NEXASPHERE:

NEXGEN 3D NETWORKS SPIN HARMONIES ACROSS 6G, AI, AND UNIFIED TN/NTN

D2.1

Use cases, Preliminary System Requirements Analysis, and KPIs

12/09/2025

D2.1: Use cases, Preliminary System Requirements Analysis, and KPIs

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Executive Summary

This document outlines the use cases, system requirements, and performance indicators for NexaSphere, targeting three sectors: aviation, automotive, and railway. The focus is the extension of coverage in remote and high-mobility environments and integration with a 3D Network.

Chapter 2 comprises a state-of-the-art section with summarizes recent 3GPP developments and initiatives from the European Space Agency and the European Commission relevant to NexaSphere's objectives. It also outlines the status of mobility-related use cases for the three verticals.

In the same chapter the use cases for the three sectors are described which are:

- Aviation use cases involve gate-to-gate high throughput connectivity, entertainment delivery and overall resource optimisation. These require high availability, seamless handover, and bandwidth aggregation across multiple link technologies such as 3GPP, non-3GPP, WiFi, and LiFi.
- Automotive focuses on V2X communications to support autonomous driving especially in urban scenarios. Extension of connectivity to rural areas for safety, convenience and increase of autonomy levels are also envisaged.
- Railway applications require reliable connectivity -also in rural and uncovered areas- for train control and share with the Aviation domain the use cases of entertainment delivery and overall resource optimisation.

Chapter 3 details the High-Level Requirements that will drive the definition of NexaSphere's System Architecture.

Finally, in Chapter 4, are defined the KPIs defined per vertical, with high importance to Data Rate, Latency, Availability and Handover time.

1 Introduction

1.1 Purpose of this Document

This document defines the use cases, preliminary system requirements, and key performance indicators (KPIs) for NexaSphere, setting the basis to reach its final goal of advancing the technological aspects of the project and, finally, contributing to the 6G standardisation roadmap. It focuses on the aviation, automotive, and railway verticals, targeting extension of future 6G coverage in remote areas to address the growing demand for ubiquitous and high-performance network availability.

The document identifies and details relevant use cases, considering the types of services that NexaSphere aims to support, summarising the needs of the three verticals. Furthermore, the document establishes functional and technical requirements derived from the use cases, specifying KPIs that will define the system performance. These KPIs will be essential for evaluating the feasibility and efficiency of NexaSphere's network and system architecture.

1.2 Scope

This document is the output of Task 2.1 (T2.1) of NexaSphere's Work Package 2 (WP2), which focuses on Scenario Definition and Analysis of Technical Requirements. WP2 addresses System Architecture, Use Cases Definition and Techno-Economic Study and is structured into three interconnected tasks:

- T2.1: Scenario definition and analysis of technical requirements
- T2.2: Overall system design, specification, and unified 6G-TN/NTN architecture
- T2.3: KPI, socio-economic impact assessment, and techno-economic analysis

Use cases defined in T2.1 - and described in this document - shall be interpreted as generic NexaSphere use cases. They are intended to provide inputs and high-level requirements for the overall system design in T2.2 and performance evaluation in T2.3.

It is important to note that the use cases described in this document are distinct from the Proof-of-Concepts (POCs) that will be demonstrated in WP6, which focus on validating specific technological components.

The outcomes of WP2 form the foundation for WP3, WP4, and WP5, which are the main research and development activities of NexaSphere.

Given the complexity of the project and the dependencies between Work Packages, iterative refinement of D2.1 is expected, integrating feedback loops between WP2 and subsequent work packages to refine and converge on the system design.
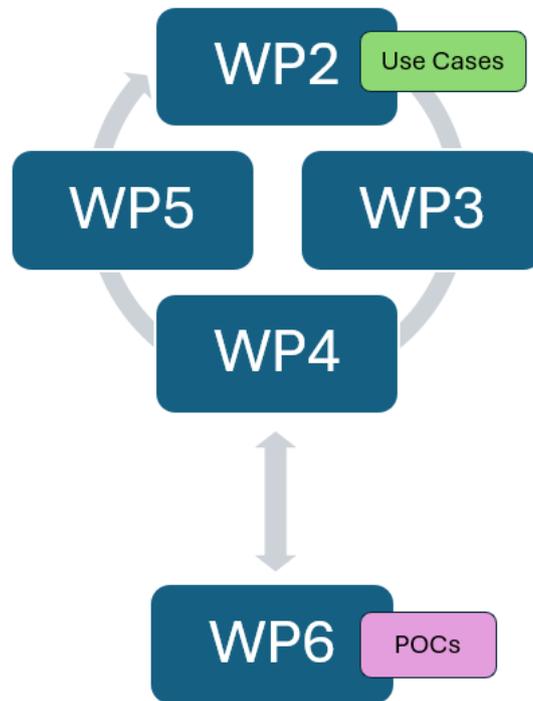
Figure 1-1 Representation of how the Use Cases defined in this document relate to the WPs and POCs

2 NexaSphere Use Cases Description

This chapter presents the use cases[1] developed for NexaSphere, focusing on three key verticals: automotive, aviation and railway. The use cases were designed through collaboration within dedicated internal working groups, each responsible for a specific sector and supervised by the NexaSphere's project coordinators to check their alignment with the project objectives.

Each working group was led by a Use Case Owner, a company with deep expertise in the respective industry - Stellantis for automotive, Safran Passenger Innovations for aviation, and Network Rail for railway. These organisations, being directly involved in their respective markets, played a crucial role in defining the primary objectives and functional scope of each use case. Their industry knowledge ensured that the identified use cases addressed real-world needs and business requirements. Beyond the Use Case Owners, members of the working groups contributed to refining the technical and operational details. Once developed, the use case underwent a thorough review to ensure coherence and adherence to the overall consortium expectations. The workflow is summarized in Figure 2-1.
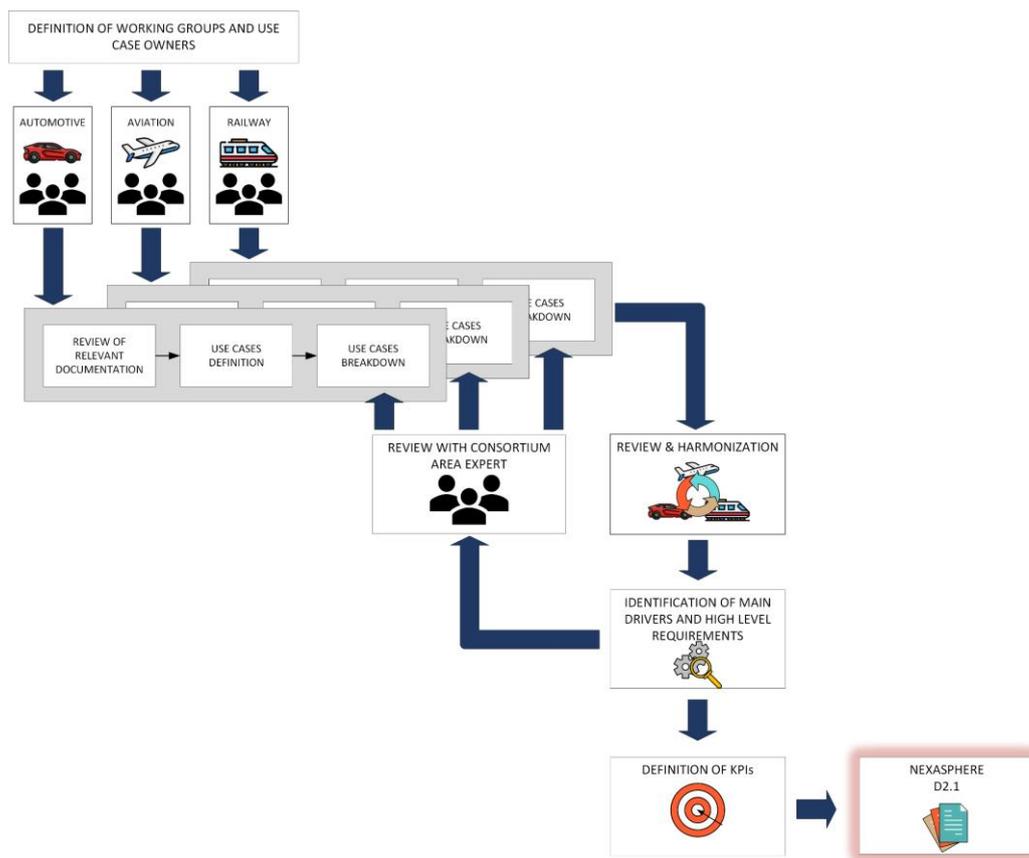
Figure 2-1 Work Logic of Task 2.1

2.1 State of the Art

2.1.1 3GPP Use Cases on Non-Terrestrial Networks (NTN)

3GPP began exploring NTN in **Release 14**, and NTN has been part of all Releases of 4G and 5G since that. Release 20 is the first release where 6G is studied and NTN will be included there as well.

The Release 14 focused on examining use cases for satellite and airborne platforms - especially where terrestrial coverage is impractical, including rural, maritime, emergency response, IoT, and broadcast scenarios. In such release, the first non-terrestrial network studies about use cases were done. Particularly, in Release 14, were defined the following scenarios for which satellite networks surpass terrestrial networks in feasibility and efficiency:

- Areas where it is impossible to deploy terrestrial towers like coverage on lakes, islands, mountains etc.
- Disaster relief: During natural disasters or other unforeseen events that entirely disable the usage of terrestrial network.
- Emergency response: Special emergency situations in the areas without terrestrial networks like public safety use cases of an accident in a power plant.
- Connected cars: non-terrestrial networks can be used as a backup or secondary connection for connected cars in the events where the primary connection failures.
- Rural areas which are hard and cost-ineffective to cover using terrestrial networks.
- Connectivity for remotely deployed sensors e.g. farms, substations, gas pipelines, remote road alerts, etc.
- Low bit-rate broadcast services: Satellites can broadcast wide area emergency messages at a more efficient resource consumption than with terrestrial networks.
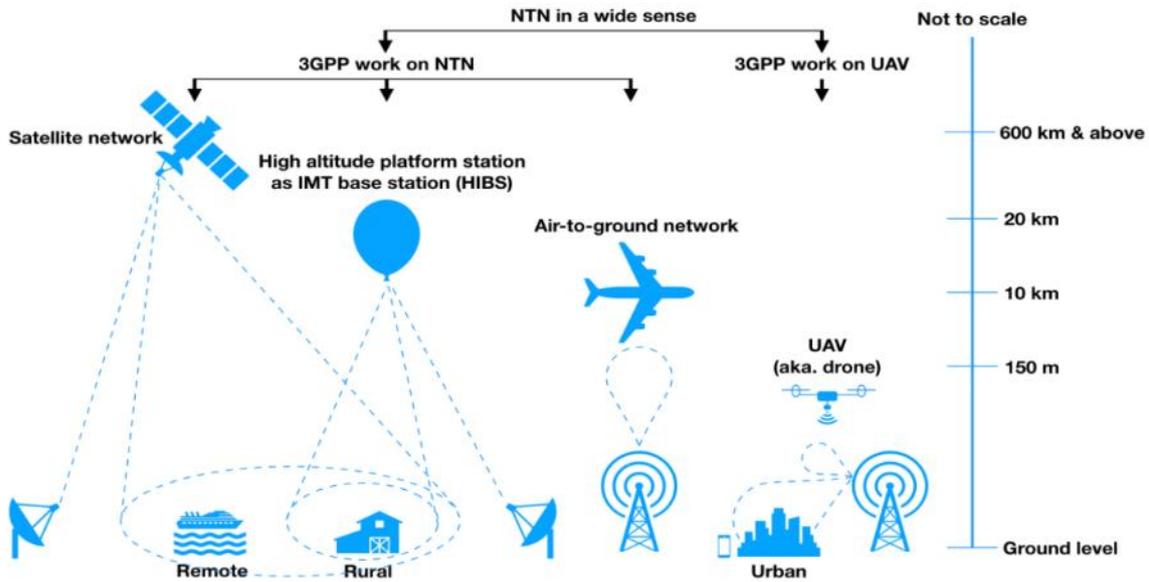
Figure 2-2 Different types of Non-Terrestrial Networks [1]

In **Release 15**, TR 38.811 defined NR-NTN fundamentals: deployment scenarios (GEO/LEO/HAPS), channel models, impact on beam management, Doppler, timing, and early solutions for RAN protocol and architecture enhancements. It specifically cited eMBB, mMTC, and URLLC use cases. This work laid the groundwork to:

- Expand 5G eMBB coverage to underserved regions cost-effectively.
- Boost service continuity for users in motion (aircraft, vessels, trains) and critical communications.
- Introduce scalable broadcast capabilities to efficiently deliver content to the network edge or directly to devices.

Release 16 advanced this with TR 22.822 and TR 38.821: detailed satellite access use cases (IoT, broadcast, backhaul, mobility), along with RAN-level support for transparent and regenerative payloads, moving beams, HARQ, timing, and SON enhancements.

In such release, the first NTN-specific bands were introduced, as reported below:

Band	Duplex Mode	User UL (ground to space)	User DL (space to ground)
n256 (S-band)	FDD	1980–2010 MHz	1980–2010 MHz
n255 (L-band)	FDD	1626.5–1660.5 MHz	1525–1559 MHz

Release 17 brought normative RF and performance specs for NTN. TR 38.863 and the relevant parts of TS 38.101-5, TS 38.108, TS 38.181, and TS 38.521-5 defined RF bands (n255/n256), UE and satellite node performance, and conformance tests—solidifying NTN readiness.

In **Release 18**, studies TR 37.911 and TR 38.882 addressed IMT-2020 satellite interface evaluation and network-based UE location verification (~5–10 km accuracy), respectively, advancing NTN maturity and reliability. Additionally, FR1 band n254 was introduced and additionally FR2 bands n510, n511, n512:

Frequency Range[2]	Band	Duplex Mode	User UL (ground to space)	User DL (space to ground)
FR1	**n256** (S-band)	FDD	1980–2010 MHz	1980–2010 MHz
FR1	**n255** (L-band)	FDD	1626.5–1660.5 MHz	1525–1559 MHz
FR1	**n254** (L/S-band)	FDD	1610–1626.5 MHz	2483.5–2500 MHz
FR2	**n512*** (Ka-band)	FDD	27500 - 30000 MHz	17300 - 20200 MHz
FR2	**n511*** (Ka-band)	FDD	28350 - 30000 MHz	17300 - 20200 MHz
FR2	**n510*** (Ka-band)	FDD	27500 - 28350 MHz	17300 - 20200 MHz
*Open for discussion				

Future work in **Release 19** and beyond will focus on regenerative payloads (on-board processing), uplink optimisation, RedCap support, broadcast signaling, and IoT-NTN store-&-forward and MAC enhancements. In addition to the NTN bands of Rel. 18, Release 19 also introduced band **n253** (UL 1668–1675 MHz / DL 1518–1525 MHz), and -as of today- Ku/Ka band options are under discussion.

Further to this, the recently started 6G study phased in 3GPP **Release 20** as elaborated in TR 22.860 has outlined several use cases to be supported by the forthcoming 6G ecosystem, notably including a few NTN-based scenarios. Amongst them, it is worthwhile mentioning the use case dealing with ubiquitous and resilient connectivity, which envisions the cooperation and the complementarity of TN and NTN systems in a number of key scenarios. Likewise, the new phase (4) on the Satellite Access still within 3GPP as part of TR 22.877, develops dedicated use cases of direct interest for the overall focus of NexaSphere, shortly recapped in the following:

- Resource and energy efficiency in a multi-orbit Satellite Access System
- Mobile base station relays (MBSRs) through multi-orbit satellite networks, including civil aviation, railway infrastructures, and automotive.
- Assisting vehicular communications via multi-orbit satellite access
- Aircraft communication services in Joint TN/NTN and multi-orbit deployments

Lastly, the orientation of ITU-R towards 6G through the IMT-2030 vision, which states that "The Non-Terrestrial Network (NTN) will complement existing terrestrial mobile networks and

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[2] Frequency Range (FR): The 3GPP defined NTN frequency ranges in which satellites can operate according to the 3GPP TS 38.108 V19.1.0 are categorized as FR1: 410 MHz – 7125 MHz and FR2: 17300 MHz – 30000 MHz.

enhance the next generation of mobile networks and services, striving to improve connectivity for users in unserved and underserved areas, benefiting both consumers and industries" (ITU-R M.2160, "Framework and overall objectives of the future development of IMT for 2030 and beyond"). In particular IMT-2030 offers specific insights relevant for the development of NexaSphere in terms of the additional usage scenarios, including ubiquitous connectivity and communication and AI that automatically point to the usage of NTN technologies. These new scenarios in addition to the eMBB (reworded in IMT-2030 as 'immersive communication') represent the foundation of the NexaSphere project, as they are part of the overarching aspects still defined in ITU-R M2160, i.e.:

- Sustainability;
- Connecting the unconnected;
- Ubiquitous intelligence;
- Security and resilience.

Which all concur to the unification of TN and NTN in a common 6G superset, which is part of the network vision of NexaSphere, whose representative use-cases are then further elaborated thereafter in this document.

The use cases that 3GPP has covered throughout the Releases 14 to 20 is collected in Table 1Table 1.

Table 1 3GPP NTN Use Cases and Relative TR Documents by Release

Release	Year	NTN Use Cases	Key TR Documents
Rel-14/ Pre-15	~2016–2017	- Feasibility of satellite access - Remote/rural coverage - Delay-tolerant services - Satellite backhaul - Direct satellite communication	TR 22.891 – Feasibility study on new services TR 38.913 – Scenarios and requirements for NR TR 22.864 – Remote area services TR 22.862 – Smart energy/grid support
Rel-15	2018	- NR over NTN feasibility - eMBB over satellite - Transparent vs. regenerative payloads - GEO/LEO/HAPS scenarios - Direct/relay access	TR 38.811 – Study on NR to support NTN
Rel-16	2020	- IoT (NB-IoT, eMTC) over satellite - Broadcast/multicast - Emergency/public safety - Time-sensitive services - UAS (Unmanned Aerial Systems) connectivity including NTN	TR 22.822 – Satellite access in 5G TR 22.860 – Feasibility study on UAS communication (incl. NTN)
Rel-17	2022	- NR for direct-to-device (handheld) - Service continuity - Mobile platform support (air/sea) - Ephemeris-based tracking - Emergency calls via satellite	TR 23.737 – 5GS architecture for NTN TR 38.821 – RAN support for NTN TR 28.808 – OAM aspects for NTN
Rel-18	2024	- Positioning via satellite - L/S/Ka-band support - Mobility across satellite footprints - Discontinuous coverage - Charging/security enhancements - Mission-critical communication over NTN	TR 37.911 – Service requirements for 5G NTN TR 38.882 – RAN enhancements for NTN TS 38.101-5 – RF specs for NR-NTN TS 38.108 – UE conformance for NTN TR 22.887 – Mission-critical use cases over NTN
Rel-19	~2025	- RedCap UEs over satellite - Store & forward - UE-to-UE via satellite - GNSS-free positioning - Public safety & multicast - Satellite-originated services	TR 22.865 – Use cases for Phase 3 NTN TR 23.700-29 – SA2 architecture for NTN TR 28.874 – Management for NTN TR 33.700-29 – Security for NTN

Rel-20	2025 (ongoing) Covers both 5G Advanced topics and first 6G work	**5G-Advanced**: - GNSS-resilient NTN - IoT voice (1–2 kbps) - Mission-critical over satellite - Multi-orbit NTN access - Indirect RAN sharing via satellite **6G Enablers**: -Integrated Sensing and Communication (ISAC) - AI/ML for NTN (mobility, XR, CSI) - UAV swarm support - XR over NTN 6G studies: Use cases, RAN study target for NTN: Aim at a harmonized 6G Radio design for TN and NTN, including their integration.	**TR 22.870 – Study on AI/ML for NTN (Rel-20 study)**

2.1.2 ESA Initiatives

The European Space Agency has a dedicated Directorate which coordinates and steers the future of connectivity beyond Earth which is the Connectivity and Secure Communications Directorate (ESA CSC). At the time of writing, ESA CSC focuses on six pillars that will guide activities post-2025:

- Industrial Competitiveness
- Mobile Convergence
- Optical & Quantum
- Governmental Connectivity
- Spectrum Sustainability
- Interplanetary Connectivity

NexaSphere aligns with ESA's efforts, specifically under the Mobile Convergence and Optical & Quantum pillars, which are addressed by ESA with the following activities:

Mobile Convergence Activities:

1. Direct-to-Device (D2D): Focus on large spaceborne antennas and on-board processing (activities 3F.001, 5B.253, 5A.088).
2. Terrestrial and Non-Terrestrial Network Coexistence: Spectrum sharing, core network, and in-orbit experiments (activities 3A.185, 3F.012, 3E.029).
3. Automotive Connectivity: Co-design and end-to-end demonstrations (activities 7C.084, 3F.010).

Optical & Quantum Activities:

1. Networking & Seamless Connectivity: End-to-end multi-orbit optical SatCom demonstrators (activities 3E.032, 5H.007).
2. Photonics & Intra-Satellite Connectivity: High-throughput data distribution and on-board processing (activities 5F.053, 5F.052).

3. Quantum Communication: Quantum key distribution (QKD) and Quantum Information Networks (activities 3A.209, 3A.212).

Furthermore, ESA started in 2024 the NTN Forum with the aim of driving collaboration among stakeholders to support the development and adoption of NTN solutions for 5G and 6G. It focusses on shaping industry standards, promoting innovation and integrating NTN into telecom networks. The forum is directed to space, satellite, mobile and terrestrial actors to align efforts, define use cases and explore industrial opportunities. It also supports discussions on standardisation, user terminals and backs demos to advance NTN deployment.

Specifically for optical satellite links, ESA Specification for Terabit/s Optical Links (ESTOL) harmonises the developments from the industry and research organisations within ESA member states, but also Japan and US. ESTOL thus paves way towards interoperable optical satellite architecture relevant for NexaSphere. The ESA HydRON program sets out to validate the ESTOL via in-orbit multi-orbit demonstration in next years. The new ESTOL releases will introduce also PNT aspects, allowing for GNSS-independent ps-level synchronisation of the NTN. The PNT aspects are independently being defined and validated in ESA in-orbit demonstration OpSTAR.

Companies within the NexaSphere Project team are already involved in such initiatives, some of which are reported in Table 2-2Table 2-2.

Table 2-2 ESA initiatives covered by members of NexaSphere Project Team

The 5G-HOSTS-SAT initiative focuses on integrating 5G and satellite communications, an area aligned with 3GPP and validated in several EU and ESA projects. Yet, real-world trials across verticals remain limited. 5G-HOSTS-SAT addresses this gap by providing a framework to validate 5G SatCom in two verticals:
- Smart Agriculture: Sensors for precision irrigation.
- Public Protection and Disaster Relief (PPDR): Extending coverage and reliability with satellite support.

The testbed uses a local 5G Non-Public Network with edge computing to host local applications. A programmable satellite backhaul connects to 5G Core elements, supporting Internet and cloud access. Cloud-native functions enable flexible distribution of the 5G Core between edge and central domains, tailored to use cases. For PPDR, fully autonomous 5G networks operate with user and control plane functions at the edge, relying on on-demand satellite backhaul for periodic updates with the control center and Internet. Satellite resources are jointly orchestrated in a multi-domain network infrastructure, aligned with resource availability.

SEVECODE (Satellite Enhanced Vehicle Connectivity Demonstrator) is a project aimed at developing a testbed to demonstrate of vehicle-to-everything (V2X) 5G applications with Non-Terrestrial Networks (NTN) and their integration with the existing 5G Terrestrial Network.
The activity is aimed at demonstrating the end-to-end performances of an integrated TN/NTN 5G hybrid network for V2X services using existing space assets.
The activity covers at least two 5G NTN V2X applications compliant with the 3GPP 5G NR, making use of satellite capacity available in FR1 or FR2. The testbed addresses both forward and return traffic, allowing to evaluate the applications KPIs and to demonstrate the TN/NTN service continuity when moving between coverage areas.

MIXELS (Demonstration of an experimental 5G g-NodeB in space) is a project aimed at developing and demonstrating in orbit an experimental 5G g-NodeB (gNB) distributed between a regenerative payload and a satellite gateway, demonstrating its main functionalities in the frame of New Radio (NR) Non-Terrestrial Networks (NTNs) from low Earth orbit satellites to be extended to medium Earth orbit

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and Geostationary Earth orbit. In particular, the case of distributed CU-DU functionalities in space are being considered, by making use of the Kepler satellite constellation with satellite interconnected by means of ISLs.

6G-LINO (6G satellite precursor - STERLING in-orbit laboratory Phases A/B/C/D/E1) is a project aimed at developing and launching a 6G-enabled satellite platform onboarding gNB functionalities and to be used for validating some relevant use cases for the unification of NTN and 6G into a unique system architecture.

2.1.3 EC Initiatives

The European Commission has established a few programs as part of the overall Horizon Europe (HE) framework, where the integration of NTN and 5G/6G systems is being explored and corresponding developments being supported. On the one hand, the Smart and Network Services (SNS) Joint-Undertaking (JU) has developed a composite framework subdivided in multiple phases to let the European Industry move from 5G to 6G deployments in alignment with the 3GPP standardisation process, which also addresses the integration of NTN systems. In particular, the present project NexaSphere has been originated by Call 3 of the SNS JU program. Then, Cluster 4 of the HE framework is specifically dedicated to "Digital, Industry and Space", and hence also addressing the case of integrating satellite systems with 5G counterpart and the related evolution to 6G. Considering the objectives of NexaSphere and the ongoing development in the aforementioned areas of HE framework, the following activities are closely aligned or relevant.

Table 2-3 EC initiatives aligned with the NexaSphere mission

5G-STARDUST (Satellite and Terrestrial Access for Distributed, Ubiquitous, and Smart Telecommunications) is a project aligned with the 5G-Advanced phase of 3GPP and aimed at demonstrating the convergence of 5G and NTN networks in a dedicated PoC. Special focus of the project is the design of a unified air interface, the exploitation of cell-free user-centric concepts, self-organized networking, and AI-based RRM and multi-connectivity functions.

6G-NTN (6G-Non-Terrestrial Networks) is a project projected into the evolution of 3GPP standards towards 6G and hence identifying the most relevant use cases and the enabling technologies at system, air interface, and networking level.

ETHER (sElf-evolving terrestrial/non-Terrestrial Hybrid nEtwoRks) is a project aligned to the evolution of terrestrial systems towards 6G and the related unification with NTN domain, by focusing on air-interface and networking aspects for a few use cases, one of the being the aeronautical communication case.

TRANTOR (5G+ evoluTion to mutioRbitAl multibaNd neTwORks) is a project focused on the unification of 6G and NTN networks, by 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.

2.1.4 Mobility Use Cases

2.1.4.1   Aviation

Over the last two decades, commercial deployments of in-flight connectivity have largely been provided by satellite network operators via their own private networks such as Intelsat (now part of SES), Eutelsat, Viasat, and more recently, Starlink [2]. However, Viasat (through Inmarsat) and Deutsche Telekom, in partnership with Nokia, introduced a different approach by creating the European Aviation Network (EAN). This system combines a dedicated S-band GEO satellite with a Europe-wide LTE ground network consisting of around 300 base stations across Europe. Officially completed in early 2018, EAN became the world's first integrated satellite and complementary LTE-based terrestrial network for aviation, delivering high-speed, low-latency connectivity tailored for aircraft operating in European airspace. The system offers over 75 Mbit/s to the aircraft and supports scalability to meet future demand [3].

More recently, aircraft communication within the 6G-NTN context has received growing attention. The Seamless Air Alliance has identified and introduced four key use cases for aviation connectivity leveraging 3GPP NTN technologies [4], underscoring the industry's increasing focus on enabling seamless, standardized, and high-performance connectivity for aircrafts.

In parallel, researchers in [5] have demonstrated a testbed that connects an airborne node to a terrestrial 5G core network via a LEO satellite backhaul as demonstrated in Figure 2-3, such as Starlink.Figure 2-3, such as Starlink. The testbed validates the feasibility of integrating NTN-based backhaul with edge computing to support advanced airborne services. Additionally, authors in [6] have proposed a framework for the dynamic collection, monitoring and distribution of network resources across heterogeneous flying objects. This system lays the foundation for enabling high-performance services and cooperative aerial networking for next generation 6G aeronautical applications. The paper 6G for Connected Sky: A Vision for Integrating TN and NTN [7] discuss on the use case of Commercial Airplane Traffic on scenarios such as Passenger operation (inflight entertainment connectivity), Aircraft operation (communication between ATC and pilots), Crew operation and Ground operation.
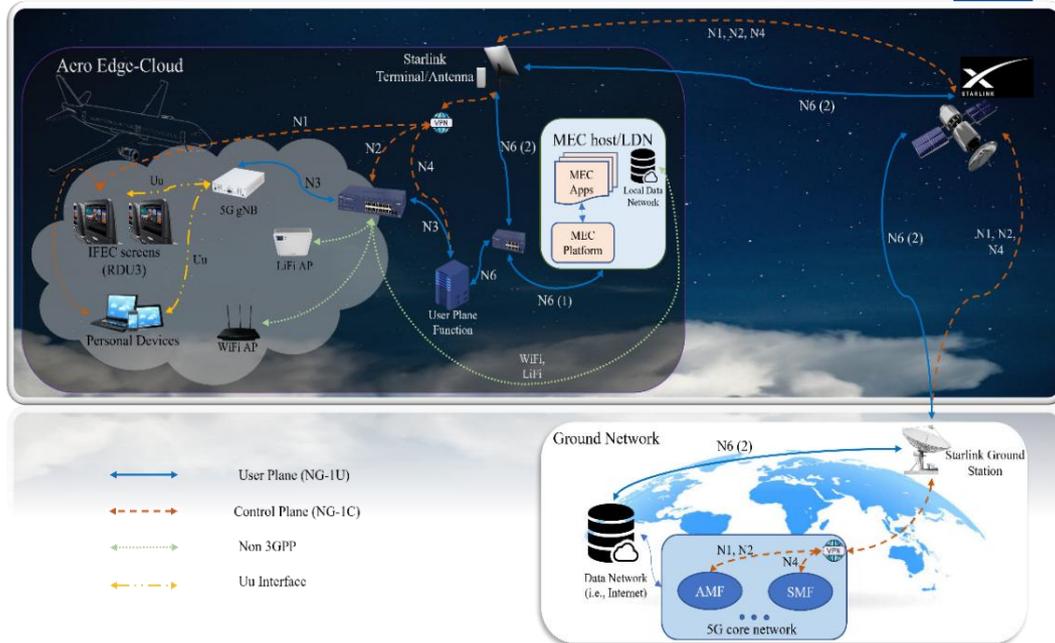
Figure 2-3: Realization of 5G Connectivity in H2020-AI@EDGE project

Within 3GPP standardisation, airplane communication was formally introduced as a use case in [8] during SA1 Meeting #108 and subsequently included in 3GPP TR 22.887 (Release 20) [9]. Furthermore, 3GPP TR 22.870 V0.2.1 [10] introduced two new use cases focused on:

1. Onboard communication for Urban Air Mobility (UAM) aircraft
2. High-data-rate communication services for commercial aircraft in 6G

These initiatives collectively underline the growing strategic interest in standardising and deploying 6G-NTN solutions for aviation.

There are also some research projects targeting 5G/6G NTN for aviation connectivity. The project 6GSKY [11] aims at solutions to enable reliable and robust connectivity for aerial and ground users via flexible and adaptive network architecture adopting multiple technologies such as satellite and direct air to ground communication (DA2GC). Also, The H2020 AI@EDGE project [12], in one of its use cases, explored a complete 5G network and edge-cloud infrastructure built on aviation-certified hardware and commercial off-the-shelf servers.

2.1.4.2 Automotive

The status of research in automotive connectivity, particularly in the realm of Cellular Vehicle-to-Everything (C-V2X) technology on which Associations like Car-to-Car Communication Consortium (C2C-CC) and 5G Automotive Association (5GAA) are working on, reflects significant advancements and collaborative efforts aimed at revolutionising the mobility ecosystem. Stellantis is a member of the 5GAA, which has been instrumental in this progress, providing detailed frameworks and use case descriptions through its technical reports [13]. These documents highlight the multifaceted applications of C-V2X, including safety enhancements, vehicle operations management, and convenience features, all of which contribute to a more efficient and safer driving experience. In addition, the 5GAA has also published its envisioned roadmap of V2X connectivity via NTN in [14].

An advancement in in the state of the art of 5G-V2X and NTN has been achieved recently with demonstrations in Paris by 5GAA. For the first time, direct communication between vehicles using 5G V2X and a satellite-based system was successfully tested in an urban setting. Demonstrations focused respectively on realising hazard warning and emergency messaging use cases in the vehicle, as well as illustrating how NTN will complement terrestrial 4G and 5G networks in the future [15].

C-V2X technology employs both direct communication between vehicles and network-based communication, facilitating robust and reliable data exchange over extended distances. This dual-mode communication is essential for the deployment of cooperative intelligent transport systems (C-ITS), which integrate vehicles, infrastructure, and pedestrians into a cohesive network. The socio-economic benefits of C-V2X are substantial, as evidenced by various studies and reports. These benefits include:

1. Improved Traffic Management: C-V2X enables real-time traffic information sharing, leading to optimized traffic flow and reduced congestion.
2. Reduction in Accidents: Enhanced communication between vehicles and infrastructure can significantly decrease the likelihood of accidents by providing timely warnings and improving situational awareness.
3. Enhanced Mobility Services: The technology supports advanced mobility solutions such as autonomous driving, which can lead to more efficient and flexible transportation options.

The 5GAA's mission is to bridge the automotive and telecommunication industries, fostering collaboration to address society's connected mobility needs. Their work includes defining Service Level Requirements (SLRs) for various use cases, ensuring that C-V2X solutions meet the stringent demands of real-world applications. The association's efforts are supported by a diverse membership, including automotive manufacturers, technology providers, and mobile operators, all working towards a common goal of safer, greener, and more efficient transportation.

Recent advancements in C-V2X technology have focused on refining methodologies for use case descriptions, considering factors such as road environments and involved actors. This has led to the development of advanced use cases with challenging requirements, pushing the boundaries of what is possible with current communication systems. As the technology continues to evolve, the integration of the most advanced connectivity capabilities promises even greater enhancements, paving the way for fully automated and connected driving experiences.

Stellantis is also a partner of the Hi-Drive European project on connected automation. In 2024 Hi-Drive established a cooperation with C2C-CC on the V2X deployment challenges and a liaison with 5GAA to learn about the roadmap of deployment of 5G Stand Alone most advanced cellular technology.

Overall, the current status of automotive connectivity research reflects a dynamic and collaborative effort to revolutionize the mobility ecosystem. With ongoing developments and the support of industry leaders, C-V2X technology is poised to play a pivotal role in shaping the future of transportation.

In this evolving landscape of technological innovation and cross-industry collaboration, Non-Terrestrial Networks (NTN) are emerging as a key enabler of global, resilient connectivity. By integrating satellite and high-altitude platform networks with terrestrial infrastructure, NTN could support advanced V2X use cases, particularly in remote or underserved areas. These networks help meet the stringent Service Level Requirements (SLRs) defined by 5GAA, ensuring consistent performance even in challenging environments. The synergy between European initiatives like Hi-Drive and the deployment roadmap of 5G Stand Alone highlights the strategic role of NTN in the future of connected and automated mobility. Ultimately, NTN technologies contribute to a safer, more sustainable, and efficient transportation ecosystem by extending the reach and reliability of vehicular communications.

2.1.4.3   Railway

The International Union of Railways (UIC) has introduced the Future Railway Mobile Communication System (FRMCS) as the successor to GSM-R, with the goal of addressing evolving railway communication needs and enabling the digital transformation of the rail sector [16].

The X2Rail Adaptive Communication System (ACS) complemented this vision by enabling flexible and adaptive management of multiple bearers, optimising resource utilisation and improving service reliability across diverse operational scenarios [17].

While FRMCS standardisation is still under development, the key application areas have been defined in the UIC FRMCS User Requirements Specification [18]. This specification organizes railway communication services into three core categories:

1) Critical Applications: Essential for operational safety and regulatory compliance, including voice emergency communications, ETCS, Automatic Train Operation (ATO) and other safety-related functions.
2) Performance Applications: Designed to enhance operational efficiency, covering services such as telemetry, Train Control and Monitoring Systems (TCMS), remote diagnostics, real-time infrastructure monitoring and train departure coordination.
3) Business Applications: Supporting wider operational and passenger-facing needs, including passenger internet, infotainment and other non-safety-related digital services. These are logically and operationally segregated from mission-critical functions.

The FRMCS framework established by UIC serves as a foundation for standardisation efforts led by the ETSI Rail Telecommunications Technical Committee (ETSI TC-RT) and 3GPP which focus on functional and system architecture development.

On-board and trackside assets must maintain continuous, deterministic communications to enable safety-critical functions such as Emergency Call, signaling data (ETCS). The TN/NTN communication layer dynamically manages bearer selection and resource allocation, maintaining session continuity even at speeds up to 500 km/h.

Accurate train localisation is key for movement authority, integrating GNSS, inertial sensors and 6G radio techniques; to deliver cm-level accuracy, supporting ETCS, ATO and zone-based train control.

AI-based mobility management ensures seamless handovers and resource adaptation during high-speed transitions, preserving service integrity across dynamic rail topologies.

Infrastructure condition monitoring is enabled by distributed IoT sensing, with data transmitted via NTN or 6G edge gateways. These services operate on performance-class bearers, separate from control channels, ensuring no impact on mission-critical flows.

Passenger connectivity is delivered through logically isolated slices, using hybrid access and edge caching to provide high-throughput services while safeguarding the performance of operational systems.

2.2 Aviation Use Cases

2.2.1 AVT-UC01: Joint Terrestrial and Satellite In-Flight Connectivity

UC Title:	Joint Terrestrial and Satellite In-Flight Connectivity

High-Level Description:	Passengers access the Internet throughout the flight via two main paths:
	1. Direct Access to the TN:
	    • Utilizes available terrestrial base stations during flight phases (takeoff, landing, low-altitude cruise) where coverage exists.
	2. Access via the Plane Customer-Premises Equipment (CPE):
	    • The plane's CPE connects to a data network through either terrestrial or satellite (NTN) links.
	    • The CPE creates an in-cabin Radio Access Network (RAN) using WiFi or 3GPP-based solutions, allowing passengers to connect using legacy devices.
	
	In either of the two cases the Passenger Device accesses the internet through a legacy interface (WiFi or 3GPP) and experiences service continuity whenever a link handover is performed (e.g., TN-NTN, NTN-NTN)

Goal(s):	Deliver Internet connectivity for passengers with legacy devices (WiFi/3GPP interfaces) across all flight phases. Achieve seamless handovers across TN and NTN links for uninterrupted user experience.

Actors:	End User
	    • Passenger with legacy device (smartphones, tablets, laptops, etc.).
	Plane Device
	    • Plane CPE (Customer Provided Equipment) providing in-cabin WiFi/3GPP RAN, bridging TN/NTN

Illustration:	
Preliminary Requirements:	KPI Requirements:

Service availability > 98%
Service interruption (due to handover) < 1 sec
Total DL > 850 Mbps per plane
Total UL > 85 Mbps per plane
Total seats: up to 450
Load factor: 85% (passengers onboard)
Take rate: 75% (Passengers using connectivity)
DL rate > 3Mbps per passenger device
UL rate > 0.3Mbps per passenger device
Downlink/uplink ratio: 10/1
UE type: CPE (airplane)

Global coverage (over the poles)

Service Requirements:
- Seamless user experience (QoE) for a UE integrated into a high-speed platform.
- Minimum service interruptions when transitioning between terrestrial and satellite networks or between satellites networks operating in different orbits (e.g., GEO, MEO or LEO).
- Uninterrupted service continuity when switching between satellites of the same network operating in any orbit.
- High-throughput performance to the UE, ensuring consistent QoE for end users/passengers.

2.2.2 AVT-UC02: Integration of 3GPP and non-3GPP technologies for access to offboard connectivity

UC Title:	**Integration of 3GPP and non-3GPP technologies for access to offboard connectivity**
High-Level Description:	The plane maintains continuous connectivity from gate-to-gate by using: 1. 3GPP Links: • TN and NTN (satellite-based) 5G-NR connections. • Active during phases of flight when 3GPP coverage is available (e.g., near airports for TN, at altitude for NTN). 2. Non-3GPP Links: • Examples include DVB-S2/S2X (satellite digital video broadcasting) and standard Satcom links. • Used as fallback or complementary links when 3GPP NR is unavailable or to supplement 3GPP links for throughput/robustness. The plane CPE dynamically manages these links and ensures continuous connection to the Core Network, even if 3GPP connectivity is not available.
Goal(s):	Achieve robust plane connectivity throughout all flight phases (including areas where NTN is unavailable).

	Support seamless connectivity by combining 3GPP and non-3GPP access technologies.
Actors:	Plane Device • Plane CPE managing 3GPP and non-3GPP links to ensure connectivity
Illustration:	
Preliminary Requirements:	Service interruption < 1 sec (Switching btw 3GPP and non-3GPP satellites) Service availability > 98% Data rate: Similar to AVT-UC01: Joint Terrestrial and Satellite In-Flight Connectivity (~850Mbps/85Mbps)Data rate: Similar to AVT-UC01: Joint Terrestrial and Satellite In-Flight Connectivity (~850Mbps/85Mbps)

2.2.3 AVT-UC03: Joint connectivity for User Access to In-Flight Entertainment

UC Title:	**Joint connectivity for User Access to In-Flight Entertainment**

High-Level Description:	Passenger receives content available on the plane (e.g. video/movies) from multiple sources (multilink/multi carrier aggregation) with 3GPP and non-3GPP carriers (WiFi/LiFi), via passenger-owned and/or dedicated (e.g. in-seat screen) devices. LiFi provides a high-speed channel when unobstructed, while WiFi and 5G (5G private network) serve as alternative or complementary links. The system dynamically switches between or aggregates multiple links to optimize content delivery.
	
	Passengers access in-flight entertainment (IFE) content from onboard sources through a combination of multiple access technologies:
	1. LiFi:
	   • Provides high-speed optical wireless communication.
	   • Used when the optical line-of-sight is clear.
	2. WiFi and 5G (Private Network):

	• Serve as complementary or backup links when LiFi is obstructed or for non-line-of-sight areas. • Provide additional coverage and capacity. 3. Multi-Link/Multi-Carrier Aggregation: The system aggregates or dynamically switches between LiFi, WiFi, and 5G links. • Optimizes throughput and adapts to real-time link conditions (e.g., user movement, device type, link congestion).
Goal(s):	Maximize aggregated throughput for in-flight entertainment services. Maintain uninterrupted content delivery regardless of user movement or link obstruction.
Actors:	Users Passengers using personal devices or dedicated IFE equipment (e.g. in-seat screens). In-Cabin IFE Onboard content delivery systems integrating LiFi, WiFi, 5G links. Passenger Devices Legacy devices (with dongles for LiFi)
Illustration:	
Preliminary Requirement:	Service Availability > 99% DL rate > 30Mbps per UE (to support 4K Video streaming) UL rate > 10Mbps per UE (1:3 uplink: downlink ratio) For handover (between RAN technologies) < 1 sec Aggregated DL: 2.8 Gbps Total seats: up to 450 Load factor: 85% (passengers onboard) Take rate: 25% (Passengers using IFE – no internet users)

2.2.4 AVT-UC04: Joint Connectivity for Gate data transfer

UC Title:	**Joint Connectivity for Gate data transfer**
High-Level Description:	New content/SW updates are automatically loaded to the aircraft at the airport using multi-link with 3GPP (5G-NR) and non-3GPP carriers (e.g. WiFi/LiFi). Data logs are automatically downloaded at the airport in the same way.

	LiFi, with its high-speed, enables rapid content loading and enhances overall data transfer performance, while complementing WiFi and 5G. Similarly, data logs are automatically downloaded using the same multi-link strategy.
Goal(s):	Reduce content load time at the gate by maximising available bandwidth and ensuring high link uptime using best available link(s) at the airport.
Actors:	Plane CPE
Illustration:	
Preliminary Requirements:	Service Availability > 99% DL/UL rate (when parked) > 10Gbps DL/UL rate (when un-parked (taxi, landing, take-off)) > 100Mbps

2.2.5 AVT-UC05: Resource Optimisation for In-Cabin Access Networks

UC 6 Name:	**Resource Optimisation for In-Cabin Access Networks**
Short Description:	In-cabin aircraft communication networks require optimized energy efficiency to ensure sustainable, high-performance connectivity while minimising power consumption. Various wireless technologies, including LiFi, WiFi, and 5G, contribute to in-flight connectivity, and optimising their power usage is essential for long-term operational efficiency. To achieve this, strategies focus on reducing the power consumption of transceivers, refining network architectures, and, if feasible, exploring alternative hardware implementations to improve overall energy efficiency.
Goal:	Minimize the power consumption of in-cabin communication networks while maintaining reliable, high-speed connectivity. Reduce overall energy usage while ensuring seamless passenger connectivity and network stability.
Actors:	In-cabin IFE equipment

	Passengers with legacy devices plus dongle for LiFi Passengers with new devices
Illustration:	
Preliminary Requirements:	Increase in energy efficiency of more than 20% in bit/Joule compared to existing solutions (target)

2.3 Automotive Use Cases

2.3.1 ATM-UC01: Connected Automated Passenger Cars in Urban Scenario

UC Title:	Connected Automated Passenger Cars in Urban Scenario
High-Level Description:	The vehicle builds a Digital Twin of its surrounding environment conditions continuously exchanging data with surrounding actors using V2X (Vehicle-to-Everything) Communication. Vehicle external inputs are merged with on-board sensor data, enhancing accuracy and extending the vehicle's perception beyond its immediate surroundings. The improved perception is then used by the path planning and control systems, enabling the vehicle to navigate potential hazards safely and make better overall decisions. The vehicle uses ETSI-SAE V2X interoperable standards for data exchange, and includes the following types: - Vehicle-to-Vehicle (V2V): vehicles share real-time data regarding their state and surrounding conditions, enhancing collective decision-making and safety. Can use DSRC or C-V2X. - Vehicle-to-Infrastructure (V2I): vehicles communicate with infrastructure elements such as traffic signals to optimize traffic flow and enhance safety features through synchronized operations, especially at intersections. Can use DSRC or C-V2X. - Vehicle-to-Pedestrians (V2P): allows vehicles to interact with pedestrians and cyclists, extending situational awareness beyond the driver's immediate environment. Primarily uses C-V2X. - Vehicle-to-Network (V2N): it connects vehicles to cloud services and broader networks to get data from external data sources. Real-time traffic updates, infrastructure data, and remote diagnostics are possible applications. It utilizes cellular network.
Goal(s):	Enable lateral and longitudinal Automated Control of a passenger car at vehicle automation SAE L4 in specific Operational Design Domains. Development of a Real-Time and 360 deg. Digital Twin including all available ODDs attributes as described in [19] such as: - Road Attributes such as morphology of the drivable area, geometry of the road (slopes, curves), lane specifications, road signs, road and roadside surface conditions, zones, structures on the road. - Environment Attributes such as weather, particulates, illumination conditions. - Road Actors presence and position, such as other vehicles, vulnerable road users, special vehicles.
Actors:	Host Vehicle (HV) Remote Vehicle (RV) Vulnerable Road Users (VRU)

Illustration:	
	Ref. [19]
Technical Requirement:	**Data Rate:** • for high vehicle density [3]exchanging sensor data about other road users / obstacles, position, speed, trajectory: uplink > 2 megabytes per second (16 Mbps) per vehicle downlink > 10 megabytes per second (80 Mbps) per vehicle (ref. 5G CARMEN EU project, these numbers consider a total of 8 vehicles close to each other). • for HD maps Uplink 5 kilobytes per second (40 kbps), Downlink: 500 kilobytes (4 Mbps) per second (per single vehicle) • For see-through 15Mbps (per single vehicle involved) **End-to-End Service Level Latency (V2V):** < from 10 to 20 ms per direct communication depending on the specific collision avoidance case. **End-to-End Service Level Latency (Mobile Data Rate):** (including uplink and downlink) < 100 ms per terrestrial / non-terrestrial network. **Vehicle Density:** 12.000 vehicles/km^2 (urban) **Reliability:** > 95 % at 500 m. Seamless functioning through all Relevant Urban Scenario Conditions

2.3.2 ATM-UC02: Hazardous Location Warning

For the present and the following use cases, the Vehicle Density reference figures are the following, from [20] par. 5.4.2:

UC Title:	**Hazardous Location Warning** **from [20] par. 6.1.5**
High-Level Description:	The HV is provided with shared near real-time data, seamlessly integrating alerts and inputs based on road conditions and potential hazards along the planned route or current path of travel. Some examples include but are not limited to:

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[3] Vehicle Density: expected number of vehicles per given area (per km2) during the execution of the Use Case. Note that indicates that multiple vehicles within the same area run the same (and potentially additional) Use Case(s) in parallel.

Typical values of maximum vehicle density for different scenarios:
• On highway: 5 000
• On rural road: 9 000
• In city: 12 000

	• Traffic congestion area detected by slowly moving RVs • Adverse weather condition areas detected by temperature changes and wiper activation. • Accident areas detected by air bag deployment events • Slippery road condition areas detected by traction control events • Disabled vehicles detected by hazard lamps or tyre pressure areas • Dangerous curves • Animal on the road • Surface conditions • Obstacle on the road
Goal(s):	Enabling of more intelligent and responsive decision-making by providing real-time situational input data to the HV for timely ingestion and processing.
Actors:	Remote Vehicle (RV) Host Vehicle (HV)
Illustration:	 Note: this image does not originate from the official 5GAA use case; rather, it is included in this document to facilitate a clearer understanding of the use case within the context of NexasSphere.
Technical Requirements:	**Range:** 400m **Data Rate:** Normal size of CAM/BSM may suffice (300B), possibly containing fields indicating common types of critical situations/events. Transmission of detailed object information is currently not foreseen. Standard transmission rate of 10 Hz should be sufficient. **Service Level Latency:** 100 ms **Reliability:** 99%

2.3.3 ATM-UC03: Software Update (Autonomous-Urgent)

UC Title:	**Software Update (Autonomous-Urgent)** **from [20] par. 6.2.1**
Category:	Operation Management
High-Level Description:	The Vehicle Manufacturer or Controlling Authority are capable of publishing over-the-air software updates for one or more ECUs on targeted HVs. Updates can be pushed and/or requested to install features or functionality based on regional or regulatory requirements.
Goal(s):	Deliver over-the-air software updates to targeted vehicles.

Actors:	Host vehicle (HV) Vehicle Manufacturer (OEM) Controlling authority (could be fleet operator, owner / user onboard, etc.) Human driver
Illustration:	 Note: this image does not originate from the official 5GAA use case; rather, it is included in this document to facilitate a clearer understanding of the use case within the context of NexaSphere.
Technical Requirement:	**Range:** Within network service provider coverage **Data Rate:** 3 GB within 2 hours (avg. 3.3 Mbps) **Latency:** 600 ms **Reliability:** 99% **Vehicle Density:** Only a fraction of all vehicles would require a specific software update due to differing vehicle manufacturers, vehicle platforms, on-board equipment, and other factors. E.g. <15 vehicles/ km^2 typically need a specific update at a time. Expected <1% of vehicles would need a specific software update at any given time.

2.3.4 ATM-UC04: See-Through for Passing

UC Title:	**6.3.2 See-Through for Passing** **from [20] par. 6.3.2**
High-Level Description:	A video stream of the RV1 front view is shown to the HV driver when approaching the vehicle with the intentions of initiating a passing maneuver using the oncoming traffic lane.
Goal(s):	The HV is provided with a clear, reliable and real-time view of the road situation in front of the vehicle allowing the driver to avoid a possible collision.
Actors:	• Host Vehicle (HV) • Remote Vehicle 1 (RV1) • Remote Vehicle 2 (RV2) • Remote Vehicle 3 (RV3)

Illustration:	
	Note: this image does not originate from the official 5GAA use case; rather, it is included in this document to facilitate a clearer understanding of the use case within the context of NexaSphere.
Technical Requirement:	**Range:** 100m **Data Rate**: 15Mbps to transmit a progressive high-definition video signal with resolution 1280x720, frame rate 30 Hz, color depth 8 bit, 24 bit resolution, subsampling 4:2:2 and a typical compression of 1:30 (e.g. with H.264). **Latency:** 50ms* **Reliability:** 99% * Additional latency requirements: • The duration of service discovery phase should be in maximum 500 ms (i.e. time duration for HV to identify if RV supports the see-through service). Service discovery includes the communication establishment phase (i.e. receive resources) as well as the discovery request and discovery response messages that HV and RV send, respectively • The see-through establishment phase (i.e. a) HV asks for see-through and b) RV provides the first video frame) should complete within maximum within 500 ms • Service discovery and see-through establishment within 1000 ms will help the driver of the HV to activate the requested see-through service quickly and take a fast decision whether to proceed within the overtake action. This also affects the engagement of the driver with the see-through application • The see-through release phase should be complete within maximum 500 ms

2.3.5 ATM-UC05: In-Vehicle Entertainment (IVE) – High-Definition Content Delivery, On-line Gaming and Virtual Reality

UC Title:	**In-Vehicle Entertainment (IVE) – High-Definition Content Delivery, On-line Gaming and Virtual Reality** **from [21] par. 5.3.6**
High-Level Description:	The Use Case concerns entertainment content delivery to the passengers of a moving or stationary vehicle. It is applicable to both automated and non-automated vehicles, where in the latter the driver is restricted in the content he or she is allowed to consume. For cars, up to four occupants can consume high-definition and immersive entertainment media content while the vehicle is stationary or moving. For buses and transporters up to 30 passengers can consume

	the same content under similar conditions. Each occupant may be interested in different content which may include video, gaming, virtual reality (VR), office work, online education, advertisement, etc. Contextual information can be embedded in the entertainment media depending on the location of the HV.
Goal(s):	Supply and deliver on-demand HD entertainment content to the HV passengers.
Actors:	Host Vehicle, HV owner, Passengers, Service providers (e.g. wireless network operators, road operators, streaming and gaming services, a combination of them, and others).
Illustration:	Note: this image does not originate from the official 5GAA use case; rather, it is included in this document to facilitate a clearer understanding of the use case within the context of NexaSphere.
Technical Requirement:	**Data Rate:** Minimum QoE: 100 Mbps downlink (Two streams of 4k resolution) Goal QoE: 1000Mbps downlink (Four streams of 8 k resolution video with estimated up to 250 Mbps per stream), 40Mbps uplink **Latency:** Minimum QoE: 150 ms Goal QoE: 20 ms **Reliability:** 99% Minimum QoE: 90 % Goal QoE: 99 %

2.3.6 ATM-UC06: Coordinated, Cooperative Driving Maneuver

UC Title:	**Coordinated, Cooperative Driving Manoeuvre from [21] par. 5.4.5**
High-Level Description:	• A main traffic participant wants to perform a certain action (e.g. lane change, exit highway, U-turn, etc.) • Participant shares this intention with other traffic participants potentially involved in the manoeuvre • The traffic participants indicate to the main traffic participant whether they support or plan to decline the planned manoeuvre

	• The main traffic participant informs a superset of the traffic participants informed whether it plans to perform the manoeuvre NB: Assume that every vehicle, on average, might plan on performing a manoeuvre using this use case as a main traffic participant once 1-20 seconds on highways with less traffic.
Goal(s):	The main traffic participant is able to evaluate whether a certain manoeuvre can be performed. Other traffic participants are informed about manoeuvres planned by the main traffic participant.
Actors:	Vehicles.
Illustration:	 Note: this image does not originate from the official 5GAA use case; rather, it is included in this document to facilitate a clearer understanding of the use case within the context of NexaSphere.
Technical Requirement:	**Data Rate*:** 40 kbps per vehicle **Range:** 500m. **Latency:** 80ms. **Service Level Reliability:** 99.9% *The Data Rate KPIs have been calculated using the same 5GAA methodology found in [21] but with different data inputs to better reflect the specific context and purpose of this document.

2.4 Railway Use Cases

2.4.1 RLW-UC01: Joint Terrestrial and Satellite on-board connectivity

UC Title:	Joint Terrestrial and Satellite on-board connectivity
High-Level Description:	Seamless, uninterrupted, high-quality communication for trains by dynamically switching between or simultaneously using TN and NTN networks. This ensures that train operations and services function without disruption, regardless of location, speed, or constraints such as tunnels, rural areas, or degraded modes. The hybrid network serves critical, performance, and business communications, ensuring a resilient, multi-connectivity network for reliable train operations. A key focus is providing uninterrupted connectivity for all railway services, including mission-critical operations, performance applications, and business communications, ensuring ultra-reliable, low-latency connectivity even in high-speed or remote/rural areas.
Goal(s):	• To provide continuous and reliable connectivity for train control, safety applications, and passenger services, ensuring seamless operations even at speeds exceeding 500 km/h. • To enhance mission-critical applications by delivering ultra-reliable, low-latency communication for automation, safety, and remote operations. To support performance and business communications, ensuring high-quality connectivity for crew, maintenance, logistics, and passenger services.
Actors:	Users: • Passengers: Using UE devices (smartphones, laptops) for business and leisure applications. Connectivity may be delivered via on-board Wi-Fi or LiFi, extending access from the TN/NTN hybrid link • Train crew/driver: Equipped with TOBA (Train On-Board Architecture) box / gateway for mission-critical, performance and business applications. • Railway operations and control systems: Managing train operations. • Railway maintenance and infrastructure Teams: Using connectivity for remote diagnostics, predictive maintenance, and monitoring.
Illustration:	

| Preliminary Requirement: | **Service Performance: Compliance with** [22].

Reliability: High availability to ensure seamless operation across TN/NTN.

Latency: Ultra-low latency to support real-time control and automation.

Capacity: Sufficient bandwidth to support multiple concurrent critical, performance, and business applications.

Seamless Handover: Smooth transition between TN and NTN to avoid service disruption.

Preliminary requirements (Contextualised by traffic type)
- Critical traffic
  - Latency: ≤100 ms:
  - Reliability: ≥99.999%
  - Availability: ≥99.999%
  - Data Rate: ≥2 Mbps per TOBA or safety terminal
  - Mobility: Must operate reliably up to 500 km/h
  - Handover: Seamless TN/NTN transition in ≤1.5 seconds without session drop
- Performance Traffic:
  - Latency: ≤500 ms
  - Reliability: ≥99.9%
  - Data Rate: 1–10 Mbps per application stream
  - Resilience: Tolerant to short disruptions, but no data loss
- Business Traffic:
  - Latency: Best effort (non-critical)
  - Reliability: ≥99%
  - Data Rate: ≥100 Mbps aggregate throughput |

	Compliance: These requirements align with 3GPP TS 22.289 v18.0.1 which define performance expectations for mission-critical, performance, and business traffic in mainline and mass transit railway environments.

2.4.2 RLW-UC02: Optimized Mobility Management and Resource Orchestration for High-speed Trains

UC Title:	Optimised Mobility Management and Resource Orchestration for High-speed Trains
High-Level Description:	Using 6G TN/NTN intelligent mobility management to dynamically optimize network resources, ensuring seamless connectivity for high-speed trains. The system leverages predictive analytics and real-time orchestration to anticipate demand variations and pre-allocate resources accordingly, reducing network congestion and improving service quality.
Goal(s):	Utilising 6G TN/NTN AI-driven mobility management to dynamically optimize network resources, ensuring seamless connectivity for high-speed trains. The system leverages predictive analytics and real-time orchestration to anticipate demand variations and pre-allocate resources accordingly, reducing network congestion and improving service quality. Optimise network resource allocation for high-speed train operations. Enhance bandwidth efficiency by dynamically adapting to traffic demand using AI-driven mobility prediction models. Reduce operational costs through real-time network orchestration and automated resource management. Ensure seamless handover and connectivity stability in high-mobility environments, including rural, urban, and cross-border transitions. Use 6G NTN multi-orbit capabilities (LEO, MEO, GEO, and HAPS) to supplement coverage and enhance service continuity.
Actors:	Railway: Leveraging AI-powered data/ analyse for network planning and optimisation. Telecom Providers: managing real-time network orchestration and adaptive mobility strategies. Train Crew/Passengers: Benefiting from seamless, high-quality connectivity for critical and non-critical services.

Illustration:	
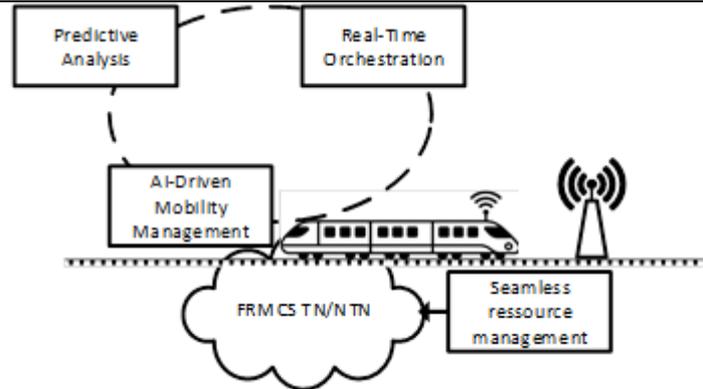
Preliminary Requirements:	Machine learning-based forecasting for demand-aware network adjustments.
	
	• Intelligent mobility handling across TN and NTN.
	• Ultra-low Latency: predictive analytics for near-zero latency decision-making in high-speed environments.
	• Dynamic spectrum management: 6G-based real-time spectrum reconfiguration to optimize efficiency.
	• Multi-Orbit NTN Integration: Adaptive network selection for LEO/MEO/GEO/HAPS to support uninterrupted coverage.
	
	Service Performance: Compliance with [22]**.**
	
	• Reliability: High availability to ensure seamless operation across TN/NTN.
	• Latency: Ultra-low latency to support real-time control and automation.
	• Capacity: Sufficient bandwidth to support multiple concurrent critical, performance, and business applications.
	• Seamless Handover: Smooth transition between TN and NTN to avoid service disruption.
	
	Preliminary requirements (Contextualised by traffic type)
	• Critical traffic
	   o Latency: ≤100 ms:
	   o Reliability: ≥99.999%
	   o Availability: ≥99.999%
	   o Data Rate: ≥2 Mbps per TOBA or safety terminal
	   o Mobility: Must operate reliably up to 500 km/h
	   o Handover: Seamless TN/NTN transition in ≤1.5 seconds without session drop
	• Performance Traffic:
	   o Latency: ≤500 ms
	   o Reliability: ≥99.9%
	   o Data Rate: 1–10 Mbps per application stream
	   o Resilience: Tolerant to short disruptions, but no data loss
	• Business Traffic:

	o Latency: Best effort (non-critical) o Reliability: ≥99% o Data Rate: ≥100 Mbps aggregate throughput Compliance: These requirements align with 3GPP TS 22.289 v18.0.1 which define performance expectations for mission-critical, performance, and business traffic in mainline and mass transit railway environments.

2.4.3 RLW-UC03: Ubiquitous IoT Integration for Railway Monitoring

UC Title:	Ubiquitous IoT Integration for Railway Monitoring
High-Level Description:	Leveraging 6G TN/NTN-enabled IoT to deploy long-life, energy-efficient sensors for real-time railway infrastructure monitoring. By integrating advanced power-saving mechanisms and energy harvesting solutions, IoT devices can operate autonomously for years while ensuring seamless TN/NTN connectivity
Goal(s):	Enable continuous real-time monitoring of railway infrastructure, including track conditions, environmental factors, and train/couch. Extend sensor operational lifespan through optimized power consumption, ultra-low-power protocols, and energy harvesting technologies. Ensure seamless TN/NTN IoT connectivity for un-interrupted data transmission in challenging railway environments. Support predictive maintenance and enhance safety through IoT-enabled AI-driven analytics.
Actors:	Railway undertaking/rolling stock owner & Maintenance teams: using IoT data for real-time track and infrastructure monitoring. Telecom providers & Network operators: Managing energy-efficient IoT communications across 6G TN/NTN.
Illustration:	
Preliminary Requirements:	Low power IoT for long-term monitoring: Ultra-low-energy devices using 6G NTN/TN narrowband IoT (for extended lifespans ~5 years). N assets: Millions (not enough maintainers to maintain it, Energy Harvesting Technologies are needed). N asset density: 2000 asset / km

Multi-Orbit NTN Support: Integration with LEO/MEO/GEO/HAPS satellites for ubiquitous IoT connectivity in remote railway zones.

Preliminary requirements (Contextualised by traffic type)

- Critical traffic
  - Latency: ≤100 ms:
  - Reliability: ≥99.999%
  - Availability: ≥99.999%
  - Data Rate: ≥2 Mbps per TOBA or safety terminal
  - Mobility: Must operate reliably up to 500 km/h
  - Handover: Seamless TN/NTN transition in ≤1.5 seconds without session drop
- Performance Traffic:
  - Latency: ≤500 ms
  - Reliability: ≥99.9%
  - Data Rate: 1–10 Mbps per application stream
  - Resilience: Tolerant to short disruptions, but no data loss
- Business Traffic:
  - Latency: Best effort (non-critical)
  - Reliability: ≥99%
  - Data Rate: ≥100 Mbps aggregate throughput

Compliance: These requirements align with 3GPP TS 22.289 v18.0.1 which define performance expectations for mission-critical, performance, and business traffic in mainline and mass transit railway environments.
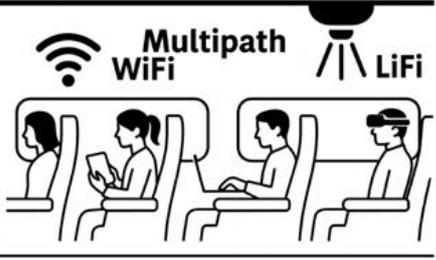
2.4.4 RLW-UC04: Joint Connectivity for User Access to On-board Entertainment

UC Title:	Joint Connectivity for User Access to On-board Entertainment
High-Level Description:	Passenger receives content available on the train (e.g. video/movies) from multiple sources (multilink/multi carrier aggregation) with WiFi and LiFi, via enhanced future passenger-owned devices. LiFi provides a high-speed channel when unobstructed, while WiFi serves as alternative or complementary link. The system dynamically switches between or aggregates multiple links (e.g., using multipath TCP) to optimize content delivery.
Goal(s):	Increase the overall user throughput and ensure uninterrupted content delivery by dynamically utilising one or multiple links based on real-time network conditions, providing optimal performance. Provide new options/flexibility of using alternative frequency bands and wavelengths for various user sub-groups and situations.
Actors:	Passenger using personal devices with support for multi-link connectivity (Wi-Fi and LiFi)

NEXASPHERE 6G

Illustration:	
Preliminary requirements:	Service Availability > 99% DL rate > 10 Mbps per UE UL rate > 2 Mbps per UE For handover to radio links when LiFi is obstructed: <1 sec

3 High-Level System Requirements for NexaSphere

The following high-level requirements are derived from the mobility use cases identified in the aviation, automotive, and railway sectors. While the focus is on Non-Terrestrial Network (NTN) capabilities - reflecting the core scope of NexaSphere - interoperability and integration with future 5G/6G Terrestrial Networks (TN) are also considered to support end-to-end connectivity across heterogeneous infrastructures.

Table 3-1 NexaSphere High-Level Requirements

Requirement ID	Title	Requirement Text
System Requirements		
REQ-SYS-010	Unified TN/NTN Architecture	The NexaSphere System shall integrate Non-Terrestrial Networks (NTN) and Terrestrial Networks (TN) under a unified and standardized architecture.
REQ-SYS-020	NTN European Coverage	The NexaSphere NTN shall achieve 100% coverage of European territory.
REQ-SYS-030	NTN European Availability	The NexaSphere NTN shall provide 99.9% (TBC) service availability across the European territory for end-user connections.
REQ-SYS-040	NTN Global Coverage	The NexaSphere NTN shall achieve 99.9% (TBC) coverage over the full Earth. Note: For aviation use cases
REQ-SYS-050	NTN Global Availability	The NexaSphere NTN shall achieve an availability of 99.99% (TBC) over the full Earth
REQ-SYS-060	RAN Access from legacy devices	The NexaSphere Radio Access Network shall be accessible by Legacy devices (Smartphones and Laptops) Note: In case of non-radio (e.g. wireless optics) Access Network the legacy device might use external peripherals to access the network.

REQ-SYS-070	Multi-Connectivity (TN/NTN) Network Support	Trains and aircrafts within the NexaSphere system shall provide user access via both Terrestrial Networks (TN) and Non-Terrestrial Networks (NTN).
REQ-SYS-080	System Scalability	The NexaSphere System shall be designed to support: -Variable traffic demand in both space and time -A multi-layered space and air segment including GEO, MEO, LEO and HAPS -Interoperability with existing Satellite Systems -Interoperability with Terrestrial Networks (including spectrum sharing and interference coordination) -Regional regulatory compliance
REQ-SYS-090	3GPP interface	The NexaSphere System shall implement 3GPP-compliant interfaces to enable integration with 5G/6G core networks.
REQ-SYS-100	Edge Computing functions	The NexaSphere System shall support deployment of edge computing functions in both TN and NTN segments to reduce latency and optimize data flow.

Service Requirements

REQ-SER-010	Automatic Network Orchestration	The NexaSphere System shall implement automatic functions for network management and orchestration based on dynamic traffic conditions, mobility and QoS requirements. Note: such functions may include predictive models, AI-based algorithms, SDNs, etc.
REQ-SER-020	Seamless TN/NTN Handover	The NexaSphere System shall support unified mobility management (handovers) without service interruption for mobile users between: 1) TN and NTN 2) Multiple elements of the NTN
REQ-SER-030	Multi-Connectivity Network Support	The NexaSphere System shall support mechanisms that allow the integration of existing satellite waveforms for backhauling.

REQ-SER-040	Service Reliability for Critical Services	The NexaSphere System shall provide a reliability no lower than 99.9999% for Railway Critical Services. Note: Railway Critical Services are specified in 3GPP TS 22.289 V18.0.1
REQ-SER-050	Multi-Connectivity (3GPP/non-3GPP) Network Support for User link	The NexaSphere System shall support mechanisms that allow the use of non-3GPP links (WiFi, LiFi) beside the 3GPP compliance links for the user service link.

Performance Requirements

REQ-PER-010	Aviation Applications Performances	The NexaSphere System shall provide connectivity to planes during all their flight phases ensuring the following performances per single plane: -Total DL > 850 Mbps (aggregated) -Total UL > 85 Mbps (aggregated) Service availability > 98% Service interruption due to handover between TN and/or NTN < 1 sec
REQ-PER-020	Non-3GPP fallback connectivity	The NexaSphere System shall be able to provide non-3GPP fallback connectivity (e.g. DVB) to aircrafts ensuring a service interruption due to handover no greater than 1 sec with a service availability greater than 98%
REQ-PER-030	Aviation joint connectivity for on-board entertainment	The NexaSphere System shall be able to deliver on-board entertainment content to users on aircrafts aggregating multiple sources (e.g. WiFi + LiFi) with the following performances per user: -Service Availability > 99% -DL rate > 30 Mbps -UL rate > 10 Mbps -Handover time < 1 sec Note: for aggregated figures assume a total of 450 users, a vehicle load factor of 85% and a take rate of 25%.

REQ-PER-040	Joint Connectivity for Gate data transfer	The NexaSphere System shall be able to transfer content from the airport gate to the aircraft CPE aggregating multiple sources (e.g. WiFi + LiFi) achieving the following performances: -Service Availability > 99% -DL/UL rate (when parked) > 10Gbps -DL/UL rate (when un-parked (taxi, landing, take-off)) > 100Mbps
REQ-PER-060	Resource Optimisation for In-Cabin Access Networks	The IFC of aircrafts shall be able to orchestrate the in-cabin connectivity parameters for direct user access achieving as a minimum: 20% increase in energy efficiency (bit/Joule) compared to existing solutions (target)
REQ-PER-070	Support Connected Automated Passenger Cars in Urban Scenario	The NexaSphere System shall provide vehicle connectivity in Urban scenarios considering the following performance requirements: -Vehicle density: 12000 vehicles/km^2 -UL rate: 16 Mbps per single vehicle -DL rate: 80 Mbps per single vehicle -Vehicle-to-Vehicle Latency: < 20 ms -End-to-End Service Latency: < 100 ms -Reliability: > 95% at 500 m Note: Unless specific traffic models are available, the capture rate in urban scenario can be estimated as 95% from TN and 5% from NTN with a total vehicle density of 12000 vehicles/km2
REQ-PER-080	Automotive Applications Performances in Rural and Suburban Areas	The NexaSphere System shall provide vehicle connectivity in rural and suburban areas ensuring the following performances: -UL rate: 15 Mbps per single vehicle -DL rate: 15 Mbps per single vehicle -Service Latency: < 50 ms -Service Availability > 99.9%

		Note: Unless specific traffic models are available, it can be assumed a vehicle density of 5000 vehicles/km^2 on highways and 9000 vehicles/km2 on rural roads.
REQ-PER-100	Support In-Vehicle Entertainment (IVE)	The NexaSphere System shall provide vehicle connectivity in rural and suburban areas ensuring the following performances: -UL rate: 40 Mbps per single vehicle -DL rate: 100 Mbps per single vehicle (goal 1 Gbps for 4 simultaneous users in a vehicle) -Service Latency: < 150 ms (goal 20 ms) -Service Availability > 90% (goal 99%) Note: Unless specific traffic models are available, it can be assumed a vehicle density of 5000 vehicles/km2 on highways and 9000 vehicles/km2 on rural roads.
REQ-PER-110	Railway Critical Applications Performances	The NexaSphere System shall be able to achieve the following performances for railway critical applications (video/voice/data) per train: -Total DL > 2 Mbps -Total UL > 2 Mbps -Reliability > 99.999% -Availability > 99.999% -Latency < 100 ms (goal 10 ms for very critical traffic) -Handover time < 1.5 seconds without session drop Note: Unless specific traffic models are available, it can be assumed a traffic area density of 1 Gbps/km of rail and a train speed of < 500 km/h
REQ-PER-120	Railway Business and Performance Applications Performances	The NexaSphere System shall be able to achieve the following performances for railway business and performance applications per train: -Total DL > 100 Mbps (aggregated) -Total UL > 100 Mbps (aggregated) -Latency < 500 ms -Reliability > 99.9% Service interruption due to handover: tolerant to short disruptions without data loss

REQ-PER-130	Ultra Low latency decision making for Railway high-speed environments	The NexaSphere System shall be able to manage and orchestrate the traffic using predictive models based on railway historical data to achieve ultra-low latency decision making in high-speed environments.
REQ-PER-140	Ubiquitous IOT Integration	The NexaSphere System shall provide IOT communication services to railway trackside assets assuming: IOT device density: > 2000/km of track IOT autonomous lifespan: > 5 years (goal)
REQ-PER-150	Railway joint connectivity for on-board entertainment	The NexaSphere System shall be able to deliver on-board entertainment content to users on trains aggregating multiple sources (e.g. WiFi + LiFi) with the following performances: Service Availability > 99% DL rate > 10 Mbps UL rate > 2 Mbps Handover time < 1 sec Note: for aggregated figures assume a total of 450 users, a vehicle load factor of 85% and a take rate of 25%.

4 Key Performance Indicators (KPIs)

The Key Performance Indicators (KPIs) collected and summarized across aviation, rail and automotive domains provide a quantitative baseline to assess the technical performance, feasibility, and value generation potential of the NexaSphere platform. This preliminary KPI definition plays a key role in evaluating the system's capability to deliver high-performance and socio-economically impactful outcomes across multiple mobility sectors.

These KPIs will serve two main purposes:

- Technical Benchmarking: Assess performance with respect to latency, data rates, reliability, availability, and resource efficiency.
- Socio-Economic Translation: Quantify downstream impacts such as safety enhancement, carbon footprint reduction, energy savings, improved passenger experience, and cost efficiency.

4.1 Aviation Domain

Aviation KPIs focus on seamless connectivity, high availability and bandwidth aggregation across terrestrial and satellite networks. Use cases such as in-flight passenger connectivity, entertainment delivery, and gate data transfer emphasize the importance of uninterrupted service across multiple orbits (LEO/MEO/GEO) and access types (3GPP, non-3GPP, WiFi, LiFi).

> **Impact**:
>
> o **Passenger Experience**: Improved in-flight services (e.g., video streaming, real-time communication) directly affect customer satisfaction and airline differentiation.
> o **Operational Efficiency**: Fast gate data offloading and remote updates support digital aircraft operations, reducing turnaround time and costs.
> o **Energy & Cost Optimisation**: KPIs on energy efficiency and model-driven resource usage will be mapped to reduced operational carbon intensity.

In the second phase, these KPIs will support cost-benefit models relating communication infrastructure upgrades to reductions in operational costs and carbon footprint.

Following the analysis presented in 2.22.2, Table 4-1Table 4-1 summarizes the current KPI definitions for the aviation domain. These indicators reflect the technical performance requirements for ensuring seamless, high-availability connectivity across terrestrial and satellite networks, supporting both passenger services and critical aircraft operations.

Table 4-1 KPIs for Aviation Use Cases

Use Case	KPI Name	Unit	Value	Notes
General Aviation NTN Connectivity	Data Rate	Mbps	High-data-rate (LEO)	Depends on use case: onboard, UAM, high-data-rate comm

General Aviation NTN Connectivity	Latency	ms	~100	Depends on application (passenger, crew, etc.)
General Aviation NTN Connectivity	Reliability	%	>99.9	
AVT-UC01: Terrestrial & Satellite In-Flight Connectivity	Service Availability	%	>98	
AVT-UC01: Terrestrial & Satellite In-Flight Connectivity	Service Interruption	s	<1	During TN-NTN handover
AVT-UC01: Terrestrial & Satellite In-Flight Connectivity	DL Rate per Passenger	Mbps	>3	
AVT-UC01: Terrestrial & Satellite In-Flight Connectivity	UL Rate per Passenger	Mbps	>0.3	
AVT-UC01: Terrestrial & Satellite In-Flight Connectivity	Total DL Rate per Plane	Mbps	>850	
AVT-UC01: Terrestrial & Satellite In-Flight Connectivity	Total UL Rate per Plane	Mbps	>85	
AVT-UC02: Integration 3GPP & Non-3GPP	Service Interruption	ms	<1	Switching between access types
AVT-UC02: Integration 3GPP & Non-3GPP	Service Availability	%	>98	
AVT-UC02: Integration 3GPP & Non-3GPP	Data Rate	Mbps	~850 DL / 85 UL	Same as AVT-UC01
AVT-UC03: In-Flight Entertainment	Service Availability	%	>99	
AVT-UC03: In-Flight Entertainment	DL Rate per UE	Mbps	>30	4K video
AVT-UC03: In-Flight Entertainment	UL Rate per UE	Mbps	>10	
AVT-UC03: In-Flight Entertainment	Aggregated DL	Gbps	2.8	
AVT-UC03: In-Flight Entertainment	Handover Duration	s	<1	Between RAN technologies
AVT-UC04: Gate Data Transfer	Service Availability	%	>99	
AVT-UC04: Gate Data Transfer	DL/UL Rate (Parked)	Gbps	>10	
AVT-UC04: Gate Data Transfer	DL/UL Rate (Taxi etc.)	Mbps	>100	
AVT-UC05: In-Cabin Optimisation	Energy Efficiency Increase	%	>20	Bit/Joule improvement

4.2 Automotive Domain

KPIs in the automotive domain target V2X communication performance, cooperative maneuvering, automated software updates, and infotainment delivery. These indicators reflect stringent technical requirements due to the decentralized, dynamic, and highly mobile nature of road traffic systems.

> **Impact**:
>
> - o **Traffic Safety**: Low-latency and high-reliability KPIs are critical to prevent collisions via hazard warnings and cooperative driving.
>
> - o **Automation Readiness**: Data rate and reliability for sensor sharing and see-through enable real-time vehicle coordination—essential for SAE Level 4 systems.
>
> - o **Digital Services**: High-throughput and low-latency connectivity supports new in-vehicle digital ecosystems (entertainment, education, VR).

In later stages, these KPIs will be input into **societal impact models**, including:

- Reduced road fatalities and injuries (monetized via statistical life valuation)
- Decreased traffic congestion and CO_2 emissions
- Market uptake models for connected and autonomous vehicles

Following the analysis presented in 2.32.3, Table 4-2Table 4-2 summarizes the current KPI definitions per domain and use case. These KPIs reflect the technical performance targets that are essential for the implementation and evaluation of NexaSphere technologies across aviation, rail, and automotive sectors.

Table 4-2 KPIs for Automotive Use Cases

Use Case	KPI Name	Unit	Value	Notes
ATM-UC01: Urban Connected Cars	Data Rate	Mbps	16-80	V2V uplink/downlink
ATM-UC01: Urban Connected Cars	Latency	ms	<10-20	Direct V2V comm
ATM-UC02: Hazardous Location Warning	Latency	ms	100	For warning broadcast
ATM-UC02: Hazardous Location Warning	Reliability	%	99	
ATM-UC03: Software Update	Data Rate	Mbps	3.3	3GB in 2 hours
ATM-UC04: See-Through	Data Rate	Mbps	15	Video stream
ATM-UC04: See-Through	Latency	ms	50	Video transmission
ATM-UC05: In-Vehicle Entertainment	Data Rate	Mbps	100 DL / 40 UL	HD/VR content

ATM-UC06: Cooperative Maneuver	Data Rate	kbps	40	Context-dependent
ATM-UC06: Cooperative Maneuver	Latency	ms	80	

4.3 Railway Domain

KPIs in the rail sector emphasize ultra-reliable low-latency communication (URLLC), seamless mobility at high speeds, and energy-efficient IoT integration. Applications span mission-critical train operations, predictive maintenance and passenger infotainment.

Impact:

- o **Safety & Automation**: Latency and reliability KPIs are tied to the safety integrity level (SIL) and continuity of ETCS/ATO systems.

- o **Infrastructure Maintenance**: Long-lifetime IoT and high asset density support cost-effective remote monitoring, reducing service disruptions.

- o **Passenger Satisfaction**: Improved bandwidth and availability boost the quality of business and leisure applications onboard.

These KPIs will be used to model risk reduction, OPEX savings, and service-level improvements, crucial for understanding the return on investment (ROI) in public and private rail infrastructure. These indicators focus on ultra-reliable, low-latency communication and continuous connectivity for high-speed rail operations, infrastructure monitoring, and onboard passenger services, aligned with the FRMCS vision.

Following the analysis presented in 2.42.4 Table 4-3Table 4-3 summarizes the current KPI definitions for the railway domain.

Table 4-3 KPIs for Railway Use Cases

Use Case	KPI Name	Unit	Value	Notes
ETCS / ATO Safety Communications	Latency	ms	<100 (goal 10)	Mission-critical, near real-time
ETCS / ATO Safety Communications	Reliability	%	>99.999	Ultra-high reliability for safety
Passenger Services	Data Rate	Mbps	100+	Sliced services with high throughput
Infrastructure Monitoring	Latency	ms	<500	Moderate latency for performance-class bearers
RLW-UC01: Terrestrial & Satellite On-board Connectivity	Reliability	%	99.9	Seamless operation across TN/NTN

RLW-UC01: Terrestrial & Satellite On-board Connectivity	Latency	ms	<100	For real-time control and automation
RLW-UC01: Terrestrial & Satellite On-board Connectivity	Seamless Handover	s	<1.5	TN <-> NTN without session drop
RLW-UC01: Terrestrial & Satellite On-board Connectivity	Capacity	Mbps	100+	For business traffic, 2 Mbps min. for Critical traffic
RLW-UC02: Optimized Mobility & Resource Orchestration	Latency	ms	Ultra-low	For AI-based prediction and orchestration
RLW-UC02: Optimized Mobility & Resource Orchestration	Resource Allocation Efficiency	%	Optimized	Using AI/ML and spectrum reallocation
RLW-UC02: Optimized Mobility & Resource Orchestration	Mobility Management	qualitative	Predictive based on train traffic	Adaptive for TN/NTN
RLW-UC03: Ubiquitous IoT Monitoring	Device Lifespan	years	~5	Reduce maintenance and operation cost
RLW-UC03: Ubiquitous IoT Monitoring	Asset Density	assets/km	2000	
RLW-UC03: Ubiquitous IoT Monitoring	Connectivity	qualitative	Seamless TN/NTN	Multi-orbit support
RLW-UC04: On-board Entertainment	Service Availability	%	>99	
RLW-UC04: On-board Entertainment	DL Rate per UE	Mbps	>10	
RLW-UC04: On-board Entertainment	UL Rate per UE	Mbps	>2	
RLW-UC04: On-board Entertainment	Handover Time	s	<1	From LiFi to other radio links

5 Conclusion

This document sets the basis for the NexaSphere system architecture providing use cases and requirements that need to be considered for the overall system development.

The state-of-the-art section provides an overview of 5G Non-Terrestrial Networks (NTN), with particular attention to 3GPP standards and mobility use cases.

The Use Cases section contains the list of most important NexaSphere mobility applications for the three verticals of Aviation, Automotive and Railway. Such use cases have been developed looking at the present and future market needs.

The Use Cases have been then consolidated to derive the High-Level Requirements, for which it is evident a need for high throughput, low latency, high availability systems.

Finally, these requirements served as the foundation for defining preliminary technical KPIs, which are paramount to guide the design of the NexaSphere system architecture in the next work packages.

To conclude, this document provides a comprehensive baseline of the use cases, requirements, and KPIs that the NexaSphere project team can utilize to design and develop the NexaSphere overall system and its components.

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7 ANNEX A – List of Abbreviations

For the purposes of this document the acronyms and abbreviations defined hereafter apply.

Abbreviation or Acronym	Meaning
3GPP	Third-Generation Partnership Project
5GAA	5G Automotive Association
ATO	Automatic Train Operation
AV	Automated Vehicle
CEPT	European Conference of Postal and Telecommunications Administrations
CPE	Customer Provided Equipment
C-V2X	Cellular Vehicle-to-Everything Communication
DL	Downlink
DSRC	Dedicated Short-Range Communication
eMBB	enhanced Mobile Broadband
ETCS	European Train Control System
ETSI	European Telecommunication Standards Institute
EU	European Union
FDD	Frequency Division Duplex
FR	Frequency Range
FRMCS	Future Railway Mobile Communication System
gNB	Next Generation NodeB
GNSS	Global Navigation Satellite Systems
GSM-R	Global System for Mobile Communications – Railway
HARQ	Hybrid Automatic Repeat Request
HD	High Definition
HV	Host Vehicle
IFE	In-Flight Entertainment
IP	Internet Protocol
ITS	Intelligent Transportation Systems
ITU	International Telecommunication Union

JU	Joint-Undertaking
KPI	Key Performance Parameter
LEO	Low Earth Orbit
LO	Local Oscillator
LTE	Long Term Evolution
MAC	Medium Access Control Sublayer of the OSI model
MEO	Medium Earth Orbit
mMTC	massive Machine Type Communications
MNO	Mobile Network Operator
MR	Medium Range
N/A	Not applicable
NGSO	Non-Geo Stationary Orbit
NOC	Network Operation Center
NR	5G New Radio
NTN	Non-Terrestrial Network
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
ORAN/O-RAN	Open Radio Access Network
OS	Operating System
OSI	Open System Interconnections
PDN	Public Data Network
PHY	Physical Layer of the OSI model
PNT	Position Navigation Timing
PRB	Physical Resource Blocks
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RedCap	Reduced Capability
RF	Radio Frequency

RRC	Radio Resource Control	
RRU	Radio Remote Unit	
RTT	Round-Trip Time	
SA (5G)	Standalone	
SatCom	Satellite Communications	
SDN	Software-Defined Network	
SNS	Smart and Network Services	
SW	Software	
TBC	To be confirmed	
TBD	To be defined	
TN	Terrestrial Network	
ToD	Tele-operated Driving	
TR	Technical Report	
TRL	Technology Readiness Level	
UL	Uplink	
uRLCC	ultra-Reliable Low latency Communications	
V2I	Vehicle-to-Infrastructure Communication	
V2N	Vehicle-to-Network Communication	
V2P	Vehicle-to-Pedestrian Communication	
V2V	Vehicle-to-Vehicle Communication	
V2X	Vehicle-to-Everything Communication	
VIN	Vehicle Identification Number	
VRU	Vulnerable Road User	
WG	Working Group	
WP	Work Package	

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