkedIn

LinkedIn allows the project to network with individuals and organizations within the networking/Satcom/telecommunication industries/ecosystems and beyond, share crucial information about project activities, and stay up to date on the latest developments in the field. The LinkedIn page has gathered **705 followers** by the end of the project. Similarly to Twitter/X, the LinkedIn account is mostly used to share the latest progress of the project, echoing key promotional messages from the project website and sharing relevant news from the project's partners, pertinent projects and the European Commission – but also via re-posting into relevant groups.

Figure 5: 5G-STARDUST LinkedIn page

YouTube

5G-STARDUST has also created an account on YouTube, one of the leading video-sharing platforms. This channel has been continuously used as the main hosting/distribution platform for the project's video output, also echoing content on Twitter/X, LinkedIn, and in-person events. At the time of writing, the channel generated **468 views**.

More details on the video content created for the project will be found in the following Section 2.3.

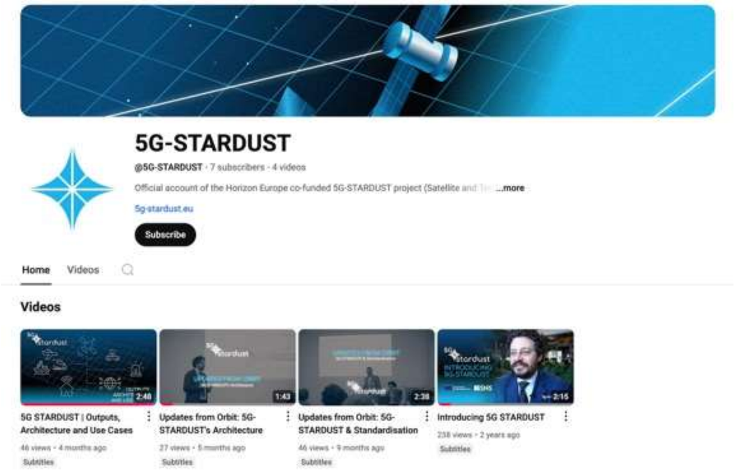

Figure 6: 5G-STARDUST YouTube channel

2.3 PROMOTIONAL MATERIALS

As planned in D7.1 and initiated in the first half of the project, WP7 also planned and created a wide range of promotional online and offline items in support of 5G-STARDUST's communication and dissemination. These materials serve to document and communicate the progress, findings, and outcomes of the project and contribute to the dissemination of knowledge, providing valuable insights to stakeholders and handy overviews for the wider community. Here below, a breakdown of additional items generated in the second half of the project.

Print

The prominent new promotional printed item created in the reporting period was a roll-up designed to support the project's participation at FOKUS FUSECO Forum (November 2024), which offered some context on 5G-STARDUST while also promoting fellow SNS JU projects ETHER and 6G-NTN to the event's visitors.

Figure 7: The 5G-STARDUST booth at FOKUS FUSECO Forum, featuring the dedicated roll-up

Video

WP7 relevantly pushed the efforts towards video production during the second half of the project, with the creation of 4 new clips, starting on the occasion of FOCUS FUSECO Forum, which offered the ideal venue for specific consortium members to convene and schedule interviews – which served as updates on the project's activities, building upon the previously released project overview video – Overall, between the official YouTube channel of the project, and releases on social media, the videos can count around **890 combined views** at the end of the project's run. Here below, more specific details on the aforementioned interviews, and additional video content.

Shot at FOCUS FUSECO Forum 2024, the video "Updates from Orbit: 5G-STARDUST & Standardisation" consists in an interview to project partner Alessandro Guidotti (CNIT), providing an update on recent standardisation developments in the SatCom domain, and on how 5G-STARDUST conducted its work within this landscape. The clip was released shortly after the event, in November 2024.

Figure 8: Screenshot from the video "Updates from Orbit: 5G-STARDUST & Standardisation"

Also shot at FOCUS FUSECO Forum 2024, the video "Updates from Orbit: 5G-STARDUST's Architecture" is a follow-up interview to the previous release, this time featuring Project Coordinator Tomaso de Cola (DLR), talking about the 5G-STARDUST architecture and the challenges that it set off to tackle. The interview was released in March 2025, to match with the new year's round of event participations.

Figure 9: Screenshot from the video "Updates from Orbit: 5G-STARDUST's Architecture"

Through animated graphics and a voice over narration developed with the help of the consortium, the video "5G STARDUST: Outputs, Architecture and Use Cases" builds upon the previous interviews by offering a bigger picture of the project, simultaneously serving as an expansion of the overview video released at the beginning of the project. As such, besides providing a detailed breakdown of the 5G-STARDUST architecture - and further project output updates - it also shows the intended used cases.

Figure 10: Screenshot from the video "5G STARDUST: Outputs, Architecture and Use Cases"

In a video shot at the 5th NTN Workshop, 5G-STARDUST partner Hemant Zope (Fraunhofer FOKUS) expertly walks us through the project's proof of concept demonstration, as held in the context of the event - which took place on November 6, 2025, in Berlin. The showcase revolved around the NTN-TN backhaul connections: the scenario presenting an end-to-end core network switching, in a transparent fashion, between TN and NTN links, tapping into better capacity and lower latency to bridge in case of issues.

Figure 11: Screenshot from the video "5G-STARDUST Proof of Concept Demonstration"

2.4 NEWSLETTER, PRESS RELEASES AND PRESS COVERAGE

Newsletter

Figure 12: Screenshots of recent 5G-STARDUST newsletters

6 Newsletters have been edited and distributed to stakeholders through 5G-STARDUST's MailerLite account, as well as made available on the project website. At the time of writing, **30 stakeholders have subscribed** to receive 5G-STARDUST's bi-yearly newsletters. In terms of content and further analysis on the efficiency of the communication:

- The 3rd newsletter (July 2024) was sent to 27 subscribers (56% opens / 15% clicks); the issue summed up the project efforts at the halfway point of its course, specifically promoting the First Integration Workshop conducted internally to the consortium, and external key activities such as the participations to EuCNC/6GSummit, PSCE Conference, ETSI Conference, and Mobile World Congress. The issue also collected articles and promotion of the project's feature in the 2024 SNS Journal and other publications, concluding by advertising fellow's SNS JU project 6G4Society's Citizen Survey.
- The 4th newsletter (December 2024) was sent to 30 subscribers (40% opens / 14% clicks); the issue served as a wrap-up of the project's second year, collecting articles on the 2025 Fall/Winter round of events (PIMRC 2024, one6G Summit, IEEE Future Networks World Forum, FOKUS FUSECO Forum 2024); it also advertised the

upcoming 5G-STARDUST-organised workshop held within IEEE Global Communications Conference 2024, and promoted the "Updates from Orbit: 5G-STARDUST & Standardisation" video.

- The 5th newsletter (July 2025) was sent to 29 subscribers (41% opens / 10% clicks); the issue promoted the additional videos released since January 2025, also providing an overview of further end-of-2024 event participations and a roundup of summer events (with particular attention dedicated to our extensive EuCNC 2025 participation).
- The 6th newsletter - scheduled to match the project's closure at the end of March 2026 - was sent to 30 subscribers (20% opens / 7% clicks, at the time of writing), collecting recap articles on latest event participation, further promotion of the "Proof of Concept" video, and for the planned final webinar.

Press releases & Press clipping

To date, 4 press releases were issued, published on the official 5G-STARDUST website and effectively disseminated to specific media outlets through the Prowly tool. Task 7.1 increased releases in the second half of the project, as planned, to boost the envisioned announcements for events organised and participated to. All press releases will continue to be made available on the dedicated section of the project's website.

The table here below lists instead all 5G-STARDUST features on publications, which have also been made available in the "Press clipping" section of the project's website (selected pages of such publications are also present in Annex A of this document).

Table 1: Press coverage in the second half of the project

Publication	URL	Lead partner involved
Innovation News Network	https://www.innovationnewsnetwork.com/the-5g-stardust-project-a-self-organised-networking-architecture-for-6g-systems/52569/	DLR
SNS Journal 2025	https://smart-networks.europa.eu/sns-journal-2025/	MAR, DLR
SNS Journal 2026	Additional article submitted, to be published in early summer 2026	MAR, DLR

2.5 SCIENTIFIC PUBLICATIONS

5G-STARDUST's partners have been active in submitting scientific papers to conference publications and scientific journals: within the second half of the project, **13 papers** have been produced. The papers are listed on the project's website – and available for download in PDF format, when feasible - in a dedicated section.

Table 2: Scientific publications M18-M39

Title	Authors	Venue
Hierarchical Reinforcement Learning for Multi-layer Multi-Service Non-Terrestrial Vehicular Edge Computing	Swapnil Sadashiv Shinde, Daniele Tarchi	IEEE Transactions on Machine Learning in Communications and Networking
NTN Architecture for PPDR in 5G-Advanced	Benjamin Barth, Roshith Sebastian, Tomaso de Cola, Alessandro Guidotti	FNFW2024
ML-Based Intelligent O-RAN Control in 6G Integrated Terrestrial and Non-Terrestrial Networks	Swapnil Sadashiv Shinde, David Naseh, Daniele Tarchi	IEEE GLOBECOM 2024
F-KANs: Federated Kolmogorov-Arnold Networks	E. Zeydan, C. J. Vaca-Rubio, L. Blanco, R. Pereira, M. Caus and A. Aydeger	1st workshop on Distributed AI for Enhanced Wireless Networks (DAINET) 2025, in conjunction with IEEE Consumer Communications & Networking Conference
Transforming 5G Mega-Constellation Communications: A Self-Organized Network Architecture Perspective	Marius Corici, Màrius Caus, Xavier Artiga, Alessandro Guidotti, Benjamin Barth, Tomaso de Cola, Justin Tallon, Hemant Zope, Daniele Tarchi, Fanny Parzysz, David Naseh, Swapnil Sadashiv Shinde	IEEE Access
Sustainability in SNS JU Projects	Flavien Ronteix-Jacquet (contributor)	SNS JU
On the Architectural Split and Radio Intelligence Controller Placement in Integrated O-RAN-enabled Non-Terrestrial Networks	J. Baranda, M. Caus, L. Blanco, C. J. Vaca-Rubio, E. Zeydan, K. Dev, Z. Li and T. DeCola	IEEE Open Journal of the Communications Society
6G for Media & Entertainment	Tomaso de Cola (contributor)	SNS JU
Efficient Message-Passing Detection for Multi-Satellite Systems Using OTFS Modulation	E. Conti, A. Piemontese, T. Foggi, G. Colavolpe, A. Vannucci	IEEE Aerospace Conference

Cell-Free Macro-Diversity Schemes in LEO Non-Terrestrial Networks With OTFS and OFDM Modulations	C. D'Andrea, T. Foggi, A. Piemontese, A. Ugolini, S. Buzzi, G. Colavolpe	IEEE Open Journal of the Communications Society
A Predictive Approach for Transport Protocol Multi-Connectivity Scheduling	Roshith Sebastian; Benjamin Barth; Tomaso de Cola; Cristian J. Vaca-Rubio; Luis Blanco; Marius Caus; Engin Zeydan	FNWF2025
Attention-Based SINR Estimation in User-Centric Non-Terrestrial Networks	Bruno De Filippo, Alessandro Guidotti, Alessandro Vanelli-Coralli	IEEE ICMLCN 2026
Synchronization in LEO 5G-NTN: Challenges and Solutions	E. Mozo, M. Caus, A. Giuliani, P. Henarejos, P. Gawlowicz, J. Tallon and M. Á. Vázquez	URSI GASS 2026

Additionally, the consortium created and submitted for publication the following papers within the project's run – their separation from the rest of the list is motivated by current non-open access availability or pending acceptance (for most recent output).

Table 3: Additional scientific publications output

Title	Authors	Venue
Multi-3GPP Connectivity Concept, Architecture and Specific Implementation Details	Marius Corici, Eric Troudt, Benjamin Barth, Roshith Sebastian, Christian Scheich, Tomaso de Cola	6GNet 2024
A Primer on Kolmogorov-Arnold Networks (KANs) for Probabilistic Time Series Forecasting	Cristian J. Vaca-Rubio, Roberto Pereira, Luis Blanco, Engin Zeydan, Màrius Caus	IEEE Communications Letters
Pragmatic Earth-Fixed Beam Management for 3GPP NTN Common Signaling in LEO Satellites	X. Artiga, M. Caus, A. Pérez-Neira	IEEE Access
Learning-Based Reactive Handover under Line-of-Sight Loss: A UE-Centric NTN Continuity Model	Marius Corici, Hauke Buhr, Thomas Magedanz	ICC 2026
Deploying Intelligence Solutions into Non-Terrestrial Network Based O-RAN Architectures	Daniele Tarchi, Swapnil Sadashiv Shinde, David Naseh	Computer Networks (Elsevier)

Within the second half of the project, all deliverable listed as open access, or currently available in their pre-print version, have also made available in a dedicated Zenodo community.

2.6 EVENTS

2.6.1 Events organised

"6G-NTN: architectures and technologies" workshop at PIMRC 2024

Figure 13: The 5G-STARDUST representatives talking during the "6G-NTN: architectures and technologies" workshop at PIMRC 2024

Partners Fraunhofer and CNIT teamed up to co-organise a workshop within PIMRC (IEEE International Symposium on Personal, Indoor and Mobile Radio Communications) in September 2024 (held in Valencia, Spain). The workshop focused on an exchange of innovative ideas and insights to shape new research directions on enabling techniques for integration and flexible network operation of NTN in 6G, targeting both infrastructural and technological aspects. CNIT also contributed to the discussion with a keynote entitled “The NTN (r)evolution”, held by representative Alessandro Guidotti, who also delivered, in the afternoon, a tutorial on 6G-NTN Architectures with Carla Amatetti of University of Bologna. The first of the two in-workshop sessions also saw a delegation from Berlin-based Fraunhofer – including Marius Corici, Hauke Buhr, Hemant Zope and Manar Zaboub – presenting “An SDN-Based Solution for Mega-Constellation Routing”. The event gathered an audience of 30 attendees, who actively participated in discussions throughout the day. The key takeaway from the workshop was that a native inclusion of the NTN component in 6G will contribute to the resilience, flexibility, and sustainability of the system enabling service improvement and market enlargement. However, to achieve a fully harmonised 3D TN-NTN system, both evolutionary and revolutionary technologies will need to be researched and developed.

FOKUS FUSECO Forum 2024

Figure 14: The 5G-STARDUST representatives in action during FOKUS FUSECO Forum 2024

FOKUS FUSECO Forum is the flagship event annually organised by project partner Fraunhofer in Berlin (Germany). This edition (held in November) focused, this time more than ever, on all efforts projecting us "Forward to 6G", as its title indicated. 5G-STARDUST also contributed to the event through presentations from CNIT and DLR as part of the in-event "3rd Euro NTN Workshop: TN NTN Unification, Non-Terrestrial Networks in the 6G Era – Current Topics and Latest Advancements".

Workshop on Ubiquitous Intelligence-at-the-Edge for Space-Air-Ground Integrated Networks (BRAIN) at IEEE Globecom 2024

Figure 15: Online promotional material for the "Workshop on Ubiquitous Intelligence-at-the-Edge for Space-Air-Ground Integrated Networks (BRAIN)" held at IEEE Globecom 2024

In early December 2024, our partners flew to Cape Town, South Africa, to attend the 2024 edition of the IEEE Global Communications Conference (GLOBECOM). Entitled "Connecting the Intelligent World through Africa", the flagship conference of the IEEE Communications Society featured a comprehensive high-quality technical program – which typically attracts around 3000 scientific researchers every year – including 13 symposia and a variety of tutorials and workshops. 5G-STARDUST partners DLR and CNIT teamed-up to co-organise there the successful in-event "Workshop on Ubiquitous Intelligence-at-the-Edge for Space-Air-Ground Integrated Networks (BRAIN)", which took place on December 12. The workshop also saw CNIT and CTTC presenting their research conducted within the framework of the project.

12th Advanced Satellite Multimedia Systems Conference + 18th Signal Processing for Space Communications Workshop (ASMS/SPSC)

Figure 16: A snapshot from ASMS/SPSC

This event – taking place in Sitges, Spain, in February 2025 - had very close ties with our consortium, as it was organised by 5G-STARDUST's coordinating partner DLR alongside CTTC, with the scientific support of the European Space Agency (ESA) and the University of Bologna. The guiding theme of the event was the role of Non-Terrestrial Networks (NTN) within future 6G systems – which couldn't be more connected with the project's work – and the partners had the further chance to showcase 5G-STARDUST through a dedicated booth (shared with fellow SNS JU project 6G-NTN) on ASMS/SPSC's exhibition floor, which could count on the visit of 170 registered participants, confirming the event's outstanding technical level and its key impact in the field of satellite communications.

"Terrestrial and non-terrestrial networks unification towards 6G" workshop at EuCNC 2025

Figure 17: Project Coordinator Tomaso de Cola (DLR) during his talk at the "Terrestrial and non-terrestrial networks unification towards 6G" workshop at EuCNC 2025

5G-STARDUST was integral part of Workshop 8 at EuCNC 2025 (held in June in Poznan, Poland), entitled "Terrestrial and non-terrestrial networks unification towards 6G": the workshop was co-organised with Eurescom and fellow SNS JU projects 6G-NTN and ETHER, and took place on EuCNC's opening day, June 3. Our Project Coordinator Tomaso de Cola (DLR) delivered a talk as part of the programme, entitled "From architecture design to lab demonstrations: the 5G-STARDUST journey". The talk illustrated the main directions taken by the project regarding a converged 5G-NTN network architecture and presented and outlined the design of an integrated testbed to demonstrate the potentials for multi-path protocol exploitation in 5G-NTN integrated networks. In particular, the main building blocks of the proof-of-concept were presented and the reference demonstration scenarios outlined.

"Integrated 6G Architectures and Technologies for Terrestrial and Non-Terrestrial Networks" workshop at PIMRC 2025

Figure 18: The "Integrated 6G Architectures and Technologies for Terrestrial and Non-Terrestrial Networks" workshop at PIMRC 2025

The project went back to PIMRC for its September 2025 edition (held in Istanbul, Turkey), co-organising – jointly with fellow SNS JU projects 6G-NTN and UNITY-6G – the workshop "Integrated 6G Architectures and Technologies for Terrestrial and Non-Terrestrial Networks" within the programme of the event. The workshop addressed one of the central challenges of 6G: how to seamlessly integrate terrestrial and non-terrestrial networks into a unified architecture. With the proliferation of satellites, high-altitude platforms, drones, and terrestrial systems, the heterogeneity of network nodes introduces significant complexity for service delivery in multi-layered, multi-frequency, and multi-mission environments; representing 5G-STARDUST and its work were the partners from CNIT.

"5th NTN Workshop – Towards a unified TN-NTN system – Current topics and latest advancements"

Figure 19: The 5G-STARDUST Proof of Concept demo presented at the 5th NTN Workshop

In November 2025, project partner Fraunhofer organised yet another event in their Berlin premises (in collaboration with ESA and Eurescom), which saw a dense programme of presentations and talks across its single-day duration - featuring DLR, SRS and CNIT on stage – and an exhibition area with a dedicated booth showcasing the project's Proof of Concept demo, alongside fellow SNS JU project ETHER. As a now recognised industry forum, reaching its fifth edition, the NTN Workshop served as an ideal showcase and exchange platform, as it focused on unification by bridging terrestrial and non-terrestrial sectors and harnessing the momentum created by 6G and O-RAN standardisation to shape new ecosystems and accelerate cross-industry convergence.

Final project webinar

Figure 20: Social media promotion item created to promote the final project webinar

At the time of writing, the consortium is planning a closing event in the form of a webinar, entitled “5G-STARDUST: The R&D Journey towards Space Connectivity” – to be held in the second half of April 2026, slightly after the end of the project - seen as a necessary extra effort to create a comprehensive wrap-up of the projects’ findings, results and expected impact.

2.6.2 Events attended

5G-STARDUST’s partners have attended or participated to **52 external events** in total over the course of the project, **40 of which in the reporting period alone**, giving keynote presentations and promoting the projects goals and achievements. The table here below summarizes the events attended. These participations have been reported in the news section and the events calendar of the project’s website and have been promoted through the social media channels and newsletters.

Table 4: Events attended M18-M39

Event	Date, location	Type of audience	Approx. audience size	Activities	Partners involved
IEEE MEDITCOM	8–11 July 2024, Spain	Academics	25-30	Presentation	DLR
IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2024)	2-5 Sept. 2024, Spain	Academics, Industry	25-30	Paper presentation, Co-organisation of workshop on "6G-NTN: architectures and technologies" and presentation and tutorial within workshop	Fraunhofer, CNIT
2024 Glue Technologies for Space Systems Technical	3 Sept. 2024, Online	Academics	30	Remote lecture "From 5G/5G-Advanced to 6G NTN"	CNIT

Panel Ph.D. Summer School					
one6G Summit 2024	5-6 Sept. 2024, Spain	Academics, Industry	200	Presentation with mention of 5G-STARDUST	CTTC
(SPAWC 2024) 2024 IEEE 25th International Workshop on Signal Processing Advances in Wireless Communications	9-13 Sept. 2024, Italy	Academics, Industry	100	Presentation with mention of 5G-STARDUST	CNIT
European Microwave Week 2024	22-27 Sept. 2024, France	Industry	5,000	5G-STARDUST project contribution about the system and PoC definition	Thales Alenia Space
IEEE VTC Fall 2024	7-10 Oct. 2024, US + remote	Academics, Industry	630	Remote keynote speech at the 3rd IEEE Workshop on “B5G/6G Support for Space/Air/Ground/Marine/Submarine Cooperative, Connected, and Autonomous Vehicles (CCAAVs)”	CNIT
ISSST 2024	14-16 Oct. 2024, UK	Academics, Industry	100	Presentation, chair of "5G and 6G Network" session	CNIT
IEEE Future Networks World Forum	15-17 Oct. 2024, UAE	Academics, Industry	20-30	Panel participation, paper presentation	DLR, CNIT
6GNet 2024	21-24 Oct.2024, France	Academics	100	Paper presentation	Fraunhofer, DLR
IEEE ComSoc 2024 Workshop 1	28 Oct. 2024, UK	Academics	70	Panel participation	CNIT
FOKUS FUSECO Forum	7-8 Nov. 2024, Germany	Academics, Industry	>100	Presentations, booth	DLR, Fraunhofer, CNIT

Satellite Network Of Experts School | SatNEx V	11-14 Nov. 2024, Spain	Academics	40-50	Presentation	CTTC
FIDAL Workshop	21 Nov. 2024, Online	Academics, Industry	40	Presentations on Proof of Concept for PPDR	DLR
IEEE INGR Satellite WG	4 Dec. 2024, Online	Academics, Industry	10	Presentation	CTTC
Workshop on Ubiquitous Intelligence-at-the-Edge for Space-Air-Ground Integrated Networks (BRAIN) - IEEE Globecom 2024	12 Dec. 2024, Cape Town, South Africa	Academics	2,000	Organisation, keynote, presentation	CNIT, DLR, CTTC
"New Perspectives for the Integration of Terrestrial and Non-Terrestrial Networks for 6G Systems", webinar organised within the IEEE International Network Generations Roadmap (INGR) Satellite Working Group	18 Dec. 2024, Online	Academics, Industry	50-60	Presentation	CNIT
V5G Valencia	3 Jan. 2025, Spain	Industry	100	Presentation with mention of 5G-STARDUST	Hispasat
12th Advanced	26-28 Feb.	Academics, Industry	170	Presentations, joint booth with 6G-NTN	CTTC, DLR

Satellite Multimedia Systems Conference + 18th Signal Processing for Space Communications Workshop	2025, Spain				
IEEE Aerospace Conference	1-8 Mar. 2025, Montana, USA	Industry, researchers, journalists	700	Paper presentation	CNIT
MWC 2025	3-6 Mar. 2025, Spain	Industry, researchers, journalists	100,000	Booths	CTTC, Hispasat, SRS, Fraunhofer, AW2S
V5G Days Valencia	27-28 Mar. 2025, Spain	Industry	100	Presentation with mention of 5G-STARDUST	Hispasat
EU-Japan Digital Week 2025	Mar. 31-Apr. 7 2025, Japan	Industry	>400	Promo material showcased	Martel
5G Forum	12-16 May 2025, Spain	Industry	900	Presentation with mention of 5G-STARDUST	Hispasat
SPACERAISE - Digital Twins for Space Manufacturing and Satellites	20 May 2025, Italy	Academics, Industry	150	"Intelligence-at-the-Edge for Space-Air-Ground Integrated Networks" 90-min lecture mentioning 5G-STARDUST	CNIT
EuCNC and 6GSummit 2025	3-6 June 2025, Poland	Policy makers, researchers, industry, EC representatives, EU-funded projects	50-60	Tutorial ("NTN (r)evolution: stepping into 6G"), workshop ("Terrestrial and non-terrestrial networks unification towards 6G"), promo materials showcase, booth, participation to Special Session 19 "AURA-6G:	Martel, DLR, CNIT, SRS, Orange, CTTC

				Towards an AI-native, service oriented, ubiquitous and verifiable 6G integrated fabric"	
IEEE MetroAeroSpace 2025	June 18-20 2025, Italy	Academics, Industry	150	CNIT co-chair of special track session #1 "Concepts and Technologies for Next-generation Integrated Terrestrial–Non-Terrestrial Networks (CONNECT)", keynote	CNIT
PIMRC 2025	1–4 Sept. 2025, Turkey	Academics, Industry	25-30	CNIT co-organising workshop "UAV-based NTN systems"	CNIT
2025 Glue Technologies for Space Systems Technical Panel Ph.D. Summer School	1-5 Sept. 2025, Italy	Academics	30	CNIT (A. Guidotti) gave a lecture at the event on Sept. 3	CNIT
ELIXIRION School 3 "Integrated Non-Terrestrial and Terrestrial 6G Networks towards Healthcare 4.0"	15 Sept. 2025, Spain	Academics	20-25	Presentation with mention of 5G-STARDUST	CTTC
SoftCOM 2025	18-20 Sept. 2025, Croatia	Academics	400	CNIT co-chair of "Symposium on New Trends in Satellite and Space Communications and Navigation"	CNIT
Thinknet 6G Event "NTN, Security & Resilience"	19 Sept. 2025, Germany	Academics, Industry	70-80	DLR showcasing project	DLR

DIA Event "Addressing Grand Challenges Through Communication Systems"	29 Sept. 2025, Germany	Academics, Industry	80	DLR delivering a presentation on "SatCom and NTN: from Data Communication to Data Infrastructure"	DLR, Martel
S5LECT Mid Term Event	22 Oct. 2025, Spain	Industry	40	Presentation	DLR
"5th NTN Workshop – Towards a unified TN-NTN system – Current topics and latest advancements"	6 Nov. 2025, Germany	Academics, Industry	80	Co-organisation, Booth, demo, presentations, talks	MAR, Fraunhofer, CNIT, DLR
Huawei workshop WINNOW	13 Nov. 2025, Italy	Industry	60	Presentation	CNIT
Fifth Visions for Future Communications Summit	25-26 Nov. 2025, Portugal	Academics, Industry	70	CNIT presenting at the event	CNIT
one6G Open Lecture 11 "Non-Terrestrial Network for 6G"	22 Jan. 2026, Online	Academics, Industry	270+	Presentation as part of the programme	DLR, CTTC, CNIT
Potentialities of 5G Terrestrial & Non-Terrestrial Networks for European Governmental Users and Services	11 Feb. 2026, Online	Industry, researchers, policy makers	70	CNIT presenting at the event	CNIT
Mobile World Congress 2026	2-5 March 2026, Spain	Industry, researchers, journalists	100,000	Booths	Fraunhofer, SRS, Hispasat

EuCNC 2026	2-5 June 2026, Spain	Policy makers, researchers, industry, EC representatives, EU-funded projects	50-80 (estimated)	Attendance planned, presented proposal for in-event workshop	DLR

3 SYNERGIES

3.1 SNS JU & SNS OPS

As stated in D7.1 and D7.2, 5G-STARDUST is a member of the Smart Networks and Services Joint Undertaking (SNS JU) under its Phase 1's Stream A (Smart communications components, systems and networks for 5G mid-term evolution systems). This Public-Private Partnership aims to foster and advance industrial leadership in Europe regarding 5G and 6G networks and services. As a member, 5G-STARDUST attends monthly **SNS JU Communication Task Force Meetings** involving representatives of all fellow Stream A projects - and beyond - where information about the respective and joint/common activities is exchanged and orchestrated, which has led – and is continuously leading - to active collaboration with the other projects.

Let us break down some key concrete results of this synergy, for the reporting period:

- 5G-STARDUST is featured among the SNS projects on the 6G SNS website and communication materials, **and it's actively contributing to and echoing SNS JU social media efforts.**

- Direct communication support of fellow SNS JU projects 6G4Society, 6G-NTN and ETHER by promoting their initiatives and activities (as their communication is also simultaneously run by Martel and they share partners and representatives with 5G-STARDUST), creating a mutually beneficial, self-sustaining system.

- Promotion of **SNS Journal 2024 and 2025** (which both carried a feature on the project) via social media, website and newsletter.

- As mentioned in Section 2.6, **several of the events the project co-organised were joint ventures with other SNS JU endeavours**, such as the EuCNC 2025 "Terrestrial and non-terrestrial networks unification towards 6G" workshop co-organised with 6G-NTN and ETHER, and the workshop "Integrated 6G Architectures and Technologies for Terrestrial and Non-Terrestrial Networks" organised with 6G-NTN and UNITY-6G in the context of PIMRC 2025. FOKUS FUSECO Forum and the connected "5th NTN Workshop – Towards a unified TN-NTN system – Current topics and latest advancements", which involved project partner Fraunhofer in their organisation, also featured active presence of other SNS JU projects and ecosystem players, showcasing and presenting their work.

3.2 OTHER RELEVANT INITIATIVES AND PROJECTS

In this section we offer instead a summary of the other initiatives the project has connected and collaborated with – and of their respective mission - with some updates from what previously presented in D7.2.

The 6G Smart Networks and Services Industry Association (6G-IA) is the voice of European Industry and Research for next generation networks and services. Its primary objective is to contribute to Europe's leadership on 5G, 5G evolution and SNS/6G research. While the European Commission represents their public side, the 6G-IA represents the private side in both the 5G Public Private Partnership (5G-PPP) and SNS JU. The 6G-IA brings together a global industry community of telecoms & digital actors, such as operators, manufacturers, research institutes, universities, verticals, SMEs and ICT associations. In the reporting period, cross-posting between the initiative and 5G-STARDUST took place, with WP7 making sure to tag and re-post the 6G-IA, given its inherent connection to SNS JU.

The European Space Agency (ESA) is Europe's gateway to space. Its mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world. Cooperating and partnering with ESA is a great opportunity to tackle the main stakeholders and researchers in the space and satellite domains. As stated above, 5G-STARDUST has sought out all relevant chances to cross paths and engage with ESA through some of the events the project took part in – like in the specific case of the 2024 FOKUS FUSECO Forum and the November 2025 5th NTN Workshop ESA co-organised. ESA also supported the November 2024 Satellite Network of Experts School (SatNEx V), which was co-organised by partner CTTC, and the 2025 ASMS/SPSC, which also saw our consortium involved (as previously mentioned).

one6G is a membership organization focused on evolving, testing and promoting next generation cellular and wireless technology-based communications solutions. By supporting global 6G research and standardization efforts, the goal is to accelerate its adoption and overall market penetration, while addressing societal and industry-driven needs for enhanced connected mobility. The shared network of the one6G initiative, alongside the knowledge base represents additional inputs for the project (both on technical and business-related manners), and a chance to create broader awareness amongst of 5G-STARDUST's key stakeholders. This also materialised as an invitation to partner CTTC to present 5G-STARDUST among the projects that the Centre is working within, during the 2024 edition of the annual one6G Summit, in Valencia, Spain.

Alliance for the IoT and Edge Computing Innovation (AIOTI) aims to lead, promote, bridge and collaborate in IoT and Edge Computing and other converging technologies research and innovation, standardisation and ecosystem building, providing IoT and Edge Computing deployment for European businesses creating benefits for European society. They cooperate with other global regions to ensure removal of barriers to development of the IoT and Edge Computing market while preserving European values, including privacy and consumer protection.

6G-NTN is a 6G SNS-funded project that aims to design and validate NTN's key technical, regulatory, and standardisation enablers for the integration of TN and NTN components into 6G, focusing on multidimensional network infrastructure, multi-constraint RANs, and multi-user terminals. As dissemination and communications in the project are also run by WP7 leader Martel, there's a direct line for collaboration and mutual support, as materialised in continuing joint workshops and showcase activities, as listed in the previous sections.

ETHER is a 6G SNS-funded project that aims at developing solutions for a Unified Radio Access Network (RAN) and for the energy-efficient, AI-enabled resource management across the terrestrial, aerial and space domains, while creating the business plans driving future investments in the area. The connection with ETHER is also of immediate nature due to Martel being partner in the project, thus resulting in the continuation to connect with ETHER in workshops and showcases' co-organisation.

6G-SANDBOX is a 6G SNS-funded project bringing a complete and modular facility for the European experimentation ecosystem (in line and under the directions set by SNS JU), which is expected to support for the next decade technology and research validation processes needed in the pathway towards 6G. Common themes and partners connected us with it, creating a fruitful collaboration which made 6G-SANDBOX a regular contributor of common presentations and workshops – this aspect though remained limited to the first half of the project (as covered in D7.2), mutual online re-sharing of promotion aside.

6G-XR is a 6G SNS-funded project on a mission to strengthen European leadership in 6G technologies by enabling next-generation XR services and infrastructures that will provide beyond-state-of-the-art capabilities towards the 6G era. Beyond the thematic/ecosystem connection, the shared Martel communication and dissemination leadership between 6G-XR and 5G-STARDUST greatly facilitates cross-posting and mutual support (which continued within the reporting period).

6G4Society is a 6G SNS-funded project aiming to ensure that societal and sustainable values are properly embedded into the development of 6G technology, bringing a sociological perspective to technological development. The project connected to 5G-STARDUST's efforts not only by bringing to the mix another essential angle, but also as its communication is led by Digital For Planet, which Martel has a direct line with, adding to the already extensive "echo chamber" system in place.

TRANTOR, is a project targeting the in-orbit validation of a complete satellite value chain involving an automated management of satellite resources across multiple bands, satellites, and orbits, and a converged radio access network. They crossed paths with us on the occasion of the aforementioned SatNEx V school, where they teamed up with our CTTC partners – which also featured within the event's programme – for a talk entitled "Performance Evaluation of 3GPP Release 17 Non-Terrestrial Networks: A debrief", covering mutual connections.

FIDAL is a project seeking to set the standard by fostering open architectures, large experimentation sites, and adopting a multi-stakeholder approach. Following this objective, the project is targeting the augmentation of human capabilities, enabling Media & Public Protection and Disaster Relief (PPDR) vertical industry players to carry out advanced technological and business validation in large-scale trial facilities of highly innovative and advanced applications, which take full advantage of Evolved 5G technologies. Within the context of such activities, FIDAL invited 5G-STARDUST's Project Coordinator, Tomaso de Cola (DLR) to be part of their November 2024 webinar, which delved into some examples of technological innovation for PPDR currently being explored within the SNS JU Community, which 5G-STARDUST belongs to.

INPACE is a Coordination and Support Action Initiative funded by the European Commission's Horizon Europe Programme, on a mission is to support the implementation of the Digital Partnerships between the European Union and Japan, South Korea, Singapore, as well as the Trade and Technology Council with India. The shared Martel communication and dissemination leadership between INPACE and 5G-STARDUST led to the promotion of the latter at the EU-Japan Digital Week 2025 (March/April 2025) - effectively bringing attention to the project within a brand new context - which INPACE co-organised. The event brought together stakeholders from the EU and Japan to focus on key priority areas for both regions, including 6G, Data Spaces, Smart Connectivity and Computing, and Trustworthy Artificial Intelligence. Among the on-site workshops there was focus on 6G Development – very much relevant to 5G-STARDUST's work – fostering dialogue between policymakers, industry leaders, and experts.

S5LECT is a fellow EU-funded project, led by SNCF and developed by Railenium, GTS (Hitachi Rail), Radiolabs, and CEIT, aiming to develop a seamless handover functionality between 5G terrestrial network, satellite link and GSM-R communication system. It thus set off on a 30-month run to study combining land and satellite networks for critical railway tasks, aiming to create a seamless handover between networks, check cybersecurity risks, propose new edge computing designs, and prove the concepts in a lab. The project outputs will help develop satellite communication solutions for railways and support testing activities to create more reliable wireless communication prototypes, speeding up the delivery of next-generation wireless communications for all railway segments. On October 2025, given the evident connection with our work, 5G-STARDUST was invited to present its achievements at the Mid Term Event organised by S5LECT, where coordinating partner DLR presented the project's specific research on multi-connectivity for 5G-Advanced and beyond.

4 IMPACT ASSESSMENT

The consortium has kept a close eye on the KPIs set at the beginning of the project, to monitor the Dissemination & Communication Results. The table below offers details on the status of KPIs at the end of the project.

Tool/Activity	Indicators	Target (M36)	Status at M39
Website	Total visits (yearly)	1500	9,000
Social media	# followers (by project end) on Twitter # followers (by project end) on LinkedIn #visits to YouTube channel (by project end)	300 100 500	215 705 468
Press releases	#published press releases (by project end)	≥ 3	4
News items on the website	#published news items (yearly)	≥ 12	27
Newsletter	#newsletters sent out	6	6
Flyers/brochures Posters/roll-ups	#developed flyers/brochures (incl. digital brochures) #produced posters/roll-ups	3 ≥ 2	1 (+update) 3
Videos	#produced videos	≥ 4	5
Events (attendance, incl. Online events)	#attended events (by project end)	≥ 15	52
Events (organisation)	#organised events (by project end) #participants in each event	≥ 2 60+	11 + Final webinar >700

5 EXPLOITATION AND SUSTAINABILITY PLAN

5.1 EXPLOITATION APPROACH AND HORIZON BOOSTER SUPPORT

5G-STARDUST exploitation strategy has been refined with the support of the Horizon Results Booster (HRB) service provided by the European Commission, is a strategic framework used to outline how the project's results will be utilized and how those results or innovations will remain viable and sustainable over time. This support helped the consortium move from a broad description of project results to a more structured exploitation approach centred on market relevance, differentiation, realistic post-project pathways, and long-term sustainability. The plan ensures that the outcomes have long-term impact, both in terms of economic value and environmental or social responsibility.

The Exploitation Plan outlines how the project results will be used and maximized after the project is completed. The goal is to ensure that the project's outputs are effectively turned into tangible benefits, such as products, services, knowledge, or societal impacts. This exploitation plan will show some of the 5G-STARDUST results and create a roadmap of how the outcomes could be applied in real-world context describing the market demand, Identifying key stakeholders (e.g., businesses, governments, or research institutions) who can help take the results forward, ensuring continued use and impact.

The Horizon booster process allowed the consortium to assess the maturity, positioning, and exploitation potential of the main project results through a set of dedicated characterization, market definition, value proposition, roadmap, and risk assessment exercises. This work was especially useful in clarifying which outcomes of the project have the strongest potential for post-project uptake and how they should be presented to future adopters, industrial partners, and other stakeholders.

As a result of this process, three Key Exploitable Results (KERs) were identified and prioritized:

Table 5: Key exploitable result table

Name	Owner	TRL	Type of result
NTN-enabled 5G gNB	SRS	6-7	Software
NTN-enabled 5G UE	CTTC	4-5	Software
AI traffic prediction engine	CTTC	4-5	Software Algorithm

These KERs are individually exploitable and address different layers of the hybrid terrestrial / non-terrestrial network value chain. At the same time, they reinforce one another and together form a coherent portfolio that reflects the strategic ambition of 5G-STARDUST: to support intelligent, standards-based, interoperable, and sustainable TN/NTN integration.

In the first iteration of the exploitation assessment, other relevant project outcomes were also screened alongside the three prioritized KERs. Although these results are valuable contributions of 5G-STARDUST, their current level of maturity suggests that additional development and validation would be needed before defining a concrete exploitation pathway. As such, they should be regarded as promising foundations for future R&I activities, with the potential to stimulate further collaboration between industry and academia and to support subsequent innovation projects beyond the duration of 5G-STARDUST.

Sustainability Plan focuses on how the results and impact of the project will continue after the funding or initial support ends. It ensures that the project is environmentally, socially, and economically sustainable outlining how the project's innovations or outcomes will continue to provide value over time.

5.2 PORTFOLIO OF KEY EXPLOITABLE RESULTS

The three KERs selected in 5G-STARDUST represent complementary technological assets spanning the infrastructure, terminal, and intelligence layers of hybrid TN/NTN networks.

The NTN-enabled 5G gNB addresses the access network layer by enabling standards-compliant NTN integration on the infrastructure side. The NTN-enabled 5G UE addresses the terminal layer by enabling user-side validation and future evolution towards NTN-capable end-user equipment. The AI traffic prediction engine addresses the intelligence layer by supporting predictive and policy-driven optimization of hybrid TN/NTN deployments.

Taken together, the three KERs define a consistent exploitation portfolio. They are not three disconnected outputs, but rather three mutually reinforcing results that contribute to a broader European proposition for future hybrid 5G and beyond-5G infrastructures.

5.2.1 Exploitation analysis per KER

5.2.1.1 NTN Enable 5G gNB (SRS)

Current 5G gNB solutions are primarily designed for terrestrial deployments and present significant limitations when extended to NTN. Particularly, they are not natively prepared to cope with long and variable propagation delays, Doppler effects, timing and location constraints, and the integration of regenerative satellite payloads across GEO and LEO orbits. These limitations hinder the seamless integration of NTN into 3GPP-compliant networks and prevent the delivery of carrier-grade 5G services over satellite links.

The proposed solution is a carrier-grade, O-RAN-based 5G gNB enhanced with native NTN capabilities. It enables seamless operation over GEO and LEO satellite systems and supports deployment scenarios involving regenerative payloads through an optimized CU/DU functional split. The solution introduces NTN-specific protocol and scheduling enhancements to ensure reliable performance under high latency and Doppler conditions, while maintaining full 3GPP compliance and interoperability with terrestrial networks. In addition, AI-driven telemetry and control mechanisms are incorporated to optimize performance and resource utilization in dynamic NTN environments.

The solution is based on an O-RAN-compliant 5G gNB architecture extended to support NTN. It enables operation over GEO and LEO satellite systems by adapting key gNB functions to the specific characteristics of satellite links. The gNB supports flexible CU/DU deployment options, allowing part of the processing to be located close to regenerative satellite payloads.

To cope with long propagation delays and dynamic link conditions, the gNB includes simplified latency-aware scheduling and adapted protocol timers and buffers. Doppler effects and synchronization requirements are handled through dedicated compensation mechanisms and the use of standardized timing and location information (SIB19).

In addition, the gNB exposes basic monitoring and control capabilities through the O-RAN E2 interface, enabling performance optimization and operational supervision in dynamic NTN environments.

The most relevant adopters of this KER are mobile network operators seeking to extend coverage via satellite, satellite network operators moving towards 3GPP-based service delivery, system integrators, mission-critical network providers, and research or institutional actors involved in advanced NTN experimentation. These stakeholders are increasingly looking for solutions that combine openness, flexibility, interoperability, and realistic deployment potential.

The main differentiation of this KER lies in the fact that it combines native NTN capability with a fully software-defined and hardware-agnostic implementation. The solution can be deployed across heterogeneous COTS infrastructures and different CPU architectures, which reduces deployment constraints and avoids unnecessary dependence on proprietary hardware ecosystems. In addition, its compliance with 3GPP and O-RAN principles lowers integration barriers and supports multi-vendor interoperability. A further advantage is that the full L1-L2-L3 stack is developed and owned by SRS, which provides a stronger basis for transparency, maintainability, customization, and support.

From an exploitation perspective, this KER has the clearest direct commercial profile within the portfolio. Its most credible post-project pathway is direct commercialization through software licensing, engineering support, tailored integration services, and continued product hardening. The roadmap developed during the exploitation support process already points in this direction, including product packaging, market-facing materials, and the engagement of early adopters capable of validating the value proposition in operational contexts.

The main risks for this KER are linked to standard evolution, industrial adoption, and the transition from a validated project result to a more robust carrier-grade market offer. These risks can be mitigated through continued alignment with 3GPP releases, phased validation with external adopters, modular product evolution, and a positioning strategy that presents the solution as a practical enabler of NTN integration rather than as a disruptive replacement for existing infrastructure.

Overall, the NTN-enabled 5G gNB should be presented as a strong commercial asset with near-term exploitation potential and clear relevance for the emerging market of standards-based hybrid TN/NTN infrastructure solutions.

Our 5G NTN RAN software helps satellite network operators who want to provide 5G coverage by drastically simplifying system-wide integration, reducing setup time, eliminating legacy interface constraints, and supporting them end-to-end throughout the deployment process, unlike legacy satellite platforms.

Provides a carrier-grade, software-defined 5G gNB enhanced for NTN operation, including:

- Support for GEO and LEO satellite environments
- NTN-specific enhancements (latency-aware scheduling, HARQ and timer adaptations, Doppler compensation)
- CU/DU functional split towards regenerative payload deployments
- O-RAN compatibility and AI-driven control via open interfaces

This KER enables standards-compliant integration of NTN within 5G infrastructures.

5.2.1.2 NTN Enable 5G UE (CTTC)

Current commercial 5G user equipment implementations are primarily designed for terrestrial networks and lack native support for the specific propagation conditions of NTN, such as long round-trip delays and high Doppler shifts, limiting their applicability for reliable broadband and mission-critical services over satellite links.

An enhanced 5G UE software solution that enables seamless operation over integrated terrestrial and non-terrestrial networks by extending a standards-compliant terrestrial UE with native NTN capabilities, allowing operators and system integrators to deploy 3GPP-based satellite access with minimal impact on existing device architectures.
The 5G NTN User equipment helps mobile network operators and satellite operators who wants to provide or extend connectivity in airplanes or vessels by avoiding specific terminal or applications and enhancing the user experience and increasing security unlike current fragmented ad-hoc connectivity solutions.

The solution extends the SRS 5G UE software, compliant with 3GPP Release 15, with NTN features specified in 3GPP Release 17. It incorporates mechanisms to handle long propagation delays and Doppler effects, enabling reliable synchronization, channel estimation, and protocol operation over satellite links within integrated TN/NTN deployments.

For this KER, it is important to distinguish clearly between direct adopters and final application domains. The most relevant adopters are not individual passengers or end consumers, but rather mobile and satellite operators, modem and antenna manufacturers, system integrators, equipment vendors, and public or institutional actors interested in NTN-capable 3GPP terminal solutions. By contrast, domains such as aviation, maritime connectivity, emergency response, or remote-area service continuity should be understood as the most relevant application contexts in which this type of technology could create value. This distinction is important because it makes the exploitation narrative more realistic. At its current maturity level, the KER is not best positioned as a ready-to-market mass-market terminal product, but rather as a valuable technology asset for validation, experimentation, integration, and technology transfer.

Its main strengths lie in three aspects. First, it supports operation over real NTN conditions rather than only in simulation or partial emulation. Second, it follows a standards-based approach aligned with 3GPP, which preserves interoperability and reduces the need for proprietary adaptations. Third, its software-defined nature makes it especially useful for research, validation, and pre-commercial development activities where flexibility and extensibility are essential. These features make the solution particularly relevant for organisations that need to test or accelerate NTN-capable terminal development without starting from scratch. In this sense, the KER helps reduce technical uncertainty and shortens the path towards future industrial productization.

The most credible exploitation path for this result is therefore based on a combination of technology transfer, software provision under the applicable licensing scheme, consultancy, customised development, and future industrial collaboration. Compared with the gNB, this KER depends more strongly on specialised downstream partners able to complete the path towards certification, hardware optimisation, and large-scale productization. This should not be seen as a weakness, but as a realistic reflection of its role in the innovation chain.

The main risks relate to dependence on hardware ecosystems, industrial partner engagement, productization costs, and access to follow-up funding. These risks can be mitigated by focusing first on professional and vertical use cases, preparing a clear transfer-oriented business approach, and targeting strategic industrial partnerships and innovation funding opportunities after the end of the project.

For the purposes of the deliverable, this KER should therefore be presented as a high-value enabler for NTN terminal validation and transfer, with strong strategic relevance even if its post-project commercialisation route is less direct than that of the gNB.

5.2.1.3 AI prediction algorithm (CTTC)

Integrated TN/NTN RAN deployments face highly variable traffic patterns and long reaction times when applying static or reactive Radio Resource Management policies, leading to sub-optimal spectrum usage, inefficient backhaul utilization, and limited support for service differentiation and SLA-driven operation. The third Key Exploitable Result is an AI traffic prediction engine developed by CTTC for use in hybrid TN/NTN environments. The solution is designed to support anticipatory and policy-driven network optimization by generating short- and medium-term traffic forecasts that can feed decision-making processes in an O-RAN-based control framework. Integrated into the Non-Real-Time RIC, the engine can support scheduling, admission control, service differentiation, and backhaul or resource management decisions across heterogeneous terrestrial and non-terrestrial segments.

This KER addresses a growing operational need. Hybrid TN/NTN deployments are expected to face variable traffic patterns, different service profiles, and non-uniform capacity conditions across time and geography. In such environments, static or purely reactive management approaches lead to inefficient resource allocation, limited service adaptability, and sub-optimal infrastructure usage. Operators increasingly need better predictive visibility to allocate capacity more efficiently and maintain service quality under changing demand conditions.

This software application helps mobile network operators and satellite operators who wants to predict future network traffic patterns by avoiding manual data collection and inefficient pre-processing and proactively allocating resources efficiently and maintaining quality of service unlike standard manual tools.

The most relevant adopters of this KER are mobile network operators, satellite operators, hybrid connectivity providers, O-RAN ecosystem actors, and engineering or operations teams responsible for network optimization. These stakeholders do not need AI in the abstract; they need actionable prediction capabilities that improve operational decisions without imposing excessive integration or compute burdens. This is precisely where the KER differentiates itself. Its value does not lie only in the use of AI/ML, but in its practical relevance for telecom operations. The engine is designed to support predictive optimization in real management loops and to shift network operation from reactive monitoring to anticipatory decision-making. In addition, the use of KAN-based forecasting offers advantages in terms of model efficiency, reduced computational complexity, and lower memory footprint compared with heavier approaches. This improves “deployability” and supports both operational and sustainability objectives. From an exploitation perspective, the most credible route combines software licensing, tailored integration, custom development, and technology transfer or follow-up collaboration with industrial actors. This KER may also benefit significantly from future validation activities in cooperation with operators interested in O-RAN, RIC-based control, and efficient AI for telecom environments.

The key risks concern data availability, generalization across heterogeneous contexts, industrial trust in AI-supported decisions, and competitive pressure from alternative analytics solutions. These risks can be mitigated through progressive dataset enrichment, benchmarking, explainability, modular integration design, and a positioning strategy that frames the engine as a practical enhancement for operational teams rather than as a disruptive replacement of existing engineering workflows.

This KER should be positioned as a strategically valuable intelligence asset for the future operation of hybrid TN/NTN networks, with increasing exploitation potential as predictive network management becomes more relevant in operational telecom environments.

5.2.2 Joint Ecosystem positioning

Although each KER has its own market logic and exploitation route, their combined value is greater than the sum of the individual results.

Together, the three KERs define a coherent technological and strategic proposition for intelligent hybrid TN/NTN infrastructures. The gNB addresses the infrastructure side, the UE addresses the terminal side, and the AI traffic prediction engine addresses the intelligence and optimization layer. This creates a portfolio that spans access, terminals, and operational intelligence in a consistent manner.

From an ecosystem perspective, this positioning is particularly relevant because it reflects a broader transition in the telecom sector towards open, software-defined, standards-compliant, and AI-assisted infrastructures. In that context, the combined offer emerging from 5G-STARDUST contributes to a European vision of interoperable and sovereign TN/NTN integration, reducing dependence on closed ecosystems and strengthening the role of European actors in a strategically important domain.

For this reason, the three KERs should be presented as individually exploitable assets that gain additional strategic differentiation when considered together. This is especially important in a market that increasingly values not only isolated components, but also end-to-end interoperability, flexibility, and operational intelligence.

5.2.3 Market perspective and differentiation by KER

5.2.3.1 KER1 – NTN-enabled 5G gNB

The market for the NTN-enabled 5G gNB is best understood as the market for operators and integrators seeking to extend 5G infrastructures into non-terrestrial domains through standards-based and interoperable solutions. It is particularly relevant for mobile and satellite operators, mission-critical service providers, and advanced integrators that need a flexible and transparent way to deploy or test NTN-enabled access networks.

What differentiates this KER is not only its NTN functionality, but the way that functionality is delivered. The solution combines native NTN support, software flexibility, compliance with 3GPP and O-RAN principles, and a full stack controlled by the developer. This gives adopters a more open, portable, and future-proof option than alternatives built around rigid or proprietary approaches. In market terms, it can be presented as a practical way to reduce integration complexity while supporting long-term evolution towards hybrid 5G and beyond-5G network architectures.

5.2.3.2 KER2 – NTN-enabled 5G UE

The market for the NTN-enabled 5G UE is more specialised and should be described carefully. The most relevant market is not a mass consumer terminal market, but a B2B technology and integration market involving operators, terminal ecosystem actors, equipment vendors, and organisations that need to validate or accelerate NTN-capable device development. Its strongest application domains include mobility, emergency services, and remote-area connectivity, but these should be framed as target deployment contexts rather than immediate direct customer groups.

Its main differentiator is that it enables realistic NTN terminal-side operation and validation through a flexible software-defined implementation aligned with 3GPP principles. Rather than positioning it as a final consumer device, it is more credible to present it as a strategic enabling asset for testing, integration, experimentation, and transfer. This gives the KER a clear role in de-risking and accelerating future NTN terminal development.

5.2.3.3 KER3 – AI traffic prediction engine

The market for the AI traffic prediction engine is the operational intelligence layer of hybrid TN/NTN networks. It is relevant for operators and integration actors that need to forecast demand more accurately and use that information to improve network efficiency, service continuity, and resource allocation. This is especially important in contexts where network conditions and traffic demand evolve dynamically and where manual or static approaches are no longer sufficient.

The solution is differentiated by its operational focus, integration potential, and efficiency. It should not be positioned simply as an AI model, but as a practical telecom-oriented prediction capability designed to support better decisions in O-RAN and hybrid network environments. Its lower complexity and lighter deployment requirements strengthen its business case and make it easier to position as an operationally useful tool rather than as an experimental analytics component.

5.2.4 Intellectual Property Rights (IPR) Management (CTTC, SRS)

Effective Intellectual Property Rights (IPR) management is pivotal within the 5G-STARDUST project, given the innovative and collaborative nature of integrating terrestrial and non-terrestrial networks (NTN) for ubiquitous connectivity. The diverse consortium, comprising research institutions, industry partners, and technology providers, necessitates a coherent IPR strategy to ensure seamless collaboration, protection of innovations, and clear exploitation paths.

Effective IPR management remains a key enabling factor for the post-project exploitation of 5G-STARDUST results. In line with Horizon Europe principles and the consortium agreement, ownership of project results is allocated to the partner or partners responsible for generating them, while access rights and joint ownership arrangements are governed under fair and transparent conditions.

From an exploitation perspective, IPR should be described in a practical and KER-oriented way. The NTN-enabled 5G gNB is suited to direct exploitation by SRS through software licensing and related support services. The NTN-enabled 5G UE is more strongly associated with software provision, transfer-oriented licensing, and future industrial uptake by downstream partners. The AI traffic prediction engine is well aligned with software licensing, customised integration, and collaboration-based exploitation paths.

The purpose of this section is not to provide a purely legal description, but to show that the identified routes to exploitation are backed by a clear ownership logic and by realistic options for protection, transfer, and commercial use.

5.3 NEW PERSPECTIVES FOR TN MOBILE NETWORK OPERATORS

The 5G-STARDUST project has shed new lights on the possibilities offered by integrated 3GPP TN / NTN systems (Terrestrial / Non-Terrestrial Networks), but has also revealed some key challenges, both technical and non-technical. In this way, the project’s outputs, but also its trickier aspects, has allowed Orange to significantly increase its understanding of the TN / NTN interplay and has greatly supported internal strategic analyses towards the design of future services and commercial offers.

5.3.1 Addressing the D2D market

The D2D market is still under construction and, despite pan-European projects such as IRIS² (which primarily addresses governmental use cases), there is still uncertainty about future business growth, in particular out of the USA. Yet, the GSMA has estimated that D2D services will create new revenue opportunities for telcos exceeding 30$b annually by 2035[1]. What's certain is that D2D without terrestrial connectivity will not attract customers on a large scale, implying that SNOs have to partner with MNOs somehow, especially SNOs that do not master mass market distribution (logistics, stores, customer care services, etc.) and depend on MNO's channels.

However, the importance of enhancing the factual attractiveness of D2D services for the mass market today is often under-estimated by satellite and terrestrial industries, which must find:

- The good balance between affordability and coverage needs, for both Europe (high ARPU but generally well-covered territories, with limited uncovered areas) and Middle East & Africa (uneven coverage with vast isolated areas, but lower ARPU -Average Revenue Per User). In both cases, targeting the right use cases and the right TN / NTN services to be delivered by customers is essential to succeed in a SNO-MNO partnership.

- The good bundling of satellite & terrestrial services, for example proposing satellite connectivity as an add-on of terrestrial services (like TV in Triple-Play offers) or developing enriched D2D connectivity offers (e.g. adding media & entertainment services for passengers of a vehicle).

- The good way to address performance evolution, maintain the customer interest and manage satellite investments.

The recipes that led to terrestrial B2C and B2B business successes may not be directly applicable to satellite, due to several specificities, as detailed in the following.

Footprint and number of subscribers: SNOs have a global footprint for a relatively low number of subscribers. This is the exact opposite for MNOs. One of the leading SNO in the D2D market recently claimed around 8 million active users worldwide, sending SMS[2]. However, we are still far from the huge volume of data and number of users managed by MNOs: more than 22 million mobile subscribers for Orange France in 2025, and more than 270 million worldwide, over the 26 countries. Obviously, this significantly impacts the way to address business and balance revenues and investments between terrestrial and satellite services.

Cost distribution and initial investment: For both MNOs and SNOs, the deployment of radio access infrastructure (antennas + towers or satellites) represents the most significant part of investment and often takes place in several phases. A partial deployment corresponds, for MNOs, to a permanent but local terrestrial service, and for SNOs, to a global but intermittent satellite service, due to satellite motion. This limits the possibility for SNOs to commercialize services before reaching a sufficient number of operational satellites, and implies a huge initial investment, for satellite manufacturing and launching. Commercial strategies of MNOs and SNOs to launch a new service thus fundamentally diverge. SNOs are facing today a transformation of their value chain as deep as the one encountered by MNOs 10-15 years ago, with softwarization, virtualization and cloudification. This will bring high flexibility in the resource

[1] GSMA Intelligence - Satellite 2.0: going direct to device, March 2022

[2] https://x.com/Starlink/status/1985832565107015708

management and should allow new digital players to enter the ecosystem and propose high valuable services.

Standardization and ecosystem evolution: Contrary to terrestrial networks, satellite systems are historically little standardized. The emergence and maturation of 3GPP NTN is expected to radically change the ecosystem and business strategies, as well as business relationships between SNOs, vendors and terminal / chipset manufacturers. In particular, the OEM landscape about NTN is likely to largely develop, thanks to interoperability, considered as an essential asset towards economy of scale. However, the price of terminals will remain a key component of the success of 3GPP NTN and should not be an entry barrier for customers, especially at the beginning, when satellite services are still working with limited performance.

Satellite beams vs NTN cells: Several innovations (and more particularly steerable / shapable beams and reconfigurable payload for softwarized systems, etc.) should ultimately enable fully integrated TN / NTN systems, based on AI-powered self-organized architectures. But this objective creates, in multi-tenant systems, overlaps between the functions and operations traditionally performed by MNOs and SNOs. This overlap is critical when designing integrated network and further investigation is required. This is also a question of security and trust, related to the exchange of sensitive data (e.g. customer and traffic information, network configuration, etc.).

Regulation: Another key specificity of non-geostationary satellite constellations is linked to the dynamic infrastructure topology. Significant adaptations of 3GPP standards have been (and are still) proposed to address related issues (e.g. Doppler effect, terminal synchronization, handovers management, etc.). However, beyond technical challenges, satellite E2E architecture is generally globally distributed, with several gateways and data hubs disseminated around the Earth. Routing strategies can be optimized, but this also implies that users' traffic can go through different countries. This raises tricky challenges with respect to national regulation and operators' legal obligations, including geolocalization, emergency calls, lawful interception, GDPR, cybersecurity directives, etc.

5.3.2 Initial thoughts on TN / NTN mobility

The 5G-STARDUST project has clearly challenged the definition of seamless TN / NTN mobility and the various options supporting this objective. It is also worth mentioning that the discussions led within the different tasks have been a valuable support for the formation of the 6G-NTN[2] Nexus project (SNS project, Stream B 03-01 2025 call), to be kicked-off in May 2026.

In all cases, seamless mobility scenarios, that allows a user to be attached or served by TN then NTN, or conversely, must be distinguished into two categories: mobility in idle mode and mobility in connected mode.

The first one can be primarily addressed with *roaming*, where the satellite network corresponds to the visited PLMN, for example in isolated areas or after a natural disaster. Despite the good mastering of terrestrial roaming agreements, NTN raises unique challenges that are currently discussed in many forums, projects and organisations, including GSMA. Topics include PLMN-IDs prioritization, border issues, network selection when the satellite cell spans over multiple countries or in international areas, determination of the country of the UE's location, handling of shared/global PLMN IDs, etc. Main objectives are to support customer satisfaction (e.g. to avoid that a user keeps attached to NTN while TN is available, for better QoS) and fulfilment of national regulations.

The second category, mobility in connected mode, could leverage 3GPP procedures such as handovers and requires much tighter TN / NTN integration. In this case, NTN and TN must be considered as belonging to the same unique network. In a multi-tenant system, several models could be considered, for example:

- *Satellite-infrastructure-as-a-service*, where the SNO proposes infrastructure and processing capabilities for MNOs to deploy their own virtualized NTN gNB, in a similar manner to the terrestrial towerco model. To this end, onboard satellite technologies should reach a higher degree of virtualization, with improved resource orchestration to manage today's limited processing capabilities and share them between operators.

- *RAN sharing*, when an NTN gNB is operated by a SNO or a third-party (e.g. a neutral host) and shared between several MNOs at national or international scale. However, the differences between terrestrial RAN sharing (as already operational in many countries) and satellite RAN sharing are not fully known, nor mastered. How to efficiently share resources between more than a few MNOs? How to adapt to different use cases and provide services with different QoS requirements and traffic profiles (e.g. Automotive for one country vs PPDR for another one)? How to share sensitive data (e.g. cell IDs, coverage zones, neighbourhoods, etc), necessary for seamless handover in connected modes? How to comply to legal obligations and national regulations? And for a business perspective, how to fairly share investment and revenues, towards a win-win partnership?

The 5G-STARDUST has also investigated a potential next step of TN / NTN mobility in connected mode, through the concept of multi-connectivity. It takes advantage of overlapping terrestrial and non-terrestrial access and could deliver optimised resource allocation through AI-powered traffic prediction and load balancing. The analyses seem to show the need to manage the whole protocol stack, and not only upper layers (above IP), to achieve high performance and support 3GPP procedures in an optimized manner.

In conclusion, and with current RAN conception, part of the answers about TN / NTN mobility come from the core network (common to TN and NTN services or not) and the player(s) which is / are operating it: the MNO, a Third-Party and / or the SNO, with or without subscribers. New models may also emerge with future O-RAN features and next NTN generations.

5.4 RISK MANAGEMENT

5.4.1 Risk Identification and Assessment

The post-project exploitation of the three KERs involves risks that are typical of innovative mid-TRL technologies in emerging hybrid TN/NTN markets.

For the NTN-enabled 5G gNB, the most relevant risks concern the evolution of standards, market adoption barriers, and the effort required to move from a validated project result to a commercially robust offer. For the NTN-enabled 5G UE, the risks are more strongly linked to hardware ecosystem dependence, industrial partner engagement, productization costs, and the need for post-project financing. For the AI traffic prediction engine, the main concerns relate to data availability, confidence in AI-supported operational decisions, and competition from other network analytics solutions.

Table 6: Risk identification and mitigation actions

KER	RISK ID	Risk Description	Likelihood	Severity	Risk Level	Mitigation Actions
5G NTN gNB	R-KER1-01	Misalignment with evolving 3GPP NTN specifications	Low	High	Medium	• Strict alignment with 3GPP-compliant interfaces and O-RAN principles • Continuous monitoring of standardization activities • Modular, software-upgradable architecture
	R-KER1-02	Limited scalability from PoC (TRL 4–5) to carrier-grade deployments	Low	High	Medium	• Validation of performance KPIs in representative PoC scenarios • Phased roadmap towards TRL 7–8 • Early integration testing with realistic traffic loads
	R-KER1-03	Reluctance of MNOs to adopt NTN gNB due to integration complexity	Medium	Medium	Medium	• Clear deployment models (direct, indirect, IAB-based) • Positioning as a complementary extension to existing 5G RANs
NTN UE	R-KER2-01	Increased device cost and power consumption	Medium	Medium	Medium	• Software-centric NTN adaptations where possible • Focus on professional and vertical markets as early adopters
	R-KER2-02	Dependency on chipset and device ecosystem readiness	High	Medium	High	• Alignment with existing COTS and chipset roadmaps • Hybrid TN/NTN operation to reduce market entry barriers
	R-KER2-03	Degraded QoE due to latency, mobility, or intermittent coverage	Medium	Medium	Medium	• Seamless TN/NTN fallback mechanisms • Mobility-aware validation in PoC scenarios
Traffic Prediction Algorithm (KAN-based)	R-KER3-01	Limited availability or representativeness of training data	Medium	High	High	• Combination of real operational data and large-scale simulation/emulation datasets • Continuous dataset enrichment beyond project duration
	R-KER3-02	Limited generalization across operators, constellations, or regions	Medium	Medium	Medium	• Training with heterogeneous datasets • Deployment-specific calibration and fine-tuning
	R-KER3-03	Low operator trust in AI-driven decision making	Medium	Medium	Medium	• Human-in-the-loop operation in early deployments • Explainability and transparent performance benchmarking
Cross-cutting (All KERs)	R-KER0-01	Slow ecosystem adoption and fragmented stakeholder interests	Medium	High	High	• Differentiated exploitation strategies (licensing, system integration, managed services) • Strategic partnerships beyond the project lifetime
	R-KER0-02	Regulatory and spectrum constraints across regions	Low–Medium	High	Medium	• Focus on globally harmonized spectrum bands • Continuous regulatory monitoring and engagement

Despite these risks, the overall exploitation outlook remains positive. The KERs benefit from strong alignment with 3GPP and O-RAN principles, software-based flexibility, modularity, and validation in realistic project environments. These characteristics improve their readiness for further industrial uptake and reduce the distance between research result and exploitable asset.

5.5 5G-STARDUST SUSTAINABILITY PILLARS

The main objective of this section is to present the impact and some of the measures of different sectors to improve the sustainability and the impact of key technologies identified and meticulously studied throughout the 5G-STARDUST project activities.

Sustainability is a core principle of the 5G-STARDUST project and is addressed through a holistic approach covering social, environmental, and financial dimensions. By enabling seamless integration of terrestrial and non-terrestrial networks, the project contributes to long-term societal value, reduced environmental impact, and economically viable deployment models for future 5G-Advanced and beyond networks.

5.5.1 Social

5G-STARDUST contributes to social sustainability by reducing the digital divide and enabling inclusive access to advanced connectivity services. The integration of NTN with terrestrial 5G networks allows the provision of broadband and mission-critical services in remote, rural, or underserved areas where terrestrial deployment is technically or economically unfeasible.

The project supports key societal use cases such as public protection and disaster relief (PPDR), mobility (air, maritime, and land transport), and global private networks, improving resilience, safety, and service continuity. In emergency and disaster scenarios, 5G-STARDUST enables rapid restoration of communications, supporting first responders and affected populations.

Furthermore, by promoting open architectures, standard-compliant solutions, and collaboration across industry, research, and public stakeholders, the project fosters knowledge sharing, skills development, and innovation capacity building across the European ecosystem.

5.5.1.1 5G-STARDUST contribution to EU agendas

The Sustainable Development Goals (SDGs) of the United Nations are a set of 17 global objectives aimed at addressing the world's most pressing challenges, such as poverty, climate change, inequality, and lack of access to basic services. They were adopted in 2015 by UN Member States as part of the 2030 Agenda for Sustainable Development, a comprehensive action plan to improve global well-being and protect the planet for future generations.

Satellite plays a crucial role on advancing on the SDGs providing coverage and connectivity in remote areas contributing on a bridge creation to de digital divide and accelerating the digital transformation. The 5G-STARDUST project results will contribute to advance in some of the SDGs of ensure healthy lives and promote well-being for all at all ages, telemedicine as remote education

Table 7: 5G-STARDUST contributions to SDGs

UN SDG	How 5G-STARDUST address this SDG?
SDG 9: Industry, Innovation, and Infrastructure Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.	By enhancing global infrastructure resilience through the seamless integration of terrestrial and non-terrestrial networks (TN-NTN), addressing connectivity gaps in un(der)served and remote areas. It introduces innovative 5G-compliant regenerative satellite payloads, unified radio interfaces, and intelligent resource allocation powered by AI-based techniques. These technological advancements significantly contribute to sustainable and robust digital infrastructures.
SDG 11: Sustainable Cities and Communities Make cities and human settlements inclusive, safe, resilient, and sustainable.	5G-STARDUST supports critical communications, especially in scenarios such as Public Protection and Disaster Relief (PPDR). By providing reliable and immediate connectivity during emergencies through integrated terrestrial and satellite networks, 5G-STARDUST ensures that cities and communities are safer, more resilient, and better prepared to respond to disasters or disruptions in traditional communication infrastructures.
SDG 13: Climate Action Take urgent action to combat climate change and its impacts.	By reducing the need for extensive terrestrial infrastructure deployment, lowering environmental impact. The use of satellite-based connectivity for global private networks and residential broadband significantly reduces the carbon footprint associated with traditional network expansion methods. Additionally, enhanced communication capabilities for connected vehicles contribute to optimizing transportation routes and efficiency, indirectly supporting emission reduction goals.
SDG 8: Decent Work and Economic Growth Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all.	By expanding broadband connectivity to remote and underserved regions, 5G-STARDUST fosters economic opportunities, enabling digital inclusion and opening new markets. Reliable internet access supports telework, telemedicine, and online education, directly contributing to increased employment opportunities and sustainable economic growth.
SDG 4: Quality Education Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.	The project's commitment to ubiquitous broadband access ensures educational resources become accessible even in remote or underserved areas. By deploying integrated access and backhaul solutions via satellite, it guarantees uninterrupted educational connectivity, facilitating inclusive and equitable educational opportunities.
SDG 10: Reduced Inequalities Reduce inequality within and among countries.	By providing universal broadband connectivity, 5G-STARDUST reduces the digital divide. Its deployment of innovative, flexible, and cost-effective satellite-based solutions ensures that underserved areas can access reliable internet services, fostering greater equity among regions and communities, and promoting social and economic inclusion.

In summary, the 5G-STARDUST project actively contributes to multiple UN SDGs by promoting inclusive and sustainable technological innovation, ensuring resilient infrastructure, enabling equitable access to quality education and economic opportunities, reducing inequalities, enhancing public safety, and indirectly supporting climate action through optimized connectivity solutions.

5G-STARDUST contributes to bridging the digital divide by implementing innovative mechanisms that enable connectivity in remote and sparsely populated areas, as well as reliable emergency communications during natural disasters. By deploying 3GPP-compliant networks in regions where terrestrial coverage is technically or economically unfeasible, the project demonstrates the advantages of integrated NTN solutions. In addition, 5G-STARDUST supports carbon footprint reduction by offloading the terrestrial segment during low-traffic periods, paving the way for the seamless integration of NTN networks into the future 6G ecosystem.

5.5.2 Environmental

While the work carried out in 5G-STARDUST provides valuable insights into the integration of terrestrial and non-terrestrial networks, some of the potential contributions identified in this section should be understood as informed projections rather than experimentally demonstrated results.

Based on the architectural design choices, system-level analysis, and the experience gained through the development and validation of the project's components, the consortium believes that the proposed approach has the potential to contribute to improved efficiency, flexibility, and scalability in hybrid TN/NTN deployments. In particular, the concepts and mechanisms developed in the project could support more predictable network operation, better resource utilisation, and enhanced service continuity across heterogeneous infrastructures.

However, it should be noted that the project did not collect sufficient quantitative data to formally demonstrate these improvements in a statistically robust manner. The available results mainly confirm the technical feasibility and architectural soundness of the proposed approach, while the quantitative performance gains would require additional validation in larger-scale deployments or operational environments. For this reason, the impacts discussed in this section should be interpreted as plausible contributions supported by technical rationale and design evidence, rather than as fully validated performance claims.

5.5.3 Financial

From a financial perspective, the sustainability of 5G-STARDUST lies in enabling commercially viable deployment models for hybrid terrestrial and non-terrestrial 5G networks in scenarios where conventional terrestrial economics are weak. Rather than competing with nationwide terrestrial roll-out, the project outcomes support a complementary model in which satellite enabled 5G is used to extend service to remote, underserved, hard-to-reach, or operationally complex locations where deploying a dedicated terrestrial site would involve disproportionate cost and effort. This positioning is consistent with the project's overall exploitation logic and with the market framing of the KERs toward operators, satellite providers, and system integrators.

A financially credible exploitation path therefore emerges around operator-facing B2B and wholesale arrangements. In particular, the NTN enabled gNB is already positioned for commercialization through software licensing, support services, and custom development contracts, while the AI traffic prediction engine is framed around software licensing and private customization agreements. These routes are important because they show that the project results can be monetized through familiar telecom and software business models rather than relying on speculative standalone mass market adoption.

From Hispasat perspective, the most relevant financial rationale is the ability to support mobile network operators and other connectivity providers with a satellite enabled extension layer that complements terrestrial infrastructure where terrestrial deployment is inefficient or uneconomic. In this context, value is created not only through additional coverage, but also through avoiding or postponing the capex and operational burden associated with building, powering, backhauling, and maintaining isolated terrestrial sites. This interpretation is also aligned with the identified customer segments for the NTN enabled gNB, which include MNOs, satellite network operators, internet/cloud providers, mission-critical users, and global enterprises requiring wide-area connectivity.

The financial sustainability of the KER portfolio is further reinforced by the fact that each result can be integrated into different layers of a broader value chain. The NTN-enabled gNB can generate revenue through commercial licensing, engineering support, and hardware-specific adaptation work. The NTN enabled UE can be provided as software copies and further monetized through integration and customization activities. The AI traffic prediction engine can be licensed as a software module and complemented by consultancy or deployment specific tuning services. This multi-track structure reduces dependence on a single commercialization route and improves resilience against slow uptake in any one segment.

The available exploitation roadmaps also suggest a realistic staged revenue logic rather than an assumption of immediate large scale market penetration. For the AI traffic prediction engine, the roadmap foresees initial licensing revenues combined with customization and business plan development, while acknowledging an initial operating loss before reaching slight profitability in later phases. For the UE and gNB related assets, the roadmaps also point to phased TRL maturation, strategic partnerships, licensing agreements, and external funding support as bridges between project completion and commercial deployment. This makes the financial story more credible, as it reflects the typical transition profile of telecom innovation assets moving from pilot validation to industrial uptake.

In addition, the project's software-centric and standards-based approach supports financial sustainability by lowering integration barriers and reducing lock in risks for adopters. The gNB solution is presented as hardware agnostic, software defined, based on open interfaces, and compliant with 3GPP and O-RAN principles, while the AI engine is positioned as a lightweight and efficient software capability that can improve capacity management and reduce operational burden. These characteristics are financially relevant because they contribute to lower deployment friction, more flexible integration paths, and more efficient use of infrastructure resources over time.

This financial rationale is also supported by current market developments in direct-to-device connectivity, where early commercialisation is being shaped primarily through partnerships between satellite operators and mobile network operators. Public information shows that Starlink has established agreements with multiple MNOs across North America, Europe, Asia-Pacific, Latin America and Africa, while MasOrange announced in February 2026 the first Starlink Direct-to-Cell pilot in Spain. Likewise, AST SpaceMobile publicly identifies strategic partners including AT&T, Verizon, Vodafone and STC group, and states that it has agreements with more than 50 mobile network operators worldwide. A demonstration with Orange Romania will also be conducted in the second half of 2026. From a Hispasat perspective, these developments reinforce the view that NTN-enabled mobile connectivity is most likely to scale through B2B, wholesale and operator-partnering models rather than through standalone retail approaches.

Overall, the financial sustainability of 5G-STARDUST should be understood as the combination of three mutually reinforcing factors: first, the project addresses use cases where hybrid TN/NTN deployment has a clear economic rationale; second, its KERs support established B2B monetization routes such as software licensing, engineering services, customization, and technology transfer; and third, from a Hispasat perspective, the results are especially relevant as enablers of operator-oriented service extension models in which satellite assets complement terrestrial 5G in a financially disciplined way.

5.5.3.1 Governance, SLA, customer ownership, data ownership and risk perspective

Beyond direct revenues, long-term sustainability also depends on how future TN/NTN services are governed and operationalized. The project's exploitation materials consistently position the KERs toward operators, satellite providers, and integrators rather than end-consumer channels, which implies that future commercialization is likely to take place in B2B, wholesale, or partner led arrangements. Under this logic, governance becomes a critical factor: technical responsibility, service assurance, integration scope, and operational accountability must be clearly allocated among the satellite operator, the mobile network operator, and any system integration partner involved.

From a Hispasat perspective, this is particularly relevant because hybrid TN/NTN services will often be delivered as part of a broader service chain rather than as an isolated satellite product. In such settings, the satellite domain may provide coverage reach, resilience, or backhaul extension, while the mobile operator or service provider may retain primary control over customer relationship, retail packaging, subscriber management, and core-network-based service logic. This division of roles supports a pragmatic commercialization approach, especially in markets where operators prefer to preserve customer ownership while relying on satellite partners for infrastructure extension and resilience. This interpretation is also coherent with the project's market segmentation toward operator and integrator ecosystems.

Service Level Agreements will therefore be central to sustainable exploitation. The AI traffic prediction engine is explicitly positioned around proactive resource allocation, congestion avoidance, and predictive SLA assurance, which means that one of its commercial values lies in helping operators move from reactive to anticipatory service management. In future deployments, SLA design will need to distinguish between radio access performance, transport continuity, satellite link availability, and application-level service expectations, especially in mission-critical or enterprise contexts. The project does not yet define specific contractual frameworks, but the KER positioning clearly indicates that SLA-sensitive operation is part of the future value proposition.

Customer ownership and data ownership are equally important. The AI/ML KER depends on operational data for model validation and improvement, and its roadmap explicitly refers to the use of anonymized data provided by mobile and satellite operators. This suggests that future exploitation will require clear arrangements regarding access to datasets, rights to use them for model training or tuning, and the boundary between operator-controlled data and third-party analytics services. In practice, this means that commercially viable exploitation will depend not only on technical performance, but also on trusted governance mechanisms covering confidentiality, anonymization, permitted reuse, and operational responsibility.

Risk management also remains part of the sustainability story. This document already identifies several relevant risks: slow ecosystem adoption, fragmented stakeholder interests, regulatory and spectrum constraints, limited scalability from PoC to carrier-grade deployments, and low operator trust in AI-driven decision-making. These are not peripheral issues; they directly affect the timing, cost, and bankability of commercialization. For this reason, sustainable exploitation depends on phased adoption strategies, standards alignment, realistic deployment models, strategic partnerships, and early validation in representative scenarios.

Taken together, governance, SLA design, customer ownership, data ownership, and risk allocation should be treated as core enablers of financial sustainability rather than as secondary legal or operational details. In operator-led hybrid TN/NTN models, the economic case becomes stronger when responsibilities are clearly split, service performance is contractually traceable, customer control remains commercially coherent, and data governance supports trusted use of AI-enabled optimization functions. This is especially relevant from Hispasat perspective, where future value creation is likely to depend on acting as a strategic infrastructure and service-enablement partner within a broader telecom ecosystem rather than as a standalone retail provider.

The table below does not aim to define fixed contractual models for future 5G-STARDUST exploitation. Rather, it summarizes the most plausible commercialization and governance configurations suggested by the project results, the KER positioning work, and the consortium's current understanding of emerging hybrid TN/NTN business models.

Table 8: Commercial and Governance Models for Hybrid TN/NTN Services

Scenario / model	Likely direct customer	Customer & credential ownership	Main implication for the satellite operator
B2B infrastructure extension	MNO or hybrid connectivity provider	The MNO/service provider keeps the end-customer relationship and subscriber management	The satellite operator acts as a coverage, resilience, or NTN infrastructure partner
Wholesale NTN capacity	MNO, MVNO enabler, or service aggregator	The downstream provider keeps commercial ownership and service logic	The satellite operator provides capacity and service reach under wholesale conditions
B2B2C partner-led model	MNO, enterprise provider, transport operator, or vertical integrator	The front-end partner normally owns the customer relationship; credential management typically remains with the service provider	The satellite operator supports continuity and hybrid coverage as an embedded connectivity partner
Neutral-host / shared NTN infrastructure	Multiple MNOs, public-sector actors, or a neutral-host entity	Each participating operator would normally retain its own customers and subscriber policies	The satellite operator provides shared infrastructure, but governance and SLA allocation become more complex
Direct-to-vertical managed solution	Public authorities, emergency actors, transport, or industrial players	Ownership may sit with the prime contractor, integrator, or vertical service provider depending on the deployment model	The satellite operator contributes as a managed connectivity and resilience enabler rather than as a retail provider

Overall, the most credible near to mid-term commercialization path for hybrid TN/NTN services appears to be operator-led and B2B-oriented, with the satellite operator acting primarily as an infrastructure, resilience, and service-enablement partner, while customer ownership, subscriber management, and retail service logic remain in most cases under the control of the mobile operator or downstream service provider. This interpretation is consistent with the project's market definition and exploitation logic.

5.5.3.2 Complementary Funding Mechanisms

To bridge the gap between project completion and market traction, additional funding sources are considered essential:

- Public funding instruments (e.g., CDTI, EIC Accelerator) to support TRL progression and industrialization.
- Private investment and industrial partnerships, particularly for technology transfer and productization.
- Follow-up EU or ESA projects, leveraging continuity in NTN and 6G research programs.

These mechanisms reduce financial pressure during early commercialization stages and accelerate time-to-market.

5.5.3.3 Scalability and Long-term Sustainability

The financial sustainability of the KERs is reinforced by:

- Alignment with growing market demand for hybrid TN/NTN solutions.
- Adoption of software-centric and modular architectures, reducing deployment costs.

- Compatibility with 3GPP and O-RAN standards, lowering integration barriers and increasing market adoption.

Additionally, the combination of infrastructure (gNB), terminal (UE), and intelligence layer (AI engine) creates opportunities for bundled offerings, increasing overall value capture across the ecosystem.

5.6 CONCLUSIONS

The exploitation and sustainability analysis developed in 5G-STARDUST shows that the project has generated a coherent and credible portfolio of results with realistic post-project potential. Rather than treating project outputs as isolated technical achievements, the consortium has structured its exploitation approach around three prioritized Key Exploitable Results (KERs) that address complementary layers of the hybrid TN/NTN value chain: infrastructure, terminal, and intelligence. This portfolio logic strengthens the overall exploitation case by showing that the results are not disconnected innovations, but mutually reinforcing assets that together support the broader objective of intelligent, interoperable, and standards-based integration between terrestrial and non-terrestrial 5G networks.

The support received through the Horizon Results Booster has been particularly valuable in moving from a generic description of project outcomes to a more structured and market-oriented exploitation strategy. Through the characterization, market definition, value proposition, roadmap, and risk assessment exercises, the consortium has been able to better clarify which results are most relevant for future uptake, which stakeholders are the most plausible adopters, and which commercialization routes appear most credible beyond the project lifetime. This has improved the robustness of the exploitation plan and helped align it with realistic deployment pathways and technology maturity levels.

From an exploitation perspective, the most convincing near- to mid-term path is not based on standalone mass-market retail adoption, but on operator-facing and partner-led models. The project results are more naturally positioned toward mobile network operators, satellite operators, hybrid connectivity providers, system integrators, and mission-critical or industrial actors than toward direct end-consumer markets. In this context, the most plausible routes to market are B2B, wholesale, licensing, engineering services, customization, and technology transfer models. This makes the exploitation logic financially more credible, since it builds on established telecom business practices and on staged industrial uptake rather than on speculative assumptions of immediate scale.

The analysis also shows that financial sustainability depends on more than the technical quality of the KERs themselves. Long-term viability will require a combination of modular and standards-based design, realistic TRL progression, strategic partnerships, and complementary funding mechanisms capable of bridging the gap between project completion and industrial productization. In this regard, the roadmaps already point to a phased transition model in which further validation, product hardening, licensing preparation, market development, and external funding support are used to progressively reduce commercialization risk. This staged approach is particularly important in hybrid TN/NTN markets, where ecosystem coordination, standards evolution, and deployment complexity can slow down time to market.

At the same time, the sustainability of 5G-STARDUST should be understood in a broader sense, encompassing social, environmental, and financial dimensions. Socially, the project contributes to reducing the digital divide and enabling more inclusive and resilient connectivity in remote, underserved, or operationally complex environments. Environmentally, its intelligent hybrid TN/NTN approach, combined with predictive traffic management and flexible software-based architectures, has the potential to improve resource efficiency, reduce over-provisioning, and support more sustainable network expansion strategies. Financially, the project supports business models in which satellite-enabled 5G complements terrestrial infrastructure where terrestrial deployment alone would be inefficient or uneconomic. Together, these dimensions reinforce the long-term relevance of the project beyond the research phase.

An important conclusion of the work is that future exploitation success will depend not only on product-market fit, but also on governance clarity. In hybrid TN/NTN environments, responsibilities for service assurance, customer ownership, subscriber management, data governance, and SLA compliance must be explicitly allocated among satellite operators, mobile operators, and integration partners. The project has not fully defined contractual frameworks for these aspects, but it has clearly shown that they are central enablers of sustainable commercialization.

Overall, 5G-STARDUST provides a strong basis for further industrial uptake, even if some of the projected benefits and business configurations will require additional validation in post-project environments. The KERs benefit from standards alignment, modularity, software-centric implementation, and validation in relevant project scenarios, all of which reduce the distance between research output and exploitable asset. The project therefore leaves not only a set of technical results, but also a structured exploitation and sustainability framework that can support follow-up funding, industrial partnerships, and future productization activities. In this sense, the main legacy of 5G-STARDUST is not only the demonstration of hybrid TN/NTN capabilities, but the establishment of a credible pathway for how these capabilities could evolve into sustainable value for operators, industry, and society.

6 PLAN OF ACTIVITIES AFTER THE PROJECT'S END

- The 5G-STARDUST web domain https://5g-stardust.eu/ will remain active for at least two years after the project's end, so that the insights collected through the project can be available to other initiatives and/or industry, SMEs, etc. so that parties interested in the field of ICT in Europe can benefit from the results achieved and connect to potential follow-ups. Martel will be available to keep the website updated and the social media channels active accordingly, if needed.

- From the exploitation and sustainability point of view, the models highlighted in Section 5.3.3 validate the commercial viability of 5G-STARDUST's work, offering an ideal jumping-off point for further exploration in upcoming project they will be involved in, separately or jointly (such as the aforementioned upcoming 6G-NTN[2] Nexus project, at least for what concerns the organisations part of both project consortia).

7 CONCLUSIONS AND LESSONS LEARNED

The document at hand reported on communication and dissemination conducted in the second half of the 5G-STARDUST project, with a comparison of the progress against the set KPIs, in addition to presenting some actions to perform after the project's end. The deliverable also presented the final exploitation plan developed.

Having relevantly fulfilled – and even expanded upon - all communication and dissemination-related KPIs (confirming a remarkable performance especially in terms of events' participation and organisation), the project consortium is satisfied with the results achieved by WP7 through a successful promotion of the work performed by the project consortium and by outlining the potential uptake of its results, benefiting project stakeholders and the extended 5G-STARDUST and SNS JU communities.

5G-STARDUST has established a credible exploitation and sustainability foundation for hybrid TN/NTN innovation. By prioritizing three complementary KERs and framing them through a structured market-oriented methodology, the project has moved beyond a purely technical narrative and toward a realistic post-project value creation strategy. The most plausible exploitation path is operator-led, B2B-oriented, and based on licensing, integration, customization, and strategic partnerships. Long-term sustainability will depend on continued TRL maturation, governance clarity, standards alignment, and complementary funding, but the project has already demonstrated the key ingredients needed to support future industrial uptake and broader societal impact.

ANNEX A – PRESS CLIPPING

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The 5G-STARDUST project: A self-organised networking architecture for 6G systems

Technology 7th November 2024

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The unprecedented service requirements demanded by the forthcoming 6G system call for a complete unification of terrestrial and non-terrestrial networks, suitably supported by converged standards and service-oriented network architecture able to seamlessly adapt to very diverse service and network dynamics.

The unification of terrestrial and non-terrestrial networks (NTN) has proven to be a compelling need to achieve a converged system architecture able to serve very diverse vertical sectors and related users, notably including PPDR, mobile transportation, societal needs, and industry 4.0. From this standpoint, the traditional approach of integrating heterogeneous network access technologies by extending or complementing the already well-defined air- and network-interfaces cannot be considered a viable approach any longer.

The motivations for a more modern converged system architecture stem from the convergence of multiple network technologies, all exhibiting very different peculiarities and, hence, calling for a more cohesive and transversal approach. Further to this, the recent service categorisation defined in the context of IMT-2030 clearly outlined the importance of service ubiquity also enabled by distributed intelligence. In this respect, a native NTN component as part of the forthcoming 6G system design is recognised as strictly pivotal to enabling new services and supporting the existing ones with better performance. However, such a unification process also opens up the door to formidable communication and networking challenges, introduced by the time-variant nature of NTN network topologies and dynamic fluctuations of data traffic and user service subscription. This extreme dynamism of the unified network system calls for a polymorphic design of the overall network architecture, able to timely and efficiently adapt to diverse service requirements and network operations/conditions. In this respect, the potentials offered by a self-organised networking paradigm are considered particularly promising, in that it can support the latest trends in terms of direct-to-satellite connectivity and to leverage the latest advancements in the context of network softwarisation and related automation.

What is the 5G-STARDUST project?

In this multi-folded framework, the 5G-STARDUST project is playing an important role towards the materialisation of such a planned convergence between terrestrial and non-terrestrial networks in the short term, i.e. focusing on the realisation of the so-called 5G-Advanced standardisation wave from 3GPP and paving the way towards 6G systems.

In more detail, 5G-STARDUST (Satellite and Terrestrial Access for Distributed, Ubiquitous, and

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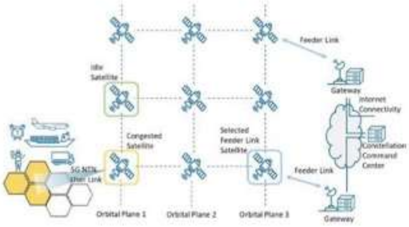
Smart Telecommunications) is a European project funded within the Smart Network Service (SNS) Joint-Undertaking (JU) initiative as part of the Horizon Europe programme. The project started on 1 January 2023 and will run until 31 December 2025, with the ultimate goal of demonstrating the achieved convergence between terrestrial and non-terrestrial networks by means of advanced laboratory testbeds.

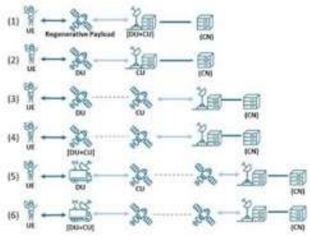


In particular, the project is aimed at demonstrating the feasibility of gNB in space, by exploiting a self-organised networking paradigm architecture and a unified radio interface. In particular, the project has been developing key functionalities to achieve optimised system performance and network automation, by means of novel AI-based strategies applied to Radio Resource Management (RRM), multi-link connectivity, and network slicing. The final main outcome of the project will be to prove the explored concepts and the related developed building blocks in a fully integrated proof-of-concept (PoC), run in a dedicated lab setup hosted by the project partner, Thales Alenia Space France, in the Toulouse (France) premises.

Flexible network architecture

As aforementioned, the main enabler for such a multi-service, multi-network concept is a flexible and modular architecture able to suitably adapt its functions according to the specific users' needs and network conditions.

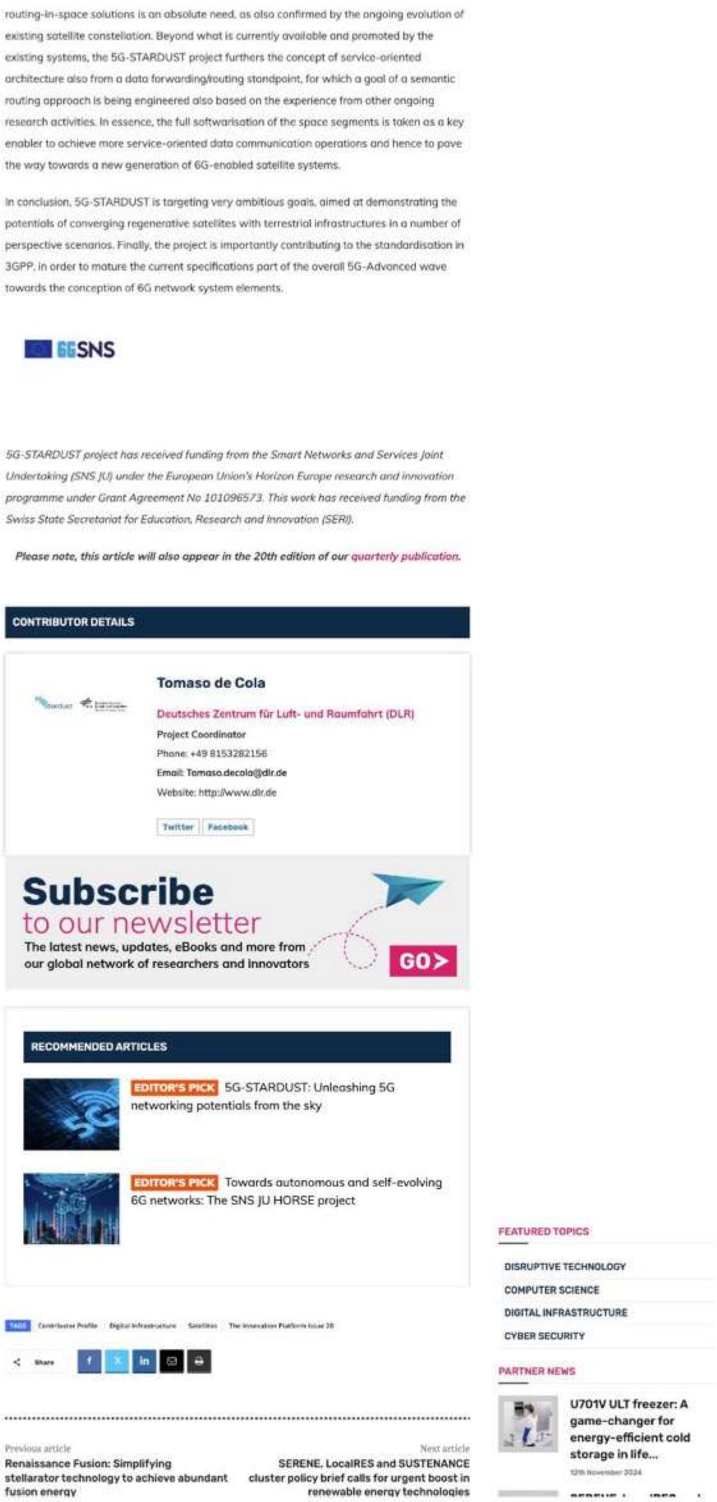
In the case of an NTN-integrated 5G/6G system, achieving such a versatile network architecture becomes even more challenging because of the nature of non-geosynchronous orbit (NGSO) satellite systems in terms of mobility of space nodes with respect to ground, often giving rise to handover events. Furthermore, the dotation of 5G/6G functionalities calls for the deployment of gNB in space, which is severely constrained by the current capabilities of satellite systems in terms of size, power, and storage. To this end, the project has come up with a flexible system architecture able to distribute gNB functionalities and overall 5G/6G functionalities in space, which can be activated according to the specific service or traffic conditions being time-wise experienced. Different options have been explored, starting from the well-consolidated practices from 3GPP and O-RAN bodies with respect to 'functional splitting', in order to find a proper trade-off between computational complexity, network functions available at the edge, and incurred control plane signalling.



In general terms, all satellites are expected to be 5G-native but the corresponding functionalities will be activated according to network orchestration, slicing, and ultimately service function chaining principles. Such an activation will be triggered either directly from ground or even in space, in the case a core network is entirely implemented onboard satellites. In this respect, proper co-ordination and convergence between terrestrial and non-terrestrial subnetworks is fundamental to carry out effective communication operations, especially in the case of multi/dual-connectivity implementation, whereby traffic segregation, sharing, or offloading from one network to another have to be carried out.

Data distribution

Last but not least, efficient data distribution across the space segment benefits from full interconnected space nodes, also from a control plane perspective.
To this end, the availability of inter-satellite links and the corresponding deployment of



routing-in-space solutions is an absolute need, as also confirmed by the ongoing evolution of existing satellite constellation. Beyond what is currently available and promoted by the existing systems, the 5G-STARDUST project furthers the concept of service-oriented architecture also from a data forwarding/routing standpoint, for which a goal of a semantic routing approach is being engineered also based on the experience from other ongoing research activities. In essence, the full softwarisation of the space segments is taken as a key enabler to achieve more service-oriented data communication operations and hence to pave the way towards a new generation of 6G-enabled satellite systems.

In conclusion, 5G-STARDUST is targeting very ambitious goals, aimed at demonstrating the potentials of converging regenerative satellites with terrestrial infrastructures in a number of perspective scenarios. Finally, the project is importantly contributing to the standardisation in 3GPP, in order to mature the current specifications part of the overall 5G-Advanced wave towards the conception of 6G network system elements.

5G-STARDUST project has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101096573. This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Please note, this article will also appear in the 20th edition of our quarterly publication.

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5G-STARDUST in Innovation News Network

5G-STARDUST

5G-STARDUST's ambition is to deliver a fully integrated 5G-NTN autonomous system with novel self-adapting end-to-end connectivity models for enabling ubiquitous radio access.

OVERVIEW

5G-STARDUST is aimed at proving the unification of Terrestrial Networks (TNs) and Non-Terrestrial Networks (NTNs) into a holistic architecture, building on the foundations of 5G and paving the way towards 6G communication systems. The proposed unification framework is conceived to flexibly serve a number of possible Use Cases (UCs), relevant for mobile and satellite operators, vendors, and service providers. In this respect, the overall concept "orbits" around the exploitation of regenerative satellite payloads, hence allowing NTN nodes to act as smart 5G space nodes, implementing gNB functions in space as well as User Plane Functions.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The architecture concept is centred on the implementation of gNB functionalities in space, either entirely within each space node or distributed (i.e. through 5G functional splits in space). In particular, the main focus is on the case of integrating 5G-enabled Low Earth Orbit satellite constellations with TNs. Hence, 5G-STARDUST's ambition is to prove the coexistence of TN and NTN segments within a unified network architecture concept, building on key pillars: 1) unified 5G NR-native radio interface, 2) self-organised network architecture, 3) user-centric satellite system design, 4) multi-link exploitation, and 5) AI-based optimisation of radio and network functions. The selected key functionalities are then being integrated in a dedicated lab testbed for final demonstration.

INNOVATION

The main innovation pillars constituting the baseline of 5G-STARDUST are i) self-organised network architecture building on a flexible space configuration with gNB operated in space, ii) unified radio interface counting on user-centric beamforming and AI-based Radio Resources Management (RRM) optimisation, as part of a reference O-RAN based architecture fusing together TN and NTN components, iii) AI-based multi-link optimisation aimed at scheduling communication link and dispatching traffic flows according to Quality of Service (QoS) requirements and link capacity availability, iv) QoS-oriented network architecture relying on an overarching Software-Defined Networking (SDN)-based layer and on Artificial Intelligence (AI)-based network slicing optimisation. As to this latter point, an important role is certainly also played by the deployment of routing algorithms in space and the switch from TN to NTN infrastructures, which is triggered and managed at Core Network (CN) level. Last but not the least, an important innovation element is the allocation of dedicated network functions in space and the potentials of even deploying application service onboard satellites, such as multi-access edge computing, further reduce the overall latency of reference services.

USE CASES/ SCENARIOS

5G-STARDUST project identified key UCs to demonstrate the functionalities of an integrated 5G-based TN-NTN network, comprising mobile transportation systems, PPDR, private and governmental networks, residential broadband, and hyperconnected automotive sector. Out of these scenarios, 5G-STARDUST further narrowed down the selection to 5G-enabled residential broadband and aeronautical communications to demonstrate the corresponding functionalities in the so-developed lab testbed. As to the first scenario, the objective is to show the seamless transition from TN to NTN achieve more cost-effective operations (i.e. network switch at night). On the other hand, the second scenario deals with the coexistence and later switch from TN to NTNs in the various phase of aircraft flights, i.e. from take-off to landing through cruising phases. As such, the objective is to provide the switch from on e network to another, once either of the two available networks (i.e. TN or NTNs) are not any longer available or offer less satisfactory QoS/QoE guarantees than the other, hence necessitating a network handover. The considered scenarios are being implemented in a common testbed lab (expected to reach TRL4/5 at the end of the project), where the main elements necessary to demonstrate end-to-end connectivity are being integrated. The overall layout of the functional testbed architecture and the description of the related SoftWare/HardWare (SW/HW) components is then summarised in the next section, where the status of the integration process is also shortly discussed. Finally, it is also worth noticing that the procured testbed will be considered the main outcome of the project in light of its capabilities of showcasing the full functionalities of an integral 5G-enabled NTN system. Nevertheless, the project has been also developing standalone simulation and emulation tools to prove the other findings of the project, though not reaching the necessary maturity for being implemented in the general Proof-of-Concept (PoC) of the project.

RESULTS

The main outcome of 5G-STARDUST is a PoC for demonstrating integrated 5G/6G-NTN communication system. The PoC includes TN and NTN segments, transporting data from servers to User Equipment through shared RAN and 5G CN infrastructures. In particular, UE prototypes operating at FR1 and FR2 frequency ranges are used, able to either use TN or NTN connectivity, achieved through dedicated gNBs, either on ground or space. The space segment is characterised by realistic channel emulators. The Centralised/Distributed Unit parts of the gNB are implemented as SW components in a dedicated HW, while the Radio Unit is directly embedded in Xilinx boards. It is noteworthy that the overall setup will be used for verifying the overall system architecture and for validating the benefits of an end-to-end 5G enabled NTN architecture, through real-world applications such as video streaming, file transfer, and web browsing. Finally, the preliminary results collected for the assessment of the unified radio interface and the self-organised network paradigm prove the performance improvements coming from the deployment of a unified 5G/6G unified network architecture in terms of servicing many use cases and offering satisfactory Key Performance Indicators.

Satellite And Terrestrial Access For Distributed, Ubiquitous And Smart Telecommunications

Coordinated by
Dr. Tomaso de Cola,
German Aerospace Centre, DLR

January 2023–December 2025

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