# Initial Functional Requirements for Data Driven Cost Effective 5G Integrated CNS As a Service

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## Abstract

The ANTENNAE solution (SESAR Solution 0521) considers the performance requirements of Communication, Navigation, and Surveillance (CNS) services as part of a holistic Integrated Communication, Navigation, and Surveillance (ICNS) infrastructure, aiming to achieve cost-effective integrated CNS operations. The ANTENNAE solution leverages the progressing evolution of 3GPP standards to meet the expected technology evolution of CNS and the SESAR JU Program's expected timeline regarding the maturity of CNS deployment scenarios (solutions). This document describes the initial Functional Requirement Definition (FRD) for the SESAR solution “Integrated CNS in 5G access networks” within the ANTENNAE project, aiming to meet the Technology Readiness Level (TRL) 2. It describes the ANTENNAE solution's technical systems, functional requirements, and assumptions. Particularly, functional requirements are described based on three key components of the ANTENNAE solution's ICNS framework as the airborne information system, the radio link system, and the ground information system.




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# ANTENNAE

DATA DRIVEN COST EFFECTIVE 5G INTEGRATED CNS AS A SERVICE

ANTENNAE

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# 1 Executive summary

In crowded airspace, where thousands of aircraft are flying, safe aviation operation would not be feasible without the support of Communication, Navigation, and Surveillance (CNS) systems. CNS is the backbone of the Air Traffic Management (ATM) and U-space systems, ensuring safe and efficient operations of modern and future aviation. These three domains complement each other and form the foundation for safe, secure, predictable, and sustainable aviation operations. Recent developments in the aviation domain have brought new considerations. Eventually, in the coming years, many small and highly automated next-generation Unmanned Aircraft (UA) are expected to operate at very-low level (VLL), mainly below 500 feet Above Ground Level (AGL). The current CNS system, originally designed for legacy manned aircraft (MA) and ATM, uses multiple fragmented hardware systems, distinct radio access technologies, frequency spectrum, and provides limited coverage at lower altitudes. This presents a significant challenge for small UA to carry multiple fragmented hardware transceivers and onboard batteries to power the CNS system devices. This makes the traditional fragmented CNS system challenging for small UAs.

ANTENNAE solution (SESAR Solution 0521) will develop a techno-economic framework for the deployment of Communication (C), Navigation (N), and Surveillance (S) as an Integrated CNS (ICNS) offered as a service or "CaaS" enabled by prevailing 3GPP standards. The emerging 5G and 6G technologies have the potential to enhance the longer-term operations of a CNS network while maintaining backwards compatibility with 3GPP standards. The ANTENNAE solution aims to ensure that the full range of CNS services can be provided at low altitude, using both xG (i.e., 5$^{th}$ Generation of Cellular Network or 6$^{th}$ Generation of Cellular Network) Terrestrial Network (TN) and Non-Terrestrial Network (NTN). This initiative is related to the emergence of Unmanned Aircraft Systems (UAS) and the development of U-space within European airspace. The use of xG would thus enable the implementation of the integrated CNS (ICNS) concept, where the three domains would no longer be separated, enabling improvement in terms of performance (performance-based CNS), spectrum utilisation, and a reduction in the number of on-board equipment required, which is particularly important for the small UA.

The ANTENNAE solution will impact a diverse range of stakeholders, including European institutions, Air Navigation Services Providers (ANSPs), standards organisations, aircraft manufacturers, and European airspace users. It would contribute towards increasing traffic capacity in European airspace by enabling the emergence of U-space and UAS Traffic Management (UTM) concepts, reducing costs and carbon footprint, and improving safety and security in comparison to the legacy deployed CNS technologies currently. The project aims to develop (demonstrate) the ANTENNAE solution's technical and operational applicability that can meet the Technology Readiness Level (TRL) 2.

This document is the initial functional requirements document (FRD) deliverable for the SESAR Solution 0521 that the ANTENNAE project develops, targeting TRL2. The purpose of this document is to identify and define the functions and requirements needed to deliver cost-effective integrated CNS services. The future projects of consortium partners will include simulation and experimental demonstrations to validate the practicality of the ANTENNAE solution at higher TRLs.

# 2 Introduction

## 2.1 Purpose of the document

UAS communications enable the command and control (C2) link between a UAS and a Remote Pilot Station (RPS). With the increasing complexity of Beyond Visual Line of Sight (BVLOS) operations, and especially in specific geographical areas, e.g., urban and restricted environments, and close to the controlled by ATM areas, it might be required to use a dedicated range of digital services to ensure the safety of UAS operations. Such a complex combination of services is called U-space in Europe. The information exchange in those systems is expected to rely on telecommunication networks. Thus, CNS infrastructure is an essential enabler for U-space systems [13].

Existing CNS infrastructures and technologies are primarily designed for commercial and general aviation to offer services in designated areas, including airports and air corridors. There remains a need for new solutions supporting CNS services for MA and UA at VLL [14][15].

This document defines the initial FRD for the ANTENNAE solution (SESAR Solution 0521) at TRL2 for the successful integration of the communication, navigation, and surveillance services in a cost-effective manner to the aviation stakeholders. This document offers a detailed overview of the system's functionalities, acting as an essential resource for both the development team and project stakeholders. Particularly, functional requirements are described based on three key components of the ANTENNAE solution's ICNS framework as follows:

- Airborne information system
- Radio link system
- Ground information system

## 2.2 Scope

Integrated CNS is expected to help the convergence of ATM and U-space, enabling more efficient and safer use of airspace, particularly in urban areas. The objective of this document is to discuss the ANTENNAE solution's initial FRD for developing an ICNS framework using the xG (i.e., 5G, 6G etc.) TN-NTN systems. The outcomes of this document will be used in the Exploratory Research Plan (ERP), Exploratory Research Report (ERR), and Final Operational Service and Environment Definition (OSED) and Final FRD documents.

This initial FRD aims to technically align aviation standards, operational requirements, and Key Performance Indicators (KPIs) with corresponding 3rd Generation Partnership Project (3GPP) technologies. Particularly, FRD will primarily address two Specific Objectives (SO) of the ANTENNAE solution (SESAR Solution 0521) as follows:

**SO.2:** Verified compliance of 3GPP 5G communication standards, KPIs, and available spectrum to satisfy CNS as a service requirement.

**SO.3:** Low altitude-specific network configuration and management policies to deliver cost-effective CNS-as-a-service in low altitude operations, across all stakeholders.

The outcomes of this FRD will be further exploited in

- Task 2.2 Research Plan for Network Architecture Evaluation
- Task 2.4 Design & Evaluation of ANTENNAE-01 Solution
- Task 2.5 Consolidation of ANTENNAE-01 Solution

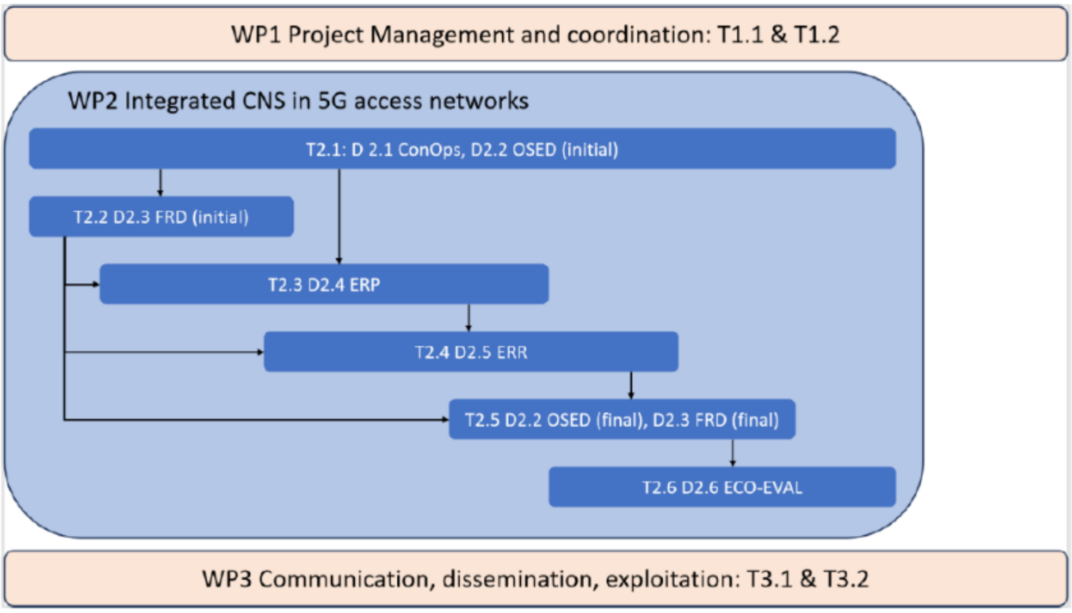


**Figure 1: PERT diagram and Task Dependencies within ANTENNAE**

The ANTENNAE solution (SESAR Solution 0521) targets **xG (i.e. 5G, 6G, etc.), which encompasses 5G and further standards**. For this reason, we will prefer the use of the term xG over 5G in this document. However, occasional references to 5G remain, as it is currently the generation defined and deployed under 3GPP mobile communication standards.

## 2.3 Intended readership

This document is addressed to a broad audience of stakeholders, ranging from ANTENNAE project partners and SESAR JU stakeholders to stakeholders involved in regulating and developing European airspace. The audience includes, but is not limited to:

- **ANTENNAE project and solution partners:** collectively develop content and track its progress,
- **SESAR Joint Undertaking:** follow the progress of the project in its capacity and for its feedback on the present document,
- **Air Navigation Service Providers (ANSPs):** understand the purpose of the solution and potentially prepare for its integration,

- **ATM and U-space service providers:** understand how the ICNS solution supports both ATM and U-space,
- **Standardization bodies:** establish new standards adapted to the new use of airspace and U-space, and CNS technologies,
- **Airport/Airfield and Vertiport owners/providers:** monitor developments in low-level (low altitude) air traffic,
- **Airspace users:** adapt to the arrival of low-altitude operations and to understand how they will be integrated into the airspace,
- **Aerospace industry:** understand advances in ICNS regarding the development and regulation of low-altitude operations,
- **Scientific community:** keep abreast of innovative advances in CNS technologies.

## 2.4 Background

Emerging U-space/UTM, Innovative Air Mobility (IAM), and Advanced Air Mobility (AAM) concepts envisage a new generation of small, highly manoeuvrable, and highly automated aircraft operating at low altitude, alongside existing helicopter and general aviation users. Coordination and deconfliction of large numbers of such aircraft, operating in primarily urban environments, requires new CNS infrastructure to ensure the safety of passengers, the public, and other stakeholders while supporting complex operations within low-level altitudes.

Leveraging the scalable waveforms of 5G New Radio (NR), modern IP-based software-defined networking, and distributed computing capabilities, the ANTENNAE solution (SESAR Solution 0521) proposes a flexible and resilient integrated CNS-as-a-Service model. This supports both low-level (low altitude) piloted and U-space operations and builds upon the mature and growing family of 3GPP 5G standards, including system architecture, deployment models, and commercial implementations.

To achieve this goal, the project consolidates the research previously done by:

- **SESAR FACT:** The feasibility of the ICNS concept was first studied in the SESAR FACT (Future All Aviation CNS Technology) project, where 4G and 5G networks were used for this purpose [16].
- **PJ14-W2 I-CNSS:** ICNS has also been studied as part of the SESAR PJ14-W2-76 (Integrated CNS and Spectrum) industrial research [17]. As the ANTENNAE-01, STELLAR Solution ID 0521 also aims to validate the applicability of existing 3GPP standards, it relies on available standards regarding data service, navigation, and surveillance.
- **CORUS-XUAM:** U-space Concept of Operations (ConOps) document explains how U-space works from an individual user's point of view. CORUS-XUAM describes a set of ideas and assumptions and discusses how does U-space system works [18].
- **PJ14 EECNS:** specification of the Future Communication Infrastructure (FCI) solution is envisioned to enable Air Traffic Control as well as Airlines Operational Communications services [19].

- **AiRMOUR:** defined ideas to ensure that urban air mobility is not only safe, secure, quiet, and environmentally friendly, but also more inclusive, cost-effective, and widely embraced by the public [20].
- **SESAR European ATM Master Plan:** CNS roadmap that needs to be developed and deployed for ATM and U-space users. ANTENNAE solution (SESAR Solution 0521) aligns well with the CNS roadmap visions provided in the European ATM Master Plan 2025 Edition [13].
- **EUROCONTROL:** In Europe, EUROCONTROL works on the relevant matters [21].
- **European Drone Strategy:** The Integrated CNS concept was introduced as part of the European Drone Strategy 2.0 [22].
- **International Civil Aviation Organization:** At the International Civil Aviation Organization (ICAO) level, a dedicated Integrated CNS and Spectrum Project was established [23].

## 2.5 Structure of the document

The document is structured as follows

- **Chapter 1 – Executive summary:** summarises the key elements and concepts of the ANTENNAE solution (SESAR Solution 0521).
- **Chapter 2 – Introduction:** presents the purpose and scope of the document. It also introduces the document's target audience and the background on which the project is based. A glossary of terms and a list of acronyms are provided for ease of reading.
- **Chapter 3 – Functional architecture view:** discusses the ANTENNAE solution overview and the supporting reasons for developing the ICNS framework. This section also discusses stakeholders affected by the ANTENNAE solution and explains why they are impacted. It also gives a basic overview of how the system works, highlighting how different parts of the system interact and what roles they play.
- **Chapter 4 – Functional requirements:** defines the functional requirements for the proposed SESAR solution.
- **Chapter 5 – Assumptions:** lists the key assumptions applicable to the ANTENNAE solution, i.e. those that have an impact on the functional requirements defined in Chapter 4.
- **Chapter 6 – References:** provides a list of the reference documents used in the preparation of this document.

## 2.6 Glossary of terms

| Term | Definition | Source of the definition |
|---|---|---|
| 3G Network | A 3D network is a network architecture that integrates nodes across three spatial dimensions, including ground, air, and space. This allows to enable connectivity in all directions and altitudes | 3GPP TR 36.873[24] |
| Air Traffic Management | The dynamic, integrated management of air traffic and airspace including air traffic services, airspace management and air traffic flow management – safely economically and efficiently – through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground-based functions | ICAO 4444 [25] |
| Exploratory Research | Explores new concepts beyond those identified in the European ATM Master Plan or emerging technologies and methods. The knowledge acquired can be transferred into the SESAR industrial and demonstration activities | European ATM Master Plan [26] |
| Integrated CNS | A unified system that enables interdependency between communication, navigation, and surveillance (CNS) technologies, taking full advantage of cross-domain synergies to improve service quality, spectrum efficiency, and CNS capabilities | ANTENNAE project preliminary definition |
| Low-Level Altitude | Altitude within 8,300 meters or 27,230 feet above Mean Sea Level (MSL)<br><br>10,000 ft MSL is an upper limit for low-altitude IAM operations. | ANTENNAE project preliminary definition |
| Very Low-Level Altitude | Altitude below 150 meters or 500 feet AGL | ICAO UTM Framework Edition 4 [27] |
| Unmanned Aircraft System (UAS) | Unmanned aircraft system (UAS) means an unmanned aircraft and the equipment to control it remotely | Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems, European |

| | | |
|---|---|---|
| | | Commission, 2019, C/2019/1821 [27][28] |
| U-Space | U-space airspace means a UAS geographical zone designated by Member States, where UAS operations are only allowed to take place with the support of U-space services<br><br>U-space service means a service relying on digital services and automation of functions designed to support safe, secure and efficient access to U-space airspace for a large number of UAS | Commission Implementing Regulation (EU) 2021/665 of 22 April 2021 on a regulatory framework for the U-space (C/2021/2671) [29]<br><br>SESAR Smart ATM U-space and urban air mobility [30] |

**Table 1: glossary of terms**

## 2.7 List of acronyms

| Term | Definition |
|---|---|
| 3GPP | 3rd Generation Partnership Project |
| 5G | 5th Generation of Cellular Network |
| 6G | 6th Generation of Cellular Network |
| A/G | Air to Ground |
| A2X | Aircraft-to-Everything |
| ACARS | Aircraft Communication Addressing and Reporting System |
| ACAS | Airborne Collision Avoidance System |
| ADS-B | Automatic Dependent Surveillance – Broadcast |
| ADSP | ATM Data Service Provider |
| AGL | Above Ground Level |
| ANSP | Air Navigation Service Providers |
| AOC | Air Operator Certificate |
| A-PNT | Alternative Positioning, Navigation, and Timing |
| A-SUR | Alternate Surveillance |
| ATC | Air Traffic Control |
| ATSU | Air Traffic Services Unit |

| | |
|---|---|
| BVLOS | Beyond Visual Line-Of-Sight |
| BS | Base Station |
| BSC | Based-Station Controllers |
| C2 | Command and Control |
| CNS | Communication Navigation Surveillance |
| CPDLC | Controller Pilot Data Link Communications |
| DAA | Detect and Avoid |
| DME | Distance Measuring Equipment |
| eMBB | Enhanced Mobile Broadband |
| FAA | Federal Aviation Administration |
| FOC | Flight Operations Centre |
| GBAS | Ground-Based Augmentation System |
| GEO | Geosynchronous Earth Orbit |
| GNSS | Global Navigation Satellite System |
| HEMS | Helicopter Emergency Medical Services (HEMS) |
| HF | High Frequency |
| ICAO | International Civil Aviation Organization |
| ICNS | Integrated CNS |
| ID | Identifier |
| ILS | Instrument Landing System |
| IP | Internet Protocol |
| ITU | International Telecommunication Union |
| KPI | Key Performance Indicator |
| LEO | Low Earth Orbit |
| MLAT | Multilateration |
| mMTC | Massive Machine-Type Communication |

| | |
|---|---|
| NB-IoT | Narrowband IoT |
| NDB | Non-Directional Beacon |
| NR | New Radio |
| NTN | Non-Terrestrial Network |
| OSED | Operational Service and Environment Description |
| QoS | Quality of Service |
| RAT | Radio Access Technology |
| RedCap | Reduced Capability |
| RPS | Remote Pilot Station |
| SAR | Search and Rescue |
| SATCOM | Satellite Communication |
| SBAS | Satellite-Based Augmentation System |
| SESAR | Single European Sky ATM Research |
| SESAR 3 JU | SESAR 3 Joint Undertaking |
| SJU | SESAR Joint Undertaking |
| SRIA | Strategic Research and Innovation Agenda |
| TACAN | Tactical air navigation system |
| TN | Terrestrial Network |
| TRL | Technology Readiness Level |
| UA | Unmanned Aircraft |
| UAM | Urban Air Mobility |
| UAS | Unmanned Aircraft Systems |
| UE | User Equipment |
| UHF | Ultra-High Frequency |
| USSP | U-space Service Provider |
| U-space | The European concept of UAS Traffic Management |

| | |
|---|---|
| VCA | VTOL-Capable Aircraft |
| VDL | VHF Data Link |
| VDLM2 | VDL Mode 2 |
| VHF | Very High Frequency |
| VLL | Very Low Level |
| VOR | VHF Omnidirectional range |
| VTOL | Vertical Take-Off and Landing |
| xG | $x^{th}$ Generation of Cellular Network |

**Table 2: list of acronyms**

# 3 Functional architecture view

## 3.1 SESAR solution overview

CNS services are a crucial component of ATM and U-space operation. ICNS is a contemporary concept that considers the C, N, and S domains as a harmonized framework. This new concept allows one domain to support and complement another domain. Given this, all the systems for C, N, and S services might be combined and harmonized into one system. This integration will improve service quality, spectrum efficiency, communication capacity, navigation predictability, and surveillance capabilities. It is vital to mention that the ANTENNAE solution shall develop an ICNS framework that allows ATM and U-space systems convergence [14][15].

The ANTENNAE solution (SESAR Solution 0521) impacts multiple communication, navigation, and surveillance technical systems. Particularly, ANTENNAE solution advocates the use of 3GPP xG technology stack to deliver CNS services including Automatic Dependent Surveillance – Broadcast (ADS-B), Airborne Collision Avoidance System (ACAS), data, Distance Measuring Equipment (DME), Ground Based Augmentation System (GBAS), instrument landing system (ILS), Multilateration (MLAT), Non-directional Beacon (NDB), Satellite Based Augmentation System (SBAS), Tactical Air Navigation System (TACAN), video, voice, and VHF omnidirectional range (VOR). Figure 2 shows the legacy CNS and proposed ICNS technical systems.

xG offers higher throughput, lower latency, and massive connectivity compared to many existing aviation technologies. ANTENNAE solution (SESAR Solution 0521) will use xG TN and NTN based 3D network cross three spatial segments including space, air and ground to deliver CNS services and support aircraft operations across large coverage areas and at very low level and low level.

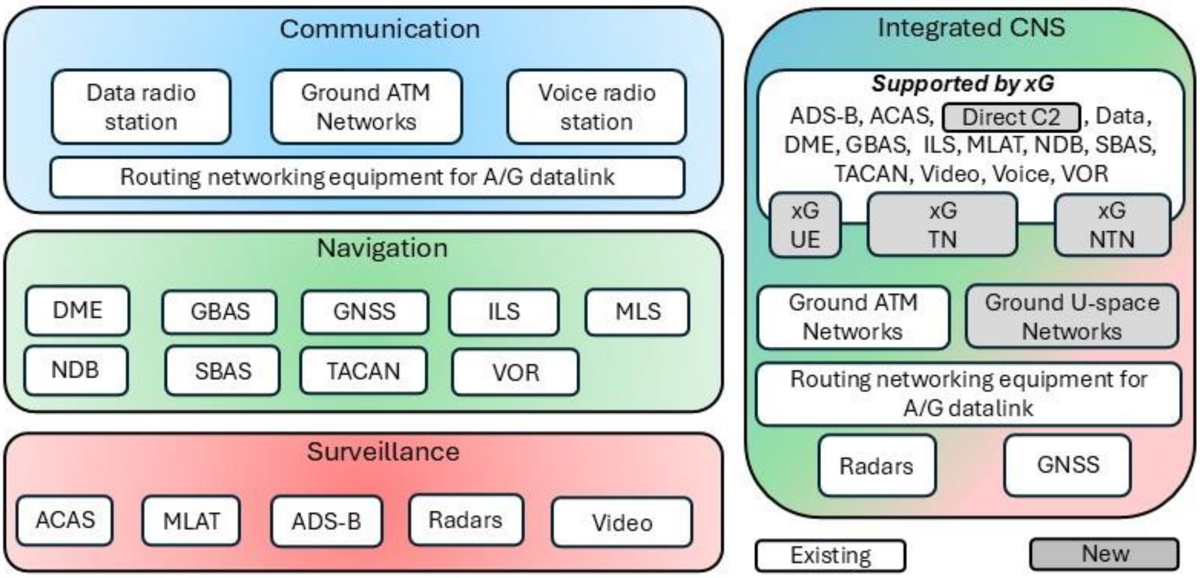


**Figure 2: An overview of legacy CNS and proposed Integrated CNS systems**

The main benefits of the ANTENNAE solution (SESAR Solution 0521) are as follows:

- Supports both ATM and U-space current and future needs.
- Delivers CNS services at low and very low altitudes for IAM and AAM operations.
- Discusses how ***3GPP 5G and future xG technologies*** can support integrated CNS services using terrestrial networks and non-terrestrial networks.
- Features a resilient network architecture with minimum hardware. Particularly, ANTENNAE solution's ICNS framework eliminates the need for multiple onboard hardware equipment and implies the convergence of the previously separate CNS services.
- Merges the traffic flows of three CNS services and handles their packets according to the needs of the required performance in a cost-efficient manner.

### 3.1.1 Supporting reasons for this SESAR solution

By integrating the three CNS domains, the ANTENNAE solution (SESAR Solution 0521) is expected to enhance the efficiency and resiliency of ATM and U-space operations, promote more efficient use of the scarce radio spectrum, and improve the quality of service for all airspace users [14]. The ANTENNAE solution is important as it aligns with the CNS roadmap outlined in the European ATM Master Plan 2025 Edition [13]. Below, we discuss the key benefits of the ANTENNAE solution.

#### 3.1.1.1 Integrated framework

ANTENNAE solution (SESAR Solution 0521) develops an integrated CNS framework that will eliminate the need for multiple onboard hardware equipment, lowering the required network devices and battery payload. Benefiting from the xG's higher bandwidth, standardized spectrum, and compact user equipment (UE), the ANTENNAE solution will take full advantage of cross-domain synergies of the three fragmented domains of CNS. ANTENNAE introduces a non-fragmented framework that enhances spectrum efficiency, improves aviation safety for both high-level and low-level altitude operations as well as public safety on the ground, optimizes airspace capacity, reduces fuel (or battery) consumption, and lowers carbon emissions. Thus, the ANTENNAE solution will enhance safety and sustainability, meeting the current and future ATM and U-space systems' needs with improved capacity, performance, and latency than the legacy CNS systems.

The focus of the project is on operations within 4,000 ft AGL, where the majority of the IAM operations are expected to take place. Using AGL instead of MSL as an altitude reference for the majority of the IAM operations is justified by the fact that some cities are located in highly elevated geographical areas, while the technical capability of many VCA will allow such operations, and the ground infrastructure, particularly enabling CNS, operates using AGL measures. Operational altitude within 4,000 ft (about 1200 m) includes VLL altitudes, which are 500 ft (150 m), where the majority of the U-space operations are expected.

The future CNS infrastructure will be based on an ICNS backbone. ANTENNAE solution envisions a future in which all aircraft are equipped with xG transceivers: integrated as "alternative" technology into legacy avionics for MA and added as "primary" technology in UA. The ICNS considered for the ANTENNAE solution will consist of the deployment of a hybrid TN and NTN network, as well as aircraft-to-everything (A2X) capabilities to offer cost-effective ICNS services. Figure 3 illustrates ANTENNAE's xG ICNS vision.

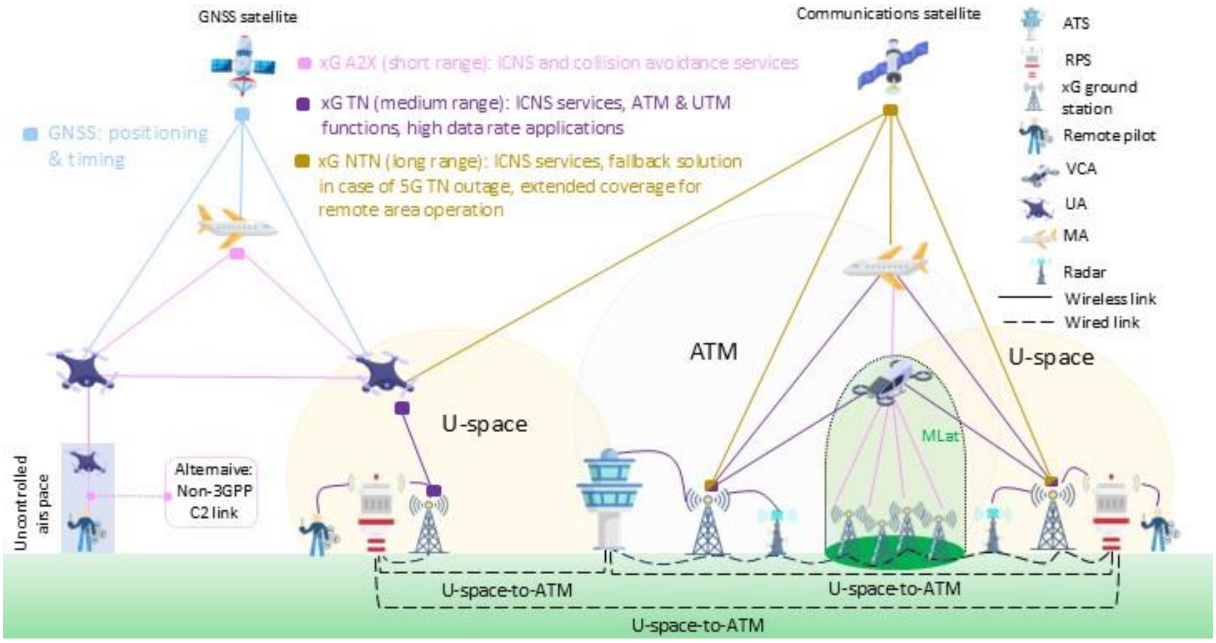


**Figure 3: An overview of the ANTENNAE solution's ICNS framework**[2]

xG ICNS framework reduces the needed hardware and network size, which contributes to the minimization of the wireless systems' carbon footprint. In addition to safe aviation operation, the ICNS system with accurate navigation service plays a crucial role in optimising the flight route, which further reduces fuel consumption, lowers operational costs, and reduces aviation carbon emissions, which currently account for 2.5 % of global carbon emissions.

### 3.1.1.2 ATM and U-space convergence

ATM and U-space rely significantly on the timely exchange of information between all participating actors, and especially on the exchange of CNS information between air and ground. The use of ATM and U-space services using the ICNS framework will, therefore, over time, continue to increase both in volume and scope. New applications such as digital voice and alternative position, navigation, and timing (A-PNT) for low altitude will have more stringent performance requirements. The ICNS infrastructure developed by ANTENNAE can be leveraged to support current and future applications.

U-space is an outstanding framework to manage the UAS traffic. The anticipated U-space operations are expected mostly at altitudes below 500 feet AGL. ATM remains responsible for the management

[2] Icons are made by multiple authors (Freepik, Smashicons, Prosymbols Premium, mynamepong, Konkapp, vectorsmarket15, Luvdat, Kanyanee Watanajitkasem, Triangle Squad, and Ylivdesign) from www.flaticon.com.

of manned aviation at higher altitudes and controlled airspaces. Search and Rescue (SAR), firefighting, and Helicopter Emergency Medical Services (HEMS) operations should be supported by ATM but may penetrate the U-space operational areas. Vertical take-off and landing (VTOL) capable aircraft (VCA) may also operate with the support of ATM but penetrate the U-space areas, as shown in Figure 4.

The continuous growth in manned and unmanned aircraft, coupled with the limited CNS coverage at VLL and availability of radio spectrum resources, demands a harmonized innovative framework for sustainable and cost-effective integrated CNS solutions for both ATM and UTM. With the growing number of any types of aircraft operating at different levels and in different airspace classes and the increasing complexity of their operations, it is essential to expect the convergence of ATM and UTM systems and the transformation of the C, N, and S systems into one integrated CNS.

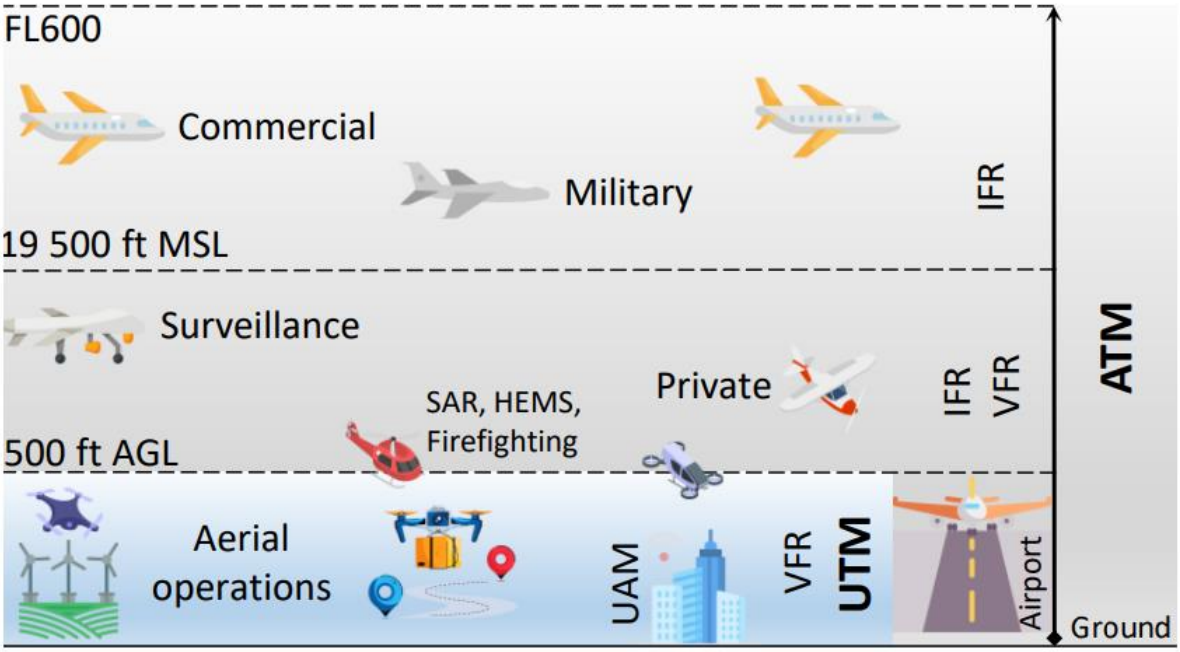


**Figure 4: Illustration of aircraft operations supported by ATM and UTM [14]**

Figure 5 shows U-space in the context of the overall ATM evolution [13]. To enable full ATM and UTM convergence at U4, the ANTENNAE solution (SESAR Solution 0521) leverages 3GPP xG hybrid TN-NTN systems for developing an ICNS framework capable of supporting both ATM and U-space stakeholders.

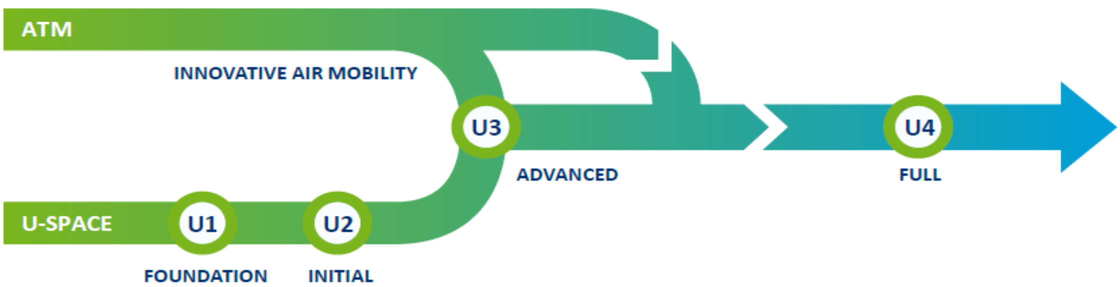


**Figure 5: U-space in the context of the overall ATM evolution. Image source: European ATM Master Plan, 2025 edition [13]**

#### 3.1.1.3 Spectrum efficient

In the current CNS ecosystem, the three domains are fragmented and poorly integrated. Each domain uses different aircraft onboard hardware transceivers, diverse ground infrastructure, and frequency spectrum as shown in Figure 6, including:

- High frequency (HF) band
- Very high frequency (VHF) band
- Ultra-high frequency (UHF) band
- C band
- L band
- Ka/Ku band
- X band

This increases development and operational costs as well as inefficient spectrum use.

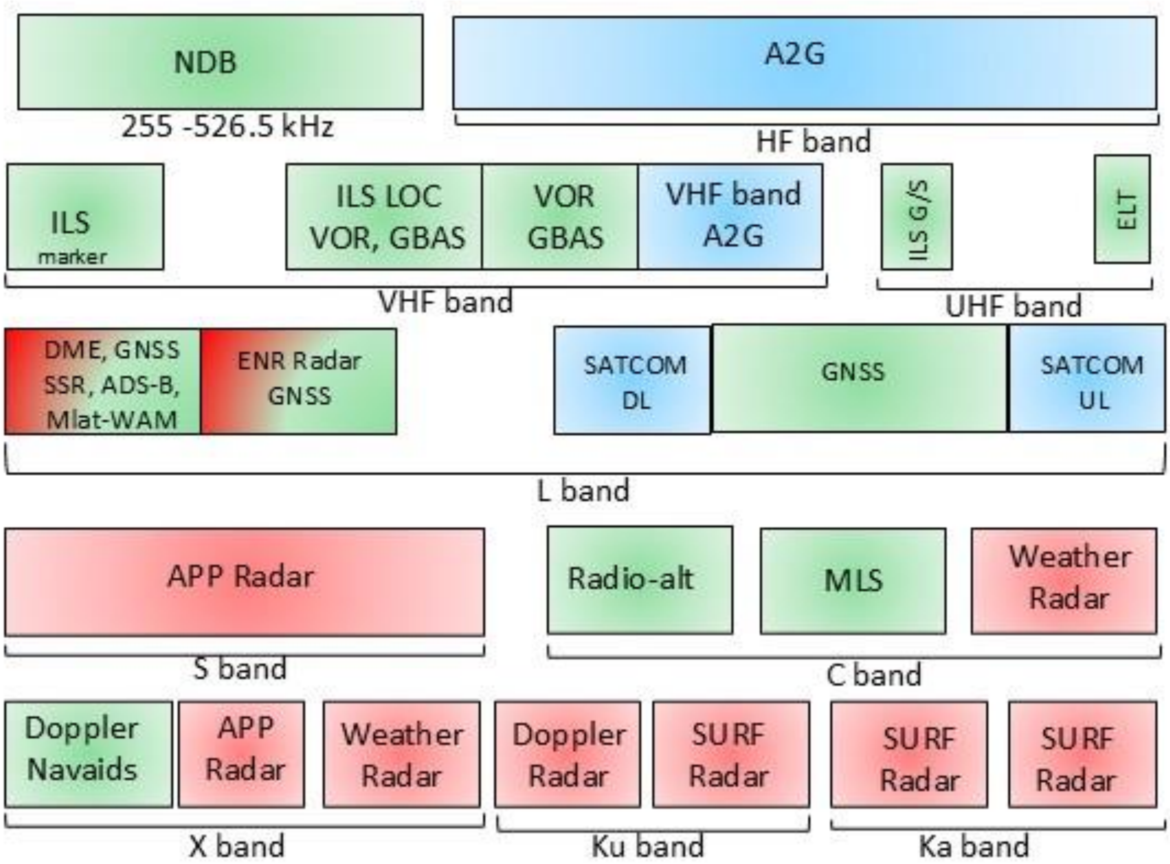


**Figure 6: Spectrum of legacy CNS systems**

Unlike legacy, fragmented CNS systems that rely on multiple dedicated hardware equipment and operate across diverse frequencies, including HF, VHF, UHF, C, L, Ka, Ku, and X bands—the ANTENNAE solution uses a unified spectrum specified by 3GPP. ANTENNAE solution (SESAR Solution 0521) maximizes spectrum efficiency using standardized 3GPP xG technology for all three communication, navigation, and surveillance services. To give one practical example, ANTENNAE uses both MLAT and Joint Communication and Sensing (JCS), which means the 5G waveform can be used to deliver data



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and facilitate the navigation and surveillance operation from the same signal. As a result, this eliminates the need for multiple frequency bands for communication, navigation, and surveillance services. It will support both current and emerging aircraft types, including VCA and UA, by effectively managing airspace complexity while maintaining high standards of safety and security. ANTENNAE solution uses the radio access technologies, radio access standards, and radio frequency spectrum defined by 3GPP specifications for the xG technology.

Figure 7 illustrates how the legacy CNS and xG ICNS framework, to be developed by the ANTENNAE solution, uses the frequency spectrum.

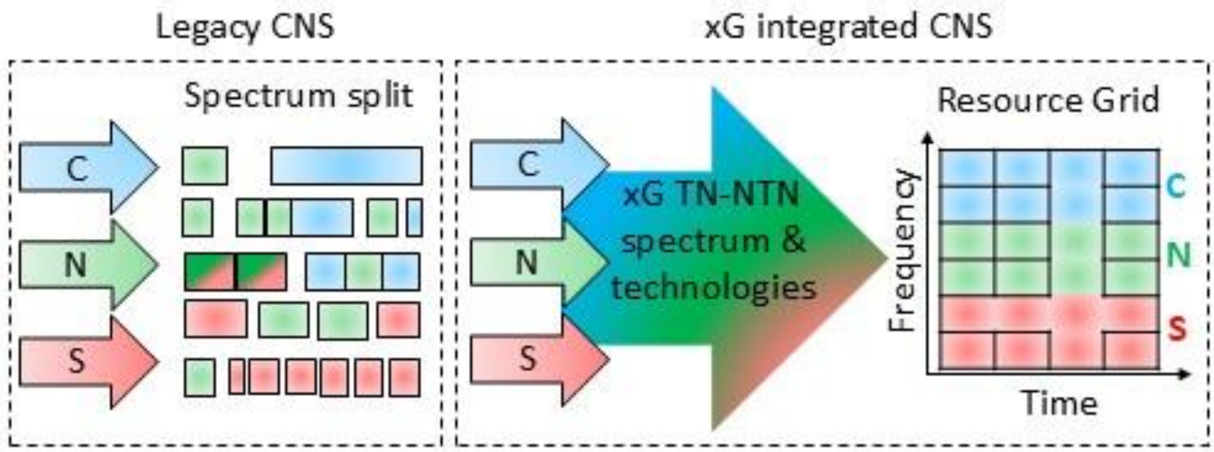


**Figure 7: A high-level illustration of the frequency spectrum used by legacy CNS and envisioned an integrated xG ICNS framework.**

### 3.1.1.4 Aligned with European CNS roadmap

The ANTENNAE solution (SESAR Solution 0521) aligns with the CNS roadmap provided in the European ATM Master Plan 2025 Edition [13]. Table 4 shows the ATM Master Plan CNS roadmap and how the ANTENNAE solution accounts for it.

| European ATM Master Plan (2025 Edition) | ANTENNAE solution (SESAR Solution 0521) |
|---|---|
| Integration of new air–ground technologies | Leverages 3GPP A2X, TN, and NTN radio channels as well as multiple radio access technologies e.g., NR, Reduced Capability (RedCap), and Narrowband IoT (NB-IoT) for delivering ICNS services. ANTENNAE solution uses 3D networks supported by xG to deliver CNS services. |
| Accommodate new applications | Supports CNS services, aircraft safety-critical communication, and is capable of handling non-safety-critical commercial communication needs for passengers and flight crew. |
| Accommodate new use cases and users | Provides sufficient data rates that can support safety, mission-critical communication, and |

| | |
|---|---|
| | broadband connectivity for onboard passengers and flight crew. 5G NR can also meet the required data rates of multiple UAS applications defined in 3GPP TS22.125 [31]. This includes 8K video live broadcast, laser mapping, HD patrol, 4K AI surveillance, real-time video, video streaming, and image transmissions. |
| Digital voice in continental | Offers high data rate communication to facilitate the transmission and reception of voice, video, as well as internet services. |
| Alternative position, navigation, and timing (A-PNT) solution implemented for en-route and TMA routes | Uses MLAT-based A-PNT to ensure the accuracy, availability, continuity, and integrity of the services at VLL as shown in Figure 3. |
| U-space airspace and high-altitude airspaces are integrated into ATM airspace navigation | Develops a harmonized and innovative ICNS framework that provides secure, sustainable, and cost-effective solutions for delivering services to both ATM and U-space. |
| Space-based GNSS-independent surveillance means | Uses both MLAT and Joint Communication and Sensing (JCS) for navigation and surveillance at low altitudes. |
| Optimised CNS resource usage: spectrum-efficient and sustainable, and rationalised infrastructure | To ensure a balance between sufficient data rates and coverage, the ANTENNAE ICNS solution strategically selects suitable frequency bands and a radio link (TN, NTN, or A2X) and radio access technologies (NR, RedCap, and NB-IoT) for broader coverage and increased capacity. |

**Table 3: The shared vision of the ANTENNAE solution and the ATM Master Plan CNS roadmap**

### 3.1.2 ATM and U-space capabilities addressed by the SESAR solution

CNS services are crucial for a successful ATM and U-space operation. Current CNS systems operate in a fragmented way. In other words, each domain requires different dedicated transceivers on board the aircraft, using different ground infrastructures as well as different frequency bands. This raises a problem for UAS, for which current CNS systems are unsuitable: the equipment is heavy and power-consuming, which does not meet the specific constraints of UAS, especially the smaller ones.

U-space and ATM services rely primarily on the use of CNS technologies to be delivered reliably. An integration between ATM and U-space is expected to benefit both systems and potentially enhance the safety of aviation. Such integration requires data exchange between the ATM and U-space, which is not yet defined.



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- First, an evolution of the current ATM systems is necessary, allowing more flexibility, resiliency, and scalability. Without these elements, ATM may not be able to absorb the massive traffic generated by UAS and VCA at low-level altitudes.
- Second, the ATM data must be shared across all the entities involved in the communication network securely, and relevant U-space data must be available at ATM services to provide the necessary awareness of the U-space operations.

Finally, ANTENNAE solution (SESAR Solution 0521) views ATM and U-space services as digital data services instead of isolated technology domains, allowing interoperability between multiple manufacturers and the automation and software assistance of low-risk operations. An example of this is detect and avoid (DAA) technologies (airborne or ground-based) and current procedures, which will need to be designed and validated to enable interoperability with other aircraft and Collision Avoidance Systems (CAS), and the joint action of ATM and U-space to advise correctly all the parts sharing the airspace. Although envisioned and under investigation by both industry and academia, the integration between ATM and U-space systems is seen as a further goal on the road to MA and UA coexistence [14].

| SESAR solution capabilities | Comments on potential updates required at capability level |
|---|---|
| Communication, Navigation, Surveillance | The system shall combine and integrate Communication/Navigation/Surveillance techniques to deliver performance-based CNS services with required availability, integrity, safety, and security requirements. |

Table 4: ANTENNAE solution capabilities

### 3.1.3 Stakeholders impacted by the SESAR solution

| Stakeholder | Why it matters to the stakeholder |
|---|---|
| U-Space Service Providers (USSPs) | The USSPs are one of the main stakeholders for the ANTENNAE project, as they are responsible for the safety management of UAS operations within the U-spaces. Project results will be shared with them so that they can benefit from the simulations of advanced CNS technologies. |
| IAM Operators | The operators will be another important beneficiary of the ANTENNAE project results. The dissemination message for this target audience will be centered around the ease and safety of operations using the widely deployed cellular networks. The simulation results will also be shared with them in this regard. |
| Telecommunication Operators | These entities would be an important target audience both for simulation results and for techno-economic analysis of different networks. |

| | |
|---|---|
| Air Navigation Service Providers (ANSPs) | To facilitate the vision of an integrated airspace, ANSPs have an important role to play and can benefit highly from the features of an ICNS system that increases real-time awareness about airspace traffic, thereby improving the safety and efficiency of manned aircraft flights. |
| European and National Aviation Authorities | The authorities will be able to use the results of the ANTENNAE project as input for developing future regulations for IAM. |
| European Union Aviation Safety Agency | Ensures the highest common level of safety protection for EU citizens. Ensures the highest common level of environmental protection. Single regulatory and certification process among Member States. Facilitate the internal aviation single market & create a level playing field. Work with other international aviation organisations & regulators. |
| Equipment manufacturer | Develops hardware (HW) solutions needed or affected by U-space and IAM operations. A manufacturer is any natural or legal person who manufactures a product or has a product designed or manufactured and markets that product under their name or trademark. |
| European Organisation for the Safety of Air Navigation (EUROCONTROL) | Support our Member States and our civil and military stakeholders (including air navigation service providers, airspace users, airports and aircraft/equipment manufacturers) in a joint effort to make aviation in Europe safer, more efficient, more cost-effective and with a minimal environmental impact. |
| Manned aircraft manufacturer | Produces manned aircraft that can operate in a U-space environment and ensures their compatibility with U-space, integrating the equipment needed for operation |
| Standardisation Bodies | The CNS requirements defined and tested within the ANTENNAE will be shared as input with the Working Group (WG) at the national and international standardisation groups, such as EUSCG, EUROCAE, RTCA and JARUS. |
| Remote pilot | A natural person responsible for safely conducting the flight of a UA by operating its flight controls, either manually or, when the UA flies automatically, by monitoring its course and remaining able to intervene and change its course at any time |
| U-space coordinator | A body that coordinates with other authorities and entities, including at the local level, the designation of U-space airspace, the establishment of airspace restrictions for UAS the determination of the U-space services to be provided in the U-space airspace |
| U-space service industry | Develops software (SW) products to realise U-space services |

**Table 5: ANETNNAE stakeholder examples and benefits**



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## 3.2 SESAR solution functional view

### 3.2.1 Interaction(s) identification

ANTENNAE solution (SESAR Solution 0521) shall be designed to exchange ICNS services between the aircraft and the relevant stakeholders in a spectrum and cost-efficient manner. The sub-section describes functional blocks and interactions between them. Figure 8 shows the data flow in the ICNS framework.

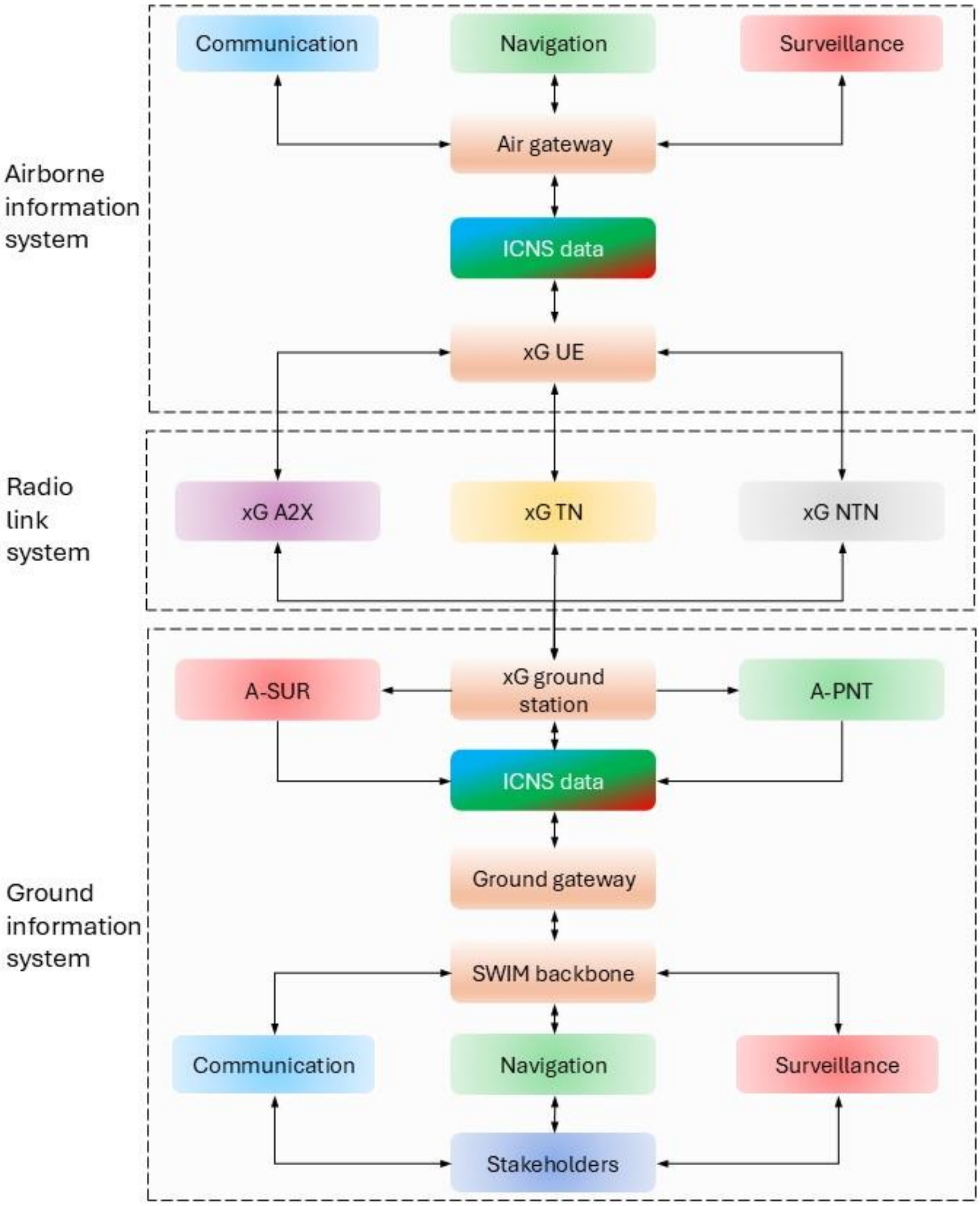


Figure 8: Integrated C, N, S data flows framework



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- **Airborne information system:** In the airborne segment, aircraft, including manned aircraft, unmanned aircraft, and VCA, are equipped with sensors and xG wireless transceivers, also called UE. xG equipment reduces the size and weight of the aircraft's on-board CNS systems. In addition, xG transceivers consume less power may reduce the needed battery resources on UAS. This system allows transmission and reception of Communication (voice, text messages, and flight data), Navigation (A-PNT, geofencing, MLAT, navaids), and Surveillance (positioning data, detect and avoid (DAA) technologies, radars) data—either between aircraft or between aircraft and ground networks. These ground networks are also connected to ATM and U-space systems. In this system, each block C, N, S treats the data separately, where the air gateway integrates three fragmented domains and merges the traffic flows of these three services and handles their packets according to the needs of the required performance in a cost-efficient manner. ANTENNAE solution's standardised xG-based airborne information system eliminates the need for multiple onboard hardware equipment, lowering the hardware payload. Specifically, the ANTENNAE solution requires that the aircraft onboard transceivers have multi-mode functionalities. Particularly, the ANTENNAE solution applies that there is an adaptive mechanism to select the suitable RAT capabilities, and it selects a RAT based on CNS data priority. The ICNS paradigm may directly impact the operational costs of UAS and VCA operations. An integrated equipment providing all the necessary CNS services plus connectivity via xG may be less expensive than having several CNS equipment and multiple datalinks.

- **Radio link system:** ANTENNAE solution (SESAR Solution 0521) uses 3GPP xG A2X, TN, and NTN radio links for delivering ICNS services. By combining TN and NTN systems, a 3D network is formed across space, air, and ground, enabling aircraft to operate over large areas and at all altitudes, from very low to very high altitudes. Radio link systems act as a wireless bridge and offer three alternative radio links for transmission and reception of the C, N, and S information between the aircraft and the relevant stakeholders.

    - **TN link:** The role of the TN system will be to provide the primary connection in areas with ground network infrastructure. In case of a TN outage, NTN will act as a fallback solution to ensure continuous connection availability and delivery of CNS services, strengthening resilience.

    - **NTN link:** At the same time, NTN will support CNS operations in regions outside of TN coverage. Additionally, NTN can help to offload the CNS traffic from TN, reducing congestion during peak hours. For BVLOS operations, the envisioned xG ICNS network architecture with integrated TN-NTN will increase connection availability, coverage, ensure service continuity, and improve resilience.

    - **A2X link:** This third option can support short-range communications, including situational awareness data between the aircraft. ANTENNAE solution (SESAR Solution 0521) uses xG A2X technologies for short-range CNS and collision avoidance service to enable airspace situational awareness.

- **Ground information system:** The ground infrastructure connects aircraft and the ground network. It provides CNS services to ATM and U-space users. It can also provide navigational



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aids, e.g., GBAS, to aircraft. The ground information system enables interactions between the different aviation stakeholders, including ATM and U-space. In the ANTENNAE solution, an aircraft is connected with communicates through the ground infrastructure by using the xG base station (called gNodeB in 5G system), which acts as a ground station. At the ground segment, the ground station is responsible for the transmission and reception of ICNS data. SWIM backbone network shares the CNS data with the relevant stakeholders.

### 3.2.2 Functional decomposition

This section provides the functional decomposition of the capability configurations and technical systems needed in the scope of the ANTENNAE solution (SESAR Solution 0521). This section presents the relevant technical systems, and their definitions are accessed from the SESAR eATM portal [32].

- **ADSP Voice:** This is the voice system provided by an ADSP (ATM Data Service Provider), allowing ATC controllers to exchange voice information with pilots and other ground personnel (ATC Controllers, airport, firefighters, etc) via the COM Infrastructure System, as well as allowing new controller HMI interactions related to voice and managed by the VoiceComm Virtual Centre services. The corresponding Voice HMIs are provided by the Virtual Center system.

- **ACAS Monitoring:** Consists of a set of distributed ACAS ground receiving stations and a central ACAS processing unit (ACAS server). The number of ACAS servers in operation is subject to the specific user requirements and user environment. The receivers are connected via usual network lines with the ACAS server. The ACAS server output is transmitted for further processing via a Ground Safety network to external linked ATM systems (s).

- **Automatic Dependent Surveillance – Broadcast:** ADS-B is a Surveillance technique that relies on aircraft broadcasting their position (calculated by onboard GNSS system), identity, and other information derived from onboard systems. The ADS-B Ground station receives the 1090 MHz SSR band signals from the Aircraft and converts them to reports in ASTERIX formats for onward transmission.

- **Communication Infrastructure:** U-space support infrastructure for Communication. It encompasses technologies and services that will provide communication among U-space actors. It includes:

    - ground-ground communications among systems and any other stakeholder: Drone Operator/Pilot, ATM, Law Enforcement, Aviation Authority

    - air-ground communications with the drone itself

- **Distance Measuring Equipment:** DME is a ground-based system that transmits a signal to enable aircraft to determine their positions. DME can be paired with VOR or ILS. Several types of DME exist, documented by ICAO in Annex 10.

- **Data Radio Station VDL2:** The Air-to-Ground (A/G) Datalink radio infrastructure enables air-ground data communication with aircraft via Datalink. The infrastructure combines radio equipment, antennas, base-station controllers (BSC), and cabling.

- **Ground ATM Networks:** The European IP (Internet Protocol)-Based backbone network provides data, and voice services and comprises PENS, sub-regional, and national IP networks.

- **GBAS Ground station:** Ground Based Augmentation System (GBAS) is a civil-aviation safety-critical system that supports local augmentation of the primary GNSS constellation(s) by providing enhanced levels of service that support all phases of approach (precision and non-precision), landing, departure, surface operations and it may support additional operations: en route and terminal operations. While the main goal of GBAS is to provide integrity assurance, it also increases the accuracy. The technology can be based on GPS L1 providing Cat I, GPS L1 providing up to Cat III, and Multi-Constellation / Multi-Frequency GBAS providing up to Cat III with improved integrity and availability compared to GBAS based on GPS L1 only.

- **ILS:** Provides precision approach and landing by broadcasting of the VHF (localiser) and UHF (glideslope) signals. ILS systems are providing globally the prime means for precision approach and landing, and will remain initially the prime source for precision approach and landing in the coming years.

- **Navigation Infrastructure:** U-space support infrastructure for navigation. It encompasses technologies that could provide signals in space to allow drone positioning and navigation (e.g. satellite-based or ground-based).

- **Non-directional beacon:** NDB transmits a continuous signal on a frequency between 190 and 1750 kHz, which acts as a radio landmark for flights. Each NDB is identified by a two- or three-letter Morse Code group which is transmitted at approximately seven words per minute. This object covers all NDB systems, including individual NDBs.

- **Primary Radar:** provides surveillance information of all aircraft regardless of their equipment. PSR civil radar only allows determining the position of the aircraft range and azimuth, it does not provide other information such as altitude or aircraft identification. This is commonly used in the APP of high-density traffic airports. The majority of PSR radars for TMA operate in S-Band, while the longer-range radars operate in L-Band.

- **Remote Pilot Station:** This technical system allows the Remote Pilot to perform all the on-board AU operations transmitting/receiving data to the Remote Piloted Aircraft.

- **SATCOM (Class A):** The “Long Term” or “Class A” Satellite Communications (SATCOM) system for Air/Ground datalink enables ATC, Air Operator Certificate (AOC), and voice services over continental and oceanic airspace for supporting the future concepts beyond 2020. It is based on ATN/IPS networks, either in a stand-alone or multi-link environment. It is an essential part of the seamless, resilient, and integrated Future Communication Infrastructure to allow the real-time sharing and management of 4D trajectories and timely access to ATM data and information services. SATCOM Class A systems provide improved datalink performance meeting ATN-B2 (and beyond, ATN-B3 once defined) requirements (latency, availability, continuity) and secure communication.

- **Secondary Radar:** SSR is used for En-Route and Approach surveillance. It provides the position (range and bearing) of the aircraft as well as its identity (Mode A code) and altitude (Mode C code). The SSR transmits signals on 1030 MHz and receives signals from the transponder on




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1090 MHz. Mode S SSR (Select) has been replacing the classic Mode A/C interrogation/reply scheme by identifying each aircraft using a unique 24-bit address. This mode allows downloading additional airborne data from the aircraft for elementary and enhanced surveillance.

- **Space Based Augmentation Systems:** SBAS, i.e. EGNOS are civil aviation safety-critical systems that support wide-area or regional augmentation through a monitoring and reference stations network and geostationary (GEO) satellites at 35,786 km altitude, which broadcast GNSS augmentation information (correction & integrity).

- **TELECOM (External):** Commercial Telecom providers Communication Systems

- **Video Surveillance:** This system groups all the non-cooperative sensors that can be used for surface surveillance, such as:

    - **Inductive loops:** detection while an aircraft or vehicle is passing over a loop and delivering positioning information. This makes it possible to track mobiles entering and exiting the monitored area
    - **Video cameras:** position extracted from video feed and converted to ASTERIX data

- **Voice Radio Station:** Enables voice communication between Flight Operations Centre (FOC), ATC, and aircraft. The infrastructure is generally provided and operated by the ANSPs.

- **Routing Networking Equipment for A/G Datalink:** Represents the ground segment of the A/G datalink infrastructure supporting both Aircraft Communication Addressing and Reporting System (ACARS) and ATN. It is operated and provided by SITA/ARINC. For example, it represents the SITA ACARS networks equipment (end-points routers), the DL Host servers in Singapore or Montreal. For ATN, it represents the A/G ATN routers and the underlying network infrastructure.

- **Wide Area Multilateration:** The wide area multilateration (WAM) system provides real-time accurate and reliable identification and location of aircraft, ground vehicles or object equipped with a Mode A/C/S transponder. The WAM system uses receiving stations that may also provide one or more ADS-B services. Wide area multilateration is a technique used to provide surveillance over a larger geographical area than MLAT.

## 3.3 High level impact of the SESAR solution on the baseline SESAR architecture

| Technical systems impacted by the SESAR solution | Functions/roles impacted by the SESAR solution | Comments on required updates |
|---|---|---|
| Communication Infrastructure | Network architecture | Communication infrastructure and technologies shall use 3GPP specifications. Communication infrastructure shall support ATM and U-space needs, including Traffic Information Service, Collaborative Interface with ATC, Procedural Interface with ATC, etc |
| Data Radio Station VDL2 | air-ground data communication | Aircraft shall carry xG UE, and ground infrastructure shall have xG base station to enable digital air-ground data communication |
| Voice Radio Station | Voice communication | Aircraft shall carry xG UE, and ground infrastructure shall have xG gNodeB to enable digital voice communication |
| SATCOM (Class A) | Datalink and voice services | xG NTN shall be used to deliver the SATCOM (Class A) services |
| Navigation Infrastructure | DME, ILS, MLS, NDB, VOR | Positioning and navigation services shall use 3GPP technologies |
| ADS-B Ground Station | broadcasting aircraft position (calculated by onboard GNSS system) | xG A2X link shall be used for broadcasting ADS-B messages, and UAS can use the A2X link for transmission of Remote ID |
| Video Surveillance | Video streaming | xG NR and RedCap should be used for providing high data rate communication to support video surveillance |

Table 6: Systems impacted by the ANTENNAE solution

# 4 Functional requirements

This section discusses the ANTENNAE solution's initial functional requirements for the successful integration of the communication, navigation, and surveillance services in a cost-effective manner using 3GPP xG technologies, particularly A2X, TN, and NTN systems.

- Airborne information system
- Radio link system
- Ground information system

This section presents the functional and interface requirements. They are addressing the "what" and not the "how". Particularly, this section explains what the systems need to do and how they should connect with other systems. It focuses on the functions and interfaces, not on the physical design or technical details — those are left to the industry to develop.

## 4.1 Airborne information system

5G use cases include Ultra-Reliable and Low Latency Communications (URLLC), enhanced Mobile Broadband (eMBB), and massive Machine-Type Communications (mMTC) for the TN systems. Due to high propagation delays and long link distances, URLLC is not feasible with NTN, especially satellites. IMT-2020 ITU-R M.2514-0 defines Highly Reliable Communication (HRC) as an alternative to URLLC for 5G NTN. eMBB offers high data rates using 5G NR technology, while mMTC uses NB-IoT/eMTC technologies to support low data rate applications. ANTENNAE solution proposes that an aircraft shall carry xG multi-mode transceivers, allowing aircraft to select the most suitable RAT based on the requirements of CNS services.

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI01.0001 |
| Title | Aircraft onboard radio transceivers |
| Requirement | Aircraft radio transceivers/UE shall have multi-mode capabilities, a small form factor, and low energy consumption |
| Status | <in progress> |
| Rationale | UE design shall be lightweight, compact, and energy-efficient to minimize dependency on large batteries and to reduce the impact on UA payload capacity. These aspects will allow UE to be incorporated into a small UA. |
| Category | <Design> <Functional> |

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI01.0002 |
| Title | Multi-mode onboard capabilities |

| | |
|---|---|
| Requirement | The aircraft radio transceivers/UE shall support multi-mode RAT capabilities, including but not limited to xG NR, RedCap, and NB-IoT. |
| Status | <in progress> |
| Rationale | Network shall dynamically select and configure the most appropriate RAT and associated parameters following the performance requirements of CNS services. Critical CNS services, such as command and control (C2) links for UAS, demand higher reliability and lower latency than non-critical data streams. Therefore, xG NR shall be used for high data rate CNS services, including the C2 link for UAS. RedCap shall support mid-range CNS services. NB-IoT shall be used for short data transmissions e.g., ACARS, telemetry. |
| Category | <Design> <Functional> |

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI01.0003 |
| Title | Seamless RAT Handover |
| Requirement | The onboard communication system shall support seamless handover between supported RATs, ensuring continuity of CNS services during transitions. |
| Status | <in progress> |
| Rationale | Unmanned and manned aircraft require uninterrupted communication links. Seamless handover guarantees the continuity of CNS services. |
| Category | <Functional> |

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI01.0004 |
| Title | Priority-based CNS data scheduling |
| Requirement | CNS data scheduling mechanisms shall have the ability to prioritize transmissions based on service criticality and latency sensitivity. |
| Status | <in progress> |
| Rationale | ICNS data shall be handled according to the needs of the required performance of each service. Prioritizing critical data over non-time-sensitive traffic will ensure optimal use of available network resources. |

| | |
|---|---|
| Category | <Data> <Functional> <Safety> |

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI01.0005 |
| Title | Cost-based CNS data scheduling |
| Requirement | Cost-based CNS data scheduling mechanisms should be used to strategically select the suitable RAT and a radio link in a cost-efficient manner. |
| Status | <in progress> |
| Rationale | ANTENNAE solution (SESAR Solution 0521) should implement a cost-based scheduler to strategically select the most economical yet suitable RAT (e.g., xG NR, RedCap or NB-IoT) and communication path among TN, NTN, or A2X for delivering CNS services. |
| Category | <Data> <Functional> |

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI01.0006 |
| Title | Performance-based CNS data scheduling |
| Requirement | Performance-based CNS data scheduling mechanisms shall be implemented to strategically select the most parameters, configurations, RAT, and radio link based on required performance criteria, i.e., as latency, throughput, and reliability. |
| Status | <in progress> |
| Rationale | The ANTENNAE solution (SESAR Solution 0521) shall include performance-aware scheduling capabilities to select optimal RAT (e.g., xG NR, RedCap, NB-IoT) and communication path (e.g., TN, NTN, A2X) according to the performance requirements of specific CNS services. |
| Category | <Data> <Functional> |

## 4.2 Radio link system

ANTENNAE solution (SESAR Solution 0521) shall use three alternative radio channels for delivering CNS services. The CNS data should be transmitted either through three separate packets or within a single aggregated packet.

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI02.0001 |
| Title | 3D network for delivering CNS services |
| Requirement | A 3D network shall be used to deliver CNS services across large coverage areas and at all altitudes, ranging from VLL to high altitudes. |
| Status | <in progress> |
| Rationale | The TN system shall provide the primary connection in developed areas with ground network infrastructure. NTN shall support CNS operations in regions outside of TN coverage. Additionally, in urban areas, NTN shall help to offload the CNS traffic from TN, reducing congestion during peak hours. In case of a TN outage, NTN shall act as a fallback solution to ensure continuous connection availability and delivery of CNS services, strengthening resilience. |
| Category | <Design> <Functional> <Interface> <Interoperability> |

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI02.0002 |
| Title | Satellite mega-constellation |
| Requirement | Satellite mega-constellations shall provide ubiquitous service availability and continuity |
| Status | <in progress> |
| Rationale | The NTN system shall have SATCOM (Class A) capabilities and shall act as a bridge between aircraft and ground infrastructure to support aircraft-to-ground data and digital voice links for ATM and U-space. SATCOM supporting NTN links shall complement the TN system during congestion and outages. |
| Category | <Design> <Functional> |

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI02.0003 |
| Title | Aircraft-to-Everything (A2X) capabilities |

| | |
|---|---|
| Requirement | A2X links shall be used for short-range CNS and collision avoidance services to enable UA situational awareness in the airspace |
| Status | <in progress> |
| Rationale | A2X radio links shall support short-range aircraft-to-aircraft and air-to-ground communication for exchanging ADS-B, C2, CPDLC, and Remote ID, ACAS/ACAS-Xu messages. Additionally, A2X shall be used to broadcast the beacons. This will allow the ground station to process the beacons for MLAT purposes to ensure A-PNT and A-SUR. |
| Category | <Design> <Functional> |

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI02.0004 |
| Title | ICNS channel bandwidth |
| Requirement | ICNS channels shall have sufficient bandwidth to achieve high data rates, depending on the number of airspace users in the region |
| Status | <in progress> |
| Rationale | At the national level, each State shall determine its spectrum allocation needs based on the number of airspace users. In the ANTENNAE solution (SESAR Solution 0521), a channel bandwidth of 20 MHz is assumed for validation purposes for Ireland's airspace. |
| Category | <Adaptability> <Functional> |

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI02.0005 |
| Title | Network slicing for CNS services |
| Requirement | Network slices shall be assigned to specific CNS services |
| Status | <in progress> |
| Rationale | xG network slicing shall be used to tailor multi-mode RATs to different CNS services. xG NR slices shall provide high throughput and low latency for critical services (e.g., ATC voice, UAS C2), RedCap shall support moderate data-rate needs (e.g., surveillance), and NB-IoT shall be used for short packet services (e.g., ACARS, telemetry). |
| Category | <Data> <Design> <Functional> |

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI02.0006 |
| Title | Smooth handovers between TN and NTN |
| Requirement | Smooth handovers between TN and NTN shall allow the core systems of both networks to work together |
| Status | <in progress> |
| Rationale | ANTENNAE solution (SESAR Solution 0521) shall account for the mobility management techniques to handle the handovers occurring due to aircraft and LEO satellite mobility. The signalling protocols shall be used to communicate properly, making it easier for the aircraft onboard the UE to switch between the TN and NTN options. |
| Category | <Functional> <Interface> <Interoperability> |

## 4.3 Ground information system

A CNS must be resilient against jamming and spoofing threats. It is worth emphasising that both GNSS and ADS-B (which further uses position information derived from GNSS) are vulnerable to jamming and spoofing threats. Additionally, the GNSS signals are weak due to the significant path loss and are not ubiquitous because of the satellite constellation designs. Similarly, the legacy ADS-B coverage is either poor or absent in oceanic/remote areas. Aireon provides a space-based ADS-B solution that supports surveillance in oceanic and remote areas. It is worth emphasizing that the space-based ADS-B solution may lack sufficient capacity to accommodate aircraft in congested airspaces, particularly when the number of manned and UAS traffic will increase in the future. To mitigate GNSS and capacity challenges, A-PNT and A-SUR methods shall be used to ensure the service availability, continuity, and reliability.

ANTENNAE solution will optimize the network coverage for VLL aerial corridors, which are defined by air traffic control authorities. The optimisation should consider improving the performance in pre-defined aerial corridors rather than extending ICNS coverage globally. This would require optimising antenna configurations and steering techniques to provide network coverage in air corridors. Additionally, data packets should be routed according to their Quality of Service (QoS) requirements, reflected in their required performance, through the ICNS network architecture to deliver the CNS data packets to their destinations.

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI03.0001 |
| Title | Optimized aerial coverage |
| Requirement | TN coverage shall be optimised specifically for VLL aerial corridors, which are defined by air traffic control authorities. |
| Status | <in progress> |
| Rationale | It will be more economically feasible to optimize the coverage in pre-defined aerial corridors rather than extending ICNS coverage. To achieve this goal, antenna steering techniques shall be used to provide TN coverage in air corridors. |
| Category | <Functional> |

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI03.0002 |
| Title | xG-based alternative positioning, navigation, and timing |
| Requirement | 5G signals combined with MLAT techniques should be used for A-PNT |
| Status | <in progress> |



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| | |
|---|---|
| Rationale | Compared to GNSS signals, xG signals are significantly more robust to jamming and spoofing threats. In case of GNSS degradation or outage, the envisioned xG ICNS can support navigation by MLAT. ANTENNAE solution (SESAR Solution 0521) should use MLAT-based A-PNT to ensure the accuracy, availability, continuity, and integrity of the services at VLL. |
| Category | <Functional> |

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI03.0003 |
| Title | Alternative Surveillance |
| Requirement | Surveillance data should be conveyed over xG data links |
| Status | <in progress> |
| Rationale | To similar the traditional ADS-B systems, the ANTENNAE solution (SESAR Solution 0521) should transmit surveillance data over xG data links. Joint Communications & Sensing (JCS) should be used as an A-SUR source. |
| Category | <Functional> |

| | |
|---|---|
| Identifier | REQ-ANTENNAE-FRD-DI03.0004 |
| Title | Real-time CNS data sharing |
| Requirement | ANTENNAE solution (SESAR Solution 0521) shall support the real-time exchange of CNS data to ATM and U-space stakeholders |
| Status | <in progress> |
| Rationale | In the ground information segment, the ANTENNAE solution (SESAR Solution 0521) shall include the System Wide Information Management (SWIM) concept enables seamless information access and interchange between all providers and users of ATM information and services. In U-space, the remote pilot station shall be able to perform all the onboard AU operations, transmitting and receiving data to the UA. |
| Category | <Data> <Functional> |

# 5 Assumptions

## 5.1 Common assumptions for the ANTENNAE solution

- **Capacity:** With the addition of the UAS and VCA air traffic, the capacity of the airspace would need to increase for low-altitude operations. Thus, the solution assumes an increase in the surveillance and traffic management capabilities. Besides, new flight routes might be possible since the xG network may provide continuous connectivity by exploiting TN-NTN hybrid connectivity in the areas where coverage is currently missing or subject to overload and congestion.

- **ICNS viability:** ICNS is a key enabler of the UAS and VCA safety and possible coexistence with larger manned aircraft. Thus, it is considered in the solution here proposed that the aircraft, both manned and unmanned, are equipped with ICNS systems and integrated 5G transceivers. Additionally, the different technologies, data messages, and signalling can be differentiated by the network and delivered to their respective peers.

- **U-space deployment:** As U-space is crucial for UAS operation and still under development, we consider that U-space is already available and provides services, including advanced services (U3) and full services (U4), following the U-space regulatory framework and the mission-specific UAS requirements, particularly BVLOS operation. ANTENNAE solution assumes that there is a high degree of integration between ATM and U-space services.

- **Restricted areas operation:** considering the necessary safety requirements for flights above urban areas and airports' vicinity, this solution assumes the existence of restricted and controlled areas where access by certain types of aircraft is permitted only by the respective authorities. UAS and VCA operations, for example, might be restricted by air or U-space corridors, where the traffic of this type of aircraft has minimal impact on other aircraft operations and citizens' safety.

- **Aircraft communication security and redundancy:** Due to their greater exposure to potential threats and lower robustness, UAS and VCA systems are assumed to have the necessary means to reduce or eliminate the effects of jamming, spoofing, and integrity threats. This includes the systems that are providing navigation, positioning, and timing to the aircraft to substitute the CNS services in use by the aircraft.

## 5.2 Specific assumptions for the ANTENNAE solution

- **xG certification:** We assume that aviation and telecommunication authorities would certify xG as safe for aviation use, particularly the application in safety services such as CNS. This includes the xG and xG mobile network providers' conformance in terms of data transmission performance, security and privacy provision, availability, and interference. Also, xG transceiver devices can be embedded in the envisioned aircraft categories and operate in a broad range of aeronautical missions.

- **Future 3GPP standards compatibility:** The solution will be valid for 5G and other future generations.

- **xG coverage:** we assume that a xG network integrates hybrid-connectivity TN-NTN, providing xG coverage continuity and handover capabilities between the networks. This also implies that the NTN, both satellite and HAP, embeds xG capabilities and handovers NTN-NTN are seamless and handled transparently to the user. The xG network, either private or public, is integrated to the ATM and U-space communication service provider, also providing all necessary xG functionalities, such as naming and addressing, mobility, privacy, security, error handling, and data switching.

- **Spectrum availability and interaction with current aeronautical systems:** the spectrum and bandwidth are enough for allowing operations considering the required CNS capacity requirements of at least 5 MHz. The bandwidth by the solution considered is 20 MHz to comply with the TR 36.777 channel model. Although carefully select to minimize the impact on the aircraft and aeronautical systems, the 3GPP n78, i.e., around 3.6 GHz, is considered to be available and licensed for the use proposed by the solution.

- **Network configuration and management policies:** Successful deployment and operation of an ICNS will rely on enabling hybrid networks and interworking between the network segments. The integration of TN with NTN would require integration between the cores of the two networks to facilitate the interworking of signalling protocols needed to enable network user devices (aircraft) to efficiently handover from one network segment to the other (TN to NTN and NTN to TN).

- **Agile network with aircraft-centric mobility design:** The multi-layered integrated TN-NTN architecture requires advanced inter-technology handover mechanisms between different components, for example, the handovers between the aircraft-to-TN segment and the aircraft-to-NTN segment. We assume that the network efficiently handles these handovers.



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# 6 References

## 6.1 Applicable documents

This FRD complies with the requirements set out in the following documents:

### Content integration

[1] ...

### Content development

[2] ...

### System and service development

[3] ...

### Performance management

[4] ...

### Validation

[5] ...

### System engineering

[6] ...

### Safety

[7] ...

### Human performance

[8] ...

### Environment assessment

[9] ...

### Security

[10] ...

### Project and programme management

[11] 101167288 ANTENNAE Grant Agreement, [25/06/2024]

[12] SESAR 3 JU Project Handbook – Programme Execution Framework, 11/04/2022, edition 01.00

## 6.2 Reference documents

[13] SESAR Joint Undertaking, European ATM Master Plan: 2025 edition

[14] M. Asad Ullah et al., "5G Integrated Communications, Navigation, and Surveillance: A Vision and Future Research Perspectives," 2025 Integrated Communications, Navigation and Surveillance Conference (ICNS), Brussels, Belgium, 2025, pp. 1-13

[15] H. Alshaer, A. Ganau, D. Brilhante, C. Cleary, M. A. Ullah and V. Kramar, "Next-Generation Integrated Communications, Navigation, and Surveillance Services," 2025 Integrated Communications, Navigation and Surveillance Conference (ICNS), Brussels, Belgium, 2025, pp. 1-10

[16] FACT Final Concept of Operations, SESAR Joint Undertaking, September 2022.

[17] PJ.14-W2-76, Integrated CNS and Spectrum "CNS Service Assessment".

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[19] PJ14 EECNS, SESAR2020_PJ14_D1.2_Final Project Report_Final_rev04

[20] AiRMOUR, D5.2 UAM EMS Business Models

[21] EUROCONTROL, Communication, Navigation and Surveillance

[22] European Commission, "A Drone Strategy 2.0 for a Smart and Sustainable Unmanned Aircraft Eco-System in Europe", November 2022.

[23] ICAO, Integrated CNSS Project

[24] 3GPP, TR 36.873, Study on 3D channel model for LTE, January 2018

[25] ICAO, Doc 4444, Procedures for Air Navigation Services – Air Traffic Management

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[27] ICAO, "Unmanned Aircraft Systems Traffic Management (UTM) – A Common Framework with Core Principles for Global Harmonization Edition 4", September 2023

[28] ICAO, Cir 328, Unmanned Aircraft Systems (UAS)

[29] Commission Implementing Regulation (EU) 2021/665 of 22 April 2021 on a regulatory framework for the U-space (C/2021/2671)

[30] SESAR Joint Undertaking, SMART ATM U-space and urban air mobility

[31] 3GPP, TS22.125, Unmanned Aerial System (UAS) support in 3GPP

[32] The European ATM Portal, https://eatmportal.eu/