6G-INTEGRATION-04-E24: Analysis report regarding needs and requirements for implementing the NPI-NTN

6G-INTEGRATION

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Executive Summary

This document contains the requirements for the subproject 6G-INTEGRATION-04 to simulate an onboard B5G system in non-terrestrial networks included HAPS.

The project will investigate and develop the following use case: (i) radio channel simulation of an onboarded B5G system using Amarisoft technology.

The development of these use cases must fulfill common requirements (general requirements) as well as specific requirements for each use case. This document provides with detailed explanations of both.

The final part of the document covers the project roadmap and the risk analysis.

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Resumen ejecutivo

Este documento continue los requisitos del subproyecto 6G-INTEGRATION-04 cuyo objetivo es simular un sistema B5G a bordo en redes no terrestres, incluyendo plataformas de gran altitud (HAPS).

El proyecto investigará y desarrollará los siguientes casos de uso: (i) simulación del canal radio de un sistema B5G a bordo de una plataforma HAPS utilizando la tecnología de Amarisoft.

El desarrollo de estos casos de uso debe cumplir con requisitos comunes (requisitos generales) y otros específicos para cada caso de uso. Este documento contiene una explicación detallada de ambos.

La última parte del documento cubre la hoja de ruta del proyecto y el análisis de riesgos.

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Glossary

3GPP	3rd Generation Partnership Project
5G	5th Generation technology standard for cellular networks
5GC	5G Core
5GS	5G System
AMF	Access and Mobility Management Function
AUSF	Authentication Server Function
B5G	Beyond 5G
CSP	Communication Service Providers
GEO	Geostationary Orbit
HAP	High Altitude Platform
LEO	Low Earth Orbit
MEO	Medium Earth Orbit
NPN	Non-Public Network
NRF	Network Repository Function
NSSF	Network Slice Selection Function
NTN	Non-Terrestrial Network
PCF	Policy Control Function
PNI-NPN	Public Network Integrated – Non-Public Network
SMF	Session Management Function
TCP	Transport Control Protocol
UE	User Equipment
UDM	Unified Data Management
UDR	Unified Data Repository

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UPF	User Plane Function

1 Overview of General Concepts

The evolution towards Beyond 5G (B5G) networks, which encompasses advancements beyond 5G 3GPP Rel16 technology, underscores the seamless integration of Non-Terrestrial Networks (NTN) with terrestrial infrastructures, including satellites and High-Altitude Platforms (HAPs). This integration is pivotal for extending connectivity to remote areas and enhancing network capacity and coverage. The 3rd Generation Partnership Project (3GPP) has been instrumental in driving these advancements. In Release 17 (R17), 3GPP has laid down specifications for incorporating NTN elements into 5G networks, thereby facilitating the realization of B5G networks.

The environment where the tests will be conducted is that of a 5G Non-Public Network (NPN) fully-equipped system deployed by Ericsson at the 5tonic [9] laboratory, located at IMDEA Networks Institute [8] premises.

In the following sections, the NTN segment will be introduced, highlighting its fundamental capabilities, and exploring the integration of NTN into a 3GPP R17 network with its reference architecture.

1.1 NTN Segment

Non-Terrestrial Networks (NTN) encompass satellites and High-Altitude Platforms (HAPs). Satellites operate in various orbits such as Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Orbit (GEO). These satellites are vital for providing wide-area coverage, particularly in remote and underserved regions. They facilitate a variety of applications, including broadband internet and IoT connectivity, offering a global reach that terrestrial networks cannot match.

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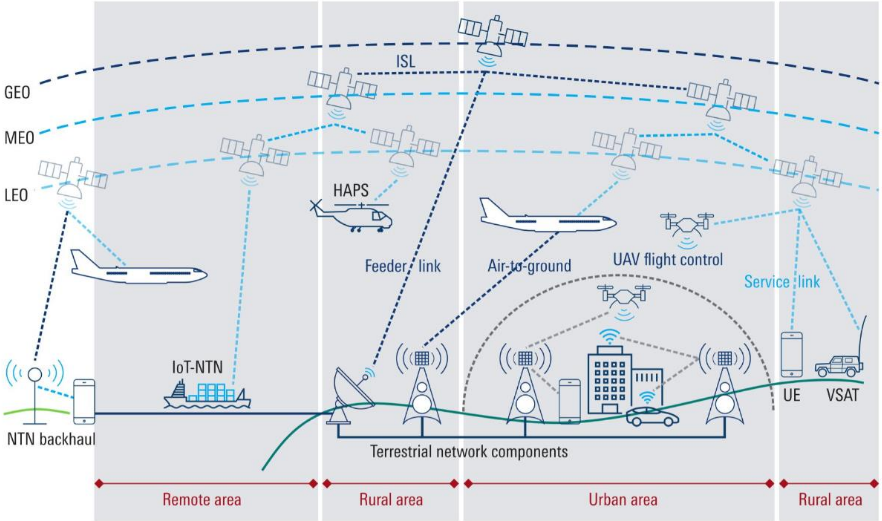

Figure 1 Non-Terrestrial Network General Scheme [5]

HAPs, situated in the stratosphere, can provide high-capacity, localized coverage. These platforms act as relay stations, enhancing telecommunications by providing stable connections that complement satellite coverage. HAPs are especially beneficial in disaster recovery scenarios and for strengthening network resilience in areas with difficult terrain or sparse infrastructure.

Integrating NTN into existing network infrastructures involves overcoming several technical challenges, such as managing the high Doppler shifts and signal delays characteristic of satellite communication, ensuring continuous service during transitions between terrestrial and non-terrestrial networks, and optimizing frequency usage to prevent interference. This integration enhances the reliability and reach of network services, ensuring consistent connectivity even in the most remote and challenging environments [1] [2].

1.2 NTN into a 3GPP R17 Network

The integration of Non-Terrestrial Networks (NTN) into the 3GPP ecosystem, particularly within the scope of 5G, introduces new architectures where elements such as High-Altitude Platform Stations (HAPS) host radio access nodes (gNBs) directly on board, delivering coverage over wide geographical areas. 3GPP Release 17 (R17) provides specifications that enable this integration, allowing 5G base stations to operate from stratospheric platforms.

This approach aims to extend 5G coverage beyond the limitations of terrestrial infrastructure by enabling user equipment (UE) to connect directly to a gNB mounted on a HAPS. These airborne gNBs can operate within either public or non-public networks (NPN) and interface with the 5G Core (5GC) via appropriate connectivity mechanisms, making it possible to provide full 5G service in remote, underserved, or infrastructure-limited regions.

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This architecture supports several relevant use cases, including:

1. **Enhanced Mobile Broadband (eMBB):** Delivering 5G access in areas lacking terrestrial coverage and to users in motion, such as vehicles or rural populations.

2. **IoT Connectivity**: Supporting large-scale device communication over wide and hard-to-reach areas.

3. **Disaster Recovery**: Rapidly deploying network services in emergency or post-disaster scenarios.

4. **Public Safety**: Enabling reliable, wide-area communication for emergency response agencies with high availability.

Deploying gNBs onboard HAPS platforms represents a significant advancement toward achieving truly ubiquitous and resilient 5G coverage. It expands the reach of modern mobile networks and unlocks new possibilities for delivering advanced connectivity worldwide.

1.2.1 Reference Architecture

The provided diagram illustrates the reference architecture considered.

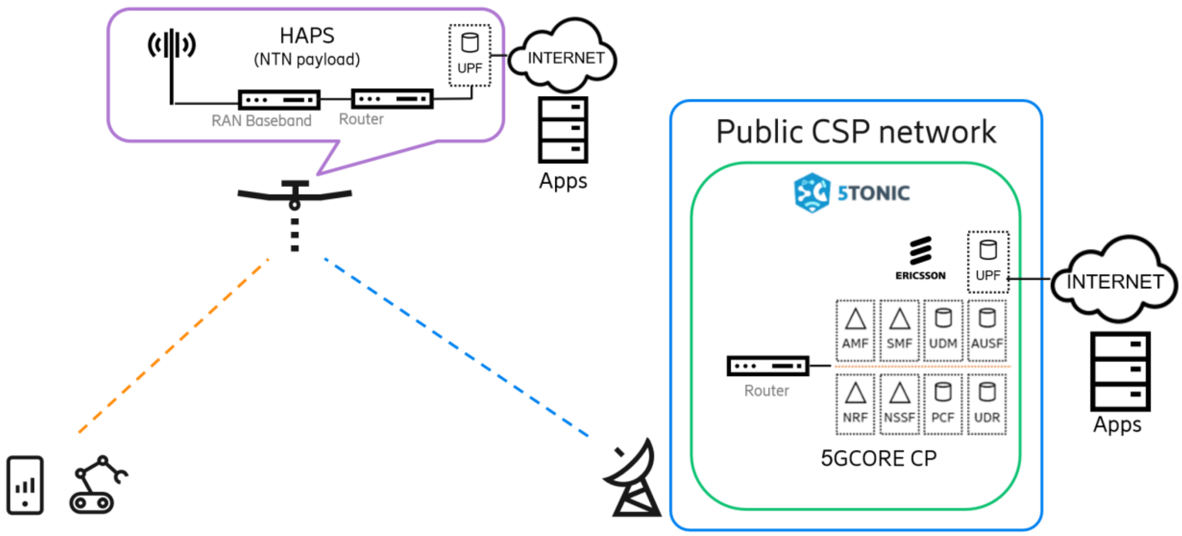

Figure 2 5G RAN on-board a HAPS

The diagram provides a case of non-public network deployment, where an industrial use case is served through the local deployment of the radio access network (RAN) and the user plane

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function (UPF) which are on-board a HAPS, while the public network provides the service for the rest of the 5G core.

1.2.1.1 Key Components:

- **HAPS:**

RAN Baseband: This component handles the radio access network processing. It interfaces with the router and is responsible for managing the radio signals received from and transmitted to the user equipment (UE).

Router: Connects the RAN Baseband to the satellite communication system. It facilitates the routing of data packets to and from the RAN Baseband.

UPF (User Plane Function): Handles data traffic routing and forwarding. It interfaces with the internet for local data traffic and the router for data requiring backhaul.

- **Public CSP Network:**

The Public CSP Network serves as a bridge to connect users to the private 5G Core Network. It includes several critical components and functions within its 5G Core Network (5GC), which can be divided into the Control Plane (CP) and User Plane (UP).

- Control Plane (CP) Functions:
  - AMF (Access and Mobility Management Function): Manages connection and mobility aspects, handling user registration, connection setup, and mobility.
  - SMF (Session Management Function): Manages session contexts and configurations, establishing and maintaining user sessions.
  - UDM (Unified Data Management): Manages subscription data, storing user profiles, and authentication information.
  - AUSF (Authentication Server Function): Handles authentication, verifying user credentials and ensuring secure access.
  - NRF (Network Repository Function): Stores and manages NF (Network Function) profiles, facilitating service discovery and interaction between network functions.
  - NSSF (Network Slice Selection Function): Handles network slice selection, enabling differentiated service levels by directing traffic to appropriate network slices.
  - PCF (Policy Control Function): Manages policy decisions, enforcing rules for QoS (Quality of Service), resource allocation, and service access.
  - UDR (Unified Data Repository): Stores structured data used by various network functions for operations like subscriber management, policy control, and session management.

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- User Plane (UP) Functions:

    - UPF (User Plane Function): Handles data traffic routing and forwarding, interfacing with the internet and the 5G Core Network. It manages packet forwarding, QoS enforcement, and traffic shaping.

1.2.1.2 Data Flow and Interactions

- **User Equipment (UE) Connectivity:**

  The UE connects to the HAPS´s RAN Baseband, which processes the radio signals and forwards data packets to the router.

- **Backhaul Connectivity:**

  The router installed in the HAPS payload makes use of the HAPS communication services to set up a secure tunnel with the 5TONIC site router, enabling end-to-end backhaul connectivity

- **Integration with 5G Core Network:**

  The 5G Core network processes these packets, manages session and mobility, applies policies, and routes the data appropriately, either towards the internet or other parts of the network.

- **Service Continuity and Coverage:**

  By hosting the gNB directly onboard the HAPS, 5G radio access can be delivered to remote or underserved areas without relying on terrestrial infrastructure. This configuration ensures continuous service availability and extended coverage, enabling users in isolated regions to access reliable 5G connectivity seamlessly.

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2 Use cases

Here we will explore the specific use case that illustrates practical applications of integrating Non-Terrestrial Networks (NTN).

The testing environment will be set up using Ericsson's 5G infrastructure deployed at the 5Tonic laboratory. The radio channel of a gNB located on a HAPS (High-Altitude Platform Station), is emulated using the Amarisoft infrastructure and the actual Flamingo gNB physically deployed in lab.

2.1 Use case: r*adio channel simulation of an onboard B5G system using Amarisoft technology*

2.1.1 Objective

The objective of this use case is to demonstrate the capability of an onboard Beyond 5G (B5G) system—leveraging Amarisoft support—to efficiently emulate and manage radio channels under realistic propagation conditions. This use case aims to assess the resilience and adaptability of the system in a non-terrestrial environment, such as a gNB deployed on a high-altitude platform station (HAPS), using the advanced channel simulation techniques provided by Amarisoft. By evaluating system performance through precise radio channel modeling, the project seeks to validate the integration of B5G solutions with novel communication infrastructures, ensuring robust service delivery in scenarios where traditional terrestrial links are impractical.

2.1.2 Scenario

In this scenario, all 5G components are deployed in 5Tonic lab. The setup also includes an Amarisoft CPE representing the user terminal and Flamingo gNB configured to operate as if it were deployed onboard a High-Altitude Platform Station (HAPS). Although physically located in the lab, the gNB is treated and behaving as airborne for the purposes of the emulation.

Amarisoft's platform is used to emulate the radio channel between the CPE and the actual gNB, accurately modeling the propagation conditions expected in a HAPS-to-ground scenario.

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This includes effects such as path loss, latency, and Doppler shift, enabling realistic evaluation of the radio link performance under non-terrestrial conditions.

2.1.3 Setup

The setup is described in the following points:

- Amarisoft CPE is connected to 5G SA network.
- Amarisoft platform emulates the channel radio conditions
- Flamingo gNB operates as onboard on HAPS.

2.1.4 Experimentation

The following tests can be conducted:

- **Throughput UL**: Measure the upload throughput at the network edge and core to compare performance.
- **Latency**: Evaluate network latency to ensure that the HAPS infrastructure does not introduce significant delays.
- **Timing Advance (TA) Measurement**: Record and analyze Timing Advance (TA) values reported by the gNB. These values provide an estimate of the simulated UE distance from the gNB and can be used to approximate the user location within the emulated environment.
- **Signal-to-Noise Ratio (SNR)**:
  Collect SNR values during the tests to monitor radio link quality and correlate signal conditions with network performance.
- **Modulation and Coding Scheme (MCS):**
  Track the MCS levels assigned by the gNB to evaluate how modulation and coding adapt to varying radio conditions.
- **Reference Signal Received Power (RSRP)**:
  Measure RSRP to assess the received signal strength at the UE and its impact on connectivity and throughput.

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3 Requirements analysis

Requirements have been exposed and described in two areas:

- "General" that define the requirements that needs to be accomplished to implement initial system and will be the base for the use case.

- "Based on use case" that describe the specific requirements that needs to be complied to achieve the use case.

3.1 General

This section describes general requirements that are the base of the PNI-NTN implementation and will be the system base for the whole project.

3.1.1 Requirement-G-01: 5G NPN Portable System

The first requirement is the implementation based in a 5G Non-Public Network (NPN) Portable System that is connected to 5TONIC network. This solution scenario is known as "Shared Radio access network and control plane" within "NPN network in conjunction with public network" as described in [6].

NPN Portable system requires the following elements:

- **Flight rack**: A portable container used as RACK for installation of Physical Twin elements.
- **Radio Access Network (RAN) Elements:**

  - Monitor terminal: User Equipment (UE) or Customer Premises Equipment (CPE) used to monitor the network End-to-End (E2E).
  - Radio Equipment and Antenna: Radio access point of the NPN Portable System.
  - 5G Node B (gNB): Base Station that processes the Radio signal of the NPN Portable System.
  - IP RAN: Router used in transport network between RAN and CORE elements.

- **Core Network Elements:**

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   - User Plane Function (UPF) handles the payload traffic from the NPN Portable System.

This architecture is 3GPP R17 compliant and could also be updated with the latest software available.

3.1.2 Requirement-G-02: Amarisoft-Based UE and Channel Emulation Platform

This requirement addresses the integration of an Amarisoft-based emulation platform to support the testing and validation of a 5G gNB hosted in a portable system. The Amarisoft system shall provide both UE emulation and radio channel simulation and will be used in conjunction with an existing physical 5G base station (gNB) installed in 5TONIC lab.

➢ **Amari UE Simbox E Series**

The Amari UE Simbox E Series is a compact and high-performance solution designed for testing small cell gNBs. It allows emulation of multiple LTE, LTE-M, NB-IoT and 5G NR (SA/NSA/NTN/RedCap) UEs simultaneously within the same spectrum, and supports a wide variety of use cases [3]:

- Support for up to 256 concurrent UEs, depending on the selected model (001, 064, 128, or 256).
- 5G Standalone (SA), 5G Non-Standalone (NSA) and 5G NTN (Non-Terrestrial Network) supported.
- Carrier Aggregation in both LTE and NR FR1 for high-throughput testing.
- VoLTE and VoNR support, through Simnovus integration.
- Integrated traffic generator with support for TCP, UDP, HTTP flows.
- Full-featured WebSocket API for automation, scripting, and remote control.
- Customizable UE profiles: IMSI, APN, IP, mobility, QoS, etc.
- Advanced channel simulation modifying PDSCH/PDCCH performance and uplink levels based on configured path loss and radio conditions.

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3.1.3 Requirement-G-03: Probes deployed in different parts of network

Test and validations require the implementation of measuement tools and we will used Software probes. The software probe is a component that extracts actual KPIs from the end-user traffic with the granularity of flow for IP traffic as it was defined in [7]. A flow is identified by a tuple of origin IP address, destination IP address, origin Port, destination Port, type of protocol.

The software probe needs to be deployed in an independent system that receives a copy of the application traffic, using port mirroring in different interfaces of the network:

- Interface N3: To access the traffic between RAN and UPF.
- Interface N6: To access the traffic between UPF and Application.

3.2 Based on use cases

This section contains specific requirements for each use case. To check and implement the activities of these requirements, general ones must be fulfilled first.

3.2.1 Requirement-UC-01

Objective is to simulate the radio propagation conditions between a terrestrial CPE (Amarisoft UE) and a gNB assumed to be located onboard a High-Altitude Platform Station (HAPS), using Amarisoft's technology and channel emulation capabilities. Although both the gNB and the CPE are physically located in the 5TONIC lab, the simulation accurately reflects the behavior of a B5G radio link under NTN-HAPS scenarios.

3.2.1.1 Functional requirements

- **Channel Emulation Enabled**
  The Amarisoft setup must support activation of channel_sim = true, allowing the injection of realistic channel effects between the CPE and the gNB.

- **Real Antenna Usage**
  The CPE and gNB shall use real antennas in the laboratory environment, ensuring interaction with the simulated channel through actual RF interfaces.

- **Support for Multiple Channel Profiles**

  - **TDLA** for open urban scenarios with reduced mobility.
  - **TDLB** for dense urban environments with higher mobility dynamics.

- **Parametrization of Channel Models**
  The radio channel simulation is driven by a set of configurable parameters that mimic HAPS-ground propagation characteristics. These are:

- **max_distance (15 km):** Maximum simulated distance between CPE and gNB, constrained by 5G TDD frame and synchronization limits.
- **min_distance (12 km):** Minimum altitude consistent with HAPS operation above commercial air traffic zones.
- **noise_spd (-174 dBm/Hz):** Standard thermal noise power spectral density. Combined with a 100 MHz bandwidth, it defines the overall noise floor (~-94 dBm).
- **position, direction, speed:** Simulates movement using GPS-like parameters, supporting dynamic mobility scenarios.
- **freq_doppler:** Simulates Doppler effect due to mobility:
  - **10 Hz** for **TDLA** model (low mobility, open urban environment),
  - **100 Hz** for **TDLB** model (higher mobility, dense urban scenario).
- **mimo_correlation:** Describes the spatial correlation between antennas:
  - **"medium"** for TDLA (moderate diversity),
  - **"high"** for TDLB (reduced diversity due to similar propagation paths).
- **A, B coefficients (10.9 or 12.2):** Channel profile shaping factors based on 3GPP TDL models.
- **delay_spread:** Indicates the range of arrival times of multipath components:
  - **20 ns** for TDLA (fewer, well-separated paths),
  - **100 ns** for TDLB (more dense multipath environment).

3.2.1.2 Measurement & Validation Requirements

- **Real-time Logging and KPIs**
  The system must capture and log in real time the following Key Performance Indicators (KPIs), which will be used to assess the performance of the simulated HAPS radio link:
  - **Timing Advance (TA):** To estimate the propagation delay and validate the simulated gNB-to-UE distance.
  - **Signal-to-Noise Ratio (SNR):** To evaluate the link quality under varying noise and interference levels.
  - **Reference Signal Received Power (RSRP):** To measure the strength of the received signal and ensure appropriate coverage simulation.

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- **Modulation and Coding Scheme (MCS):** To monitor the link adaptation behavior under different simulated channel conditions.
- **Throughput (DL/UL):** To assess the effective data rates achieved by the UE during the simulation.
- **Latency:** To measure end-to-end delay introduced by the radio link and processing, and ensure compliance with B5G requirements.

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4 Risk analysis

Below, the identified risks are described, along with possible mitigation actions.

4.1 R01: Hardware supply chain

Currently, hardware equipment is affected by delayed delivery times, typically between 6 and 18 months, impacting especially networking equipment. Ericsson takes this situation into account when planning installations at 5Tonic. To mitigate this issue, Ericsson has a certain stock of equipment that can be used temporarily while the final ordered products arrive.

4.2 R02: HAPS-based system simulation

For the use case experimentation defined in this proposal, it is assumed that Amarisoft technology will be used to simulate the radio link between a user terminal (CPE) and a gNB configured to operate as if it were installed onboard a High-Altitude Platform Station (HAPS).

The simulation environment will replicate the key propagation characteristics expected in a HAPS-to-ground scenario, such as Doppler shift, delay spread, path loss, and MIMO correlation. These aspects will be configured according to standard channel models (e.g., TDLA, TDLB) and managed by team. All components are physically deployed in the lab, but the system will be treated as a representative model of an airborne 5G node to validate radio channel behavior in non-terrestrial conditions.

4.3 R03: Test Device Compatibility

The test device, represented by the Amarisoft CPE, must support the 5G NR functionalities required for proper interaction with the gNB, including uplink/downlink synchronization, appropriate numerology, and mobility support. It must also be compatible with the simulated radio channel conditions emulated by the Amarisoft platform (e.g., delay spread, Doppler shift, and MIMO correlation).
To ensure reliable execution of the use case, the device configuration will be validated in advance, and Amarisoft tools will be used to adjust parameters in real time as needed to maintain interoperability and stable performance.

4.4 R04: Timing Advance and Uplink Synchronization Constraints

In a simulated HAPS scenario, the distance between the user terminal (CPE) and the gNB affects the Timing Advance (TA) mechanism, which is critical for uplink synchronization. Although 5G midband systems can tolerate extended delays, the maximum supported distance is constrained by parameters such as the TDD pattern, subcarrier spacing, and preamble format used by the gNB. If the simulated path exceeds this effective range, uplink transmissions may fall outside the receiver's expected timing window, leading to desynchronization.
To mitigate this risk, the simulation setup will explicitly configure the distance, timing, and frame structure parameters to remain within the operating bounds of the Amarisoft stack and

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gNB. This ensures that channel behavior remains realistic while avoiding synchronization issues.

4.5 R05: Incorrect Channel Model Configuration

The reliability of the channel simulation hinges on accurate parameter selection. Misconfiguration of Doppler frequency, delay spread, or distance values could lead to unrealistic or invalid results, ultimately compromising the evaluation of the HAPS scenario. This risk is mitigated by using well-established channel models such as TDLA and TDLB, and by basing the parameter values on 3GPP technical specifications and empirical studies of airborne platforms. Every model configuration will be documented and validated before running simulations.

5 Roadmap

The plan will be focused on adapting the laboratory environment and the integration of the use cases and the demos execution. The original project plan was included in the proposal

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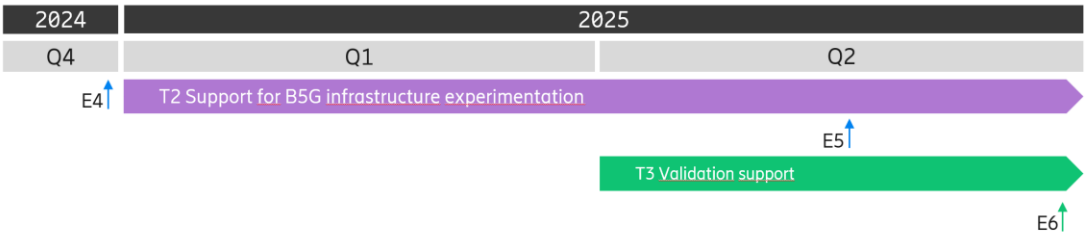
delivered by Ericsson during the public bidding process. However, the following figure reflects the plan adapted:



Deliverables:
E4 (6G-INTEGRATION-04-E23), Dec/24. Activities plan for the first year
E5 (6G-INTEGRATION-04-E24), May/25. Analysis report regarding needs and requirements for implementing the NPI-NTN gNB.
E6 (6G-INTEGRATION-04-E25), Jun/25. Integration testing report

Tasks:
T2 (6G- INTEGRATION-01-A10), Jan/25 to Jun/25. – Support for B5G infrastructure testing
T3 (6G-INTEGRATION-04-A13), Apr/25 to Jun/25. – Support for experimental validation of the test bench.

Figure 3 Project Plan

5.1 Task 2: Support for experimentation in a B5G network

(January 2025 – June 2025)

Ericsson will provide support for the simulation of the B5G network in the NTN segment, providing the 5TONIC 5G Core, in order to prepare for the experimental phase defined in the next task.

The support for the onboarding of the 5G network in NTN is mentioned among the verification tasks. This task is not included in the scope of this Ericsson proposal, as providing the necessary equipment is beyond the scope of *Ericsson España S.A.U* and, given the nature of the project, Ericsson cannot commit to supporting the integration of a non-Ericsson gNB.

This task has the following deliverable:

- 6G-INTEGRATION-04-E24 Analysis report regarding needs and requirements for implementing the NPI-NTN gNB (May 2025)

5.2 Task 3: Simulation and validation

(April 2025 – June 2025)

During this phase, simulation and validation of the B5G network will be executed.

This task has the following deliverable for the subproject-04:

- 6G-INTEGRATION-04-E25 Integration testing report. (June 2025)

6 Works Cited

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