Operational Services and Environment Description for Data Driven Cost Effective 5G Integrated CNS As a Service

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Abstract

This document describes the status of the Operational Services and Environment Description (OSED) for SESAR solution "Integrated CNS in 5G access networks" within the ANTENNAE project, aiming to achieve the Technology Readiness Level (TRL) 2.

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DATA DRIVEN COST EFFECTIVE 5G INTEGRATED CNS AS A SERVICE

ANTENNAE

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1 Executive summary

The performance requirements for communication, navigation, and surveillance (CNS) systems are becoming increasingly complex and demanding, particularly in low altitude operations. ANTENNAE project will develop a techno-economic framework for the deployment of communication (C), navigation (N), and surveillance (S) as separate services, as well as an Integrated-CNS (ICNS) offered as a service or “CaaS” enabled by prevailing 3GPP standards and technologies for 5G/5GA networks.

The ANTENNAE project considers the performance requirements of CNS as part of a holistic Integrated-CNS (ICNS) infrastructure, to achieve cost-effective integrated CNS operations. These represent the pillars for the integration of aircraft in a CNS architecture that streams surveillance and navigation data through closed-loop A2G datalink transport, to support a digital terrestrial integrated CNS as a service (CaaS).

The progressing technology evolution of 5G/5GA (3GPP) standards aligns with the expected technology evolution of CNS and the SESAR JU Program’s expected timeline regarding the maturity of CNS deployment scenarios. Emerging 6G technology has the potential to enhance the longer-term operation of a CNS network via the application of KPIs and incorporation AI to further optimize required performance while maintaining backwards compatibility with 5G/5GA.

The ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521) “Data Driven Cost Effective 5G CNS As a Service” of the ANTENNAE project focuses on the development of a Communications, Navigation, and Surveillance (CNS) infrastructure for low-level operation using 5G. This document defines the Operational Service and Environment Description (OSED) of the project, providing a high-level overview of the project, defining the ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521) while highlighting the characteristics of the environment in which the ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521) is intended to be implemented, and presenting the differences brought about by the new operational methods provided.

The aim of the ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521) is to ensure that the full range of CNS services can be provided at low altitude, using both 5G Terrestrial Networks (TNs) and Non-Terrestrial Networks (NTNs). This initiative is related to the emergence of Unmanned Aircraft Systems (UAS) and the development of U-space within European airspace. The use of 5G would thus enable the implementation of Integrated CNS (ICNS), where the three domains would no longer be separated, enabling improvements in terms of performance (performance-based CNS), spectrum utilisation, and a reduction in the number of on-board equipment required, which is particularly important.

The ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521) will impact a diverse range of stakeholders, including European institutions, Air Navigation Services Providers (ANSPs), standards organisations, aircraft manufacturers, and European airspace users. It hopes to increase traffic capacity in European airspace by contributing to the emergence of a U-space concept which is similar to the UAS Traffic Management (UTM) concept, reducing costs relative to the CNS technologies currently in use, and improving safety and security.

The project hopes to demonstrate the ANTENNAE solution's (ANTENNAE-01, STELLAR Solution ID 0521) technical and operational applicability at Technology Readiness Level (TRL) 2 using a simulation-based approach, particularly through use cases.

2 Introduction

2.1 Purpose of the document

This document defines the Operational Service and Environment Description (OSED) for ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521) that the ANTENNAE project develops targeting TRL2. The project aims to validate the applicability of 3GPP standards and 5G/5GA technologies for delivering CNS services at low altitudes, considering both Terrestrial Networks (TN) and Non-Terrestrial Networks (NTN).

The possibilities offered by the technologies as an Integrated CNS (ICNS) service, will be investigated. A particular focus is on the urban environment, where operations are diversifying and intensifying, especially with the anticipated emergence of Very Low Level (VLL) and Low Level (LL) operations of Unmanned Aircraft Systems (UAS) and Vertical Take-Off and Landing (VTOL) Capable Aircraft (VCA).

The aim of this document is, therefore, to introduce the initial operational service and environment description (OSED) for the ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521) ANTENNAE in this version. The document describes the approach established to study the feasibility of using 5G terrestrial and non-terrestrial networks to provide ICNS services at low altitude, specifically for UAS and VCA operations.

2.2 Scope

This document's scope is set based on a detailed review of the main objectives of Work Package 2, “Integrated CNS in 5G access networks,” of the ANTENNAE project. It also provides a guideline for the research and simulation phases arising from the project's progress.

The ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521) ANTENNAE, Integrated CNS, is expected to help meet the need for integration between Air Traffic Management (ATM) and U-space/UTM, enabling more efficient and safer use of airspace, particularly in urban areas. The document details the solution's environment and the technical challenges it faces.

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

- Air Operator Certificate (AOC) service providers: to prepare for the arrival of new low altitude commercial operations,
- Standardization bodies: to establish new aviation and telecommunications standards adapted to the new use of airspace and CNS technologies,
- Airport owners/providers: to monitor developments in low-level air traffic,
- Airspace users: to adapt to the arrival of low-altitude operations and to understand how they will be integrated into the airspace,
- Aerospace industry: to understand advances in ICNS and the development and regulation of low-altitude operations,
- Scientific community: to keep abreast of innovative advances in CNS technologies.

2.4 Background

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 evaluated for this purpose [13]. ICNS has also been studied as part of the SESAR PJ14-W2-76 (Integrated CNS and Spectrum) industrial research [14]. As the ANTENNAE solution (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. The Integrated CNS concept was introduced as part of the European Drone Strategy 2.0 [15]. In Europe, EUROCONTROL works on the relevant matters [16]. At the International Civil Aviation Organization (ICAO) level, a dedicated Integrated CNS and Spectrum Project was established [17].

2.5 Structure of the document

The present document is divided into 5 chapters following this structure:

- Chapter 1 – Executive summary: summarises the key elements and concepts of the SESAR solution OSED,
- 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 – Operational Services and Environment Description: contains the document's core. It begins with a detailed summary of the solution and continues with a detailed description of the operating environment, including operational features, roles and responsibilities, and ATM characteristics. It also details the new operating method and compares it with the previous one,
- Chapter 4 – Key assumptions: describes the assumptions made for the different parts of the project,
- Chapter 5 – References: provides a list of the reference documents used in the preparation of this document.

The document also contains one appendix:

- Appendix A – Stakeholder identification and Benefit Impact Mechanisms (BIM): identify the key stakeholders for the project and the benefit impacts at a high level.

2.6 Glossary of terms

Term	Definition	Source of the definition
5GA	In Rel. 18, the 3GPP envisions to enhance the performance of the current 5G standard enabling new use cases, bringing energy efficiency, intelligent Radio Access Network (RAN) automation, non-terrestrial networks, Multiple Input Multiple Output (MIMO) evolution, and including services that focus on uplink communication and connect people moving at high velocities.	3GPP Third Generation Partnership Project [18]
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 [19]
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 [20]
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 initial definition
Low Level Altitude	Altitude within 8 300 metres or 27 230 feet above Mean Sea Level (MSL)	ANTENNAE project initial definition
Very Low-Level Altitude	Altitude below 150 meters or 500 feet AGL	ICAO UTM Framework Edition 4 [21]

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 [22] [23]
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 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) [24] SESAR Smart ATM U-space and urban air mobility [25]

Table 1: glossary of terms

2.7 List of acronyms

Term	Definition
3GPP	3rd Generation Partnership Project
5G	5th Generation of Cellular Network
5GA	5G Advanced
A/C	Aircraft
A/G	Air to Ground
A2X	Aircraft-to-Everything
ACARS	Aircraft Communication Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependant Surveillance – Broadcast
ADS-C	Automatic Dependent Surveillance – Contract
ADS-L	Automatic Dependant Surveillance – Light
ADSP	ATM Data Service Provider

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AeroMACS	Aeronautical Mobile Airport Communications System
AIM	Aeronautical Information Management
ANSP	Air Navigation Service Providers
AOC	Air Operator Certificate
A-PNT	Alternative Positioning Navigation and Timing
A-SUR	Alternate Surveillance
ATC	Air Traffic Control
ATS	Air Traffic Services
ATSP	Air Traffic Service Provider
ATSSS	Access Traffic Steering, Switching and Splitting
ATSU	Air Traffic Services Unit
BLOS	Beyond Line-Of-Sight
BS	Base Station
C2	Command and Control
CNPC	Control and Non-Payload Communications
CNS	Communication navigation surveillance
CPDLC	Controller Pilot Data Link Communications
CSP	Communications Service Provider
DAA	Detect And Avoid
DME	Distance Measuring Equipment
eMBB	Enhanced Mobile Broad Band
ESA	European Space Agency
eVTOL	Electric VTOL
FAA	Federal Aviation Administration
FOC	Flight Operations Centre
FSPL	Free-Space Path Loss

GA	Grant agreement
GEO	Geosynchronous Earth Orbit
GNSS	Global Navigation Satellite System
HAPS	High Altitude Platform System
HPBW	Half Power Beamwidth
ICAO	International Civil Aviation Organization
ICNS	Integrated CNS
ID	Identifier
ILS	Instrument Landing System
INS	Inertial Navigation System
IP	Internet Protocol
ITU	International Telecommunication Union
KPA	Key Performance Area
KPI	Key Performance Indicator
LDACS	L-band Digital Aeronautical Communications System
LEO	Low Earth Orbit
LL	Low Level
LOS	Line-Of-Sight
LL	Low Level
MEO	Medium Earth Orbit
MET	Meteorological Information Management
MLAT	Multilateration
mMTC	Massive Machine-Type Communication
MNO	Mobile Network Operator
MSP	Mobility Service Provider
NDB	Non-Directional Beacon

NM	Network manager
NR	New Radio
NTN	Non-Terrestrial Network
OFDM	Orthogonal Frequency-Division Multiplexing
OSED	Operational Service and Environment Description
PI	Performance Indicator
PPK	Post-Processing Kinematic
QoS	Quality of Service
RAT	Radio Access Technology
RedCap	Reduced Capability
RLF	Radio Link Failure
RNP	Required Navigation Performance
RPA	Remotely Piloted Aircraft
RPS	Remote Pilot Station
RSP	Required Surveillance Performance
RTK	Real-Time Kinematic
S3JU	SESAR 3 Joint Undertaking
SATCOM	Satellite Communication
SDN	Software-Defined Networking
SDO	Strategic Deployment Objective
SESAR	Single European Sky ATM Research
SESAR 3 JU	SESAR 3 Joint Undertaking
SJU	SESAR Joint Undertaking
SRIA	Strategic Research and Innovation Agenda
TN	Terrestrial Network
TRL	Technology Readiness Level

TTT	Time-To-Trigger
UAM	Urban Air Mobility
UAS	Unmanned Aircraft Systems
UE	User Equipment
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

Table 2: list of acronyms

3 Operational service and environment definition (OSED)

3.1 ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521): a summary

The development of low-altitude CNS infrastructure is essential for European airspace. Emerging U-Space/UTM and IAM/AAM concepts envisage a new generation of small, highly maneuverable, and highly automated aircraft operating at low altitudes alongside existing helicopter and general aviation users. The coordination and the deconfliction of large numbers of such aircraft operating in primarily urban environments require new CNS infrastructure to ensure safe and reliable service is provided to passengers, the public, and other stakeholders while supporting complex low-altitude operations.

Current CNS infrastructures offer limited coverage at low altitudes, due to terrain masking, obstacles and low Line-Of-Sight (LOS) probability and airspace surveillance signals. By integrating 5G TNs and NTNs, as shown in Figure 1, the ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521) aims to offer the full range of CNS services to all classes of aircraft operating at low altitudes while supporting key ATM stakeholders, including U-Space Service Providers (USSPs), ANSPs, and aircraft operators.

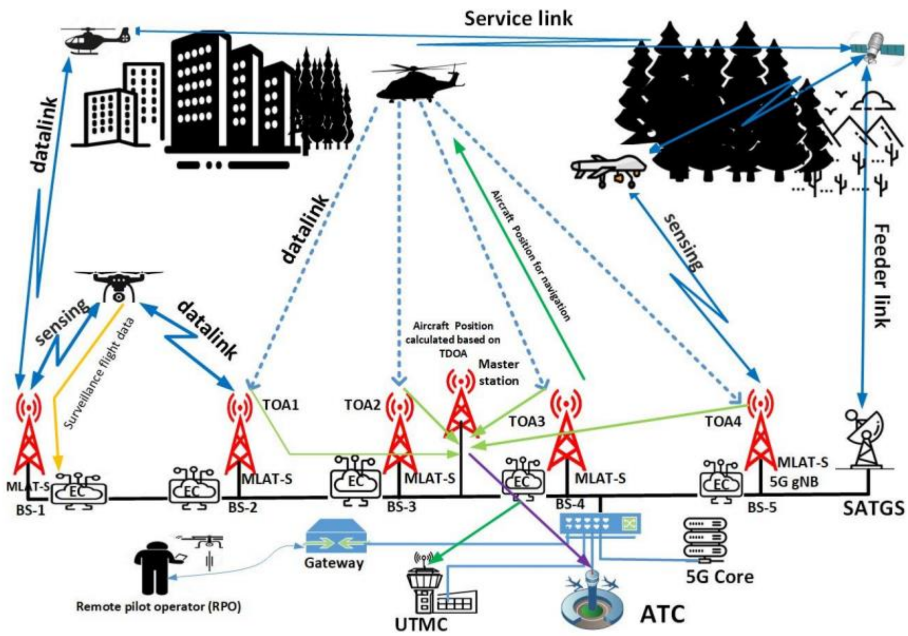

Figure 1: ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521) concept

In the light of these factors, the implementation of a U-Space/UTM appears necessary, in order to ensure their operations and safety. Interconnectivity between aviation actors served by ATM and U-space is crucial, and one of the keys to this interaction is CNS technology for exchanging the critical data.

Currently, the CNS landscape remains fragmented. Each domain is allocated its own equipment on board aircraft and on the ground, sending information over different frequency bands, resulting in inefficient use of spectrum and higher costs. The integrated CNS proposed by the solution would lead to unified use of the same technology stack for all 3 services. The full range of CNS services could therefore be issued to all classes of aircraft operating at low altitude, optimizing performance, spectrum usage, hardware requirements and resistance to jamming and spoofing.

Due to the current generational approach taken by 3GPP in its mobile communication standards, the solution proposes not only investigate the current standard, 5G, but also the future standards that might follow 5G. The rollout of new mobile communication standards became very diligent since 4G/LTE, favoring gradual migration to the new standard, backward compatibility and coexistence with the previous standard. Therefore, the MNOs can commit to a long-term investment in updating their network due to the equipment long lifespan. Also, the end users have time to adequate with the new technology, since the previous standard will stay in service for 5 to 10 years, on average. Finally, the solution targets xG, which comprehends 5G and the further standards, but in this document, we refer to 5G due to the wide availability of documents, standards, and ubiquity in Europe.

SESAR solution ID	**SESAR solution title**	**SESAR solution definition**	**Justification (why the solution matters?)**
0521	Integrated CNS in 5G Access Networks	With the emergence of Unmanned Aircraft Systems (UAS), there is a growing need to provide reliable CNS services at low altitudes. To meet this need, solution 0521 proposes to use 5G networks to provide the full range CNS services by integrating these previously separate activities, using both terrestrial and non-terrestrial networks. The aim is to ensure that CNS services are provided to all low-altitude aircraft, focusing primarily on an urban environment, where UAS, VCA helicopters and general aviation will coexist. This integration of the 3 domains, the ICNS, will offer improvements in terms of performance, spectrum utilization, on-board hardware	The 0521 solution fits perfectly into the ATM master plan [20] developed by SESAR, particularly as regards the implementation of U-space and connected ATM. As mentioned in point 3.5 of the 2025 edition of the ATM master plan, the development of new forms of mobility, of which U-space is a key element, is part of the vision of expanding the use of European airspace. By proposing a means of delivering performance-based CNS services at low altitudes using a commercially available technology, ANTENNAE responds perfectly to the Strategic Deployment Objective (SDO) 10.3 “Implement a common ATM-U-space interface and dynamic airspace reconfiguration service to help Air Traffic Control (ATC) actors in charge of airspace

		requirements and resistance to jamming and spoofing.	reconfigurations to increase safety, keeping crewed and uncrewed aircraft segregated within the designated U-space airspace". It also meets the expectations for U-space set out in the Strategic Research and Innovation Agenda (SRIA) (SRIA point 3.4), and its seamless integration with traditional ATM (SRIA 2.2.2).

Table 3: ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521) scope

3.1.1 Deviations with respect to the SESAR solution definition

At the moment, solution 0521 does not cause any deviation from the existing SESAR solution definition.

3.2 Detailed operational environment

3.2.1 Operational characteristics

3.2.1.1 Low altitude definition

As solution 0521 focuses on the use of ICNS for low-altitude operations, it is necessary to identify its properties. Indeed, different definitions can be found depending on the institutions and projects carried out beforehand. FACT project [13] targets flight operations at 3,500 ft, 3,500 ft, and 300 ft for fixed-wing, helicopter and drone scenarios, respectively.

The ANTENNAE project researches the low-level altitude from three different perspectives, which are the following:

1. Communications policies,
2. Aviation policies,
3. Aircraft state-of-the-art.

3.2.1.1.1 Communication policies

The 300 m altitude limit was introduced in the 3GPP TS 22.125 standard [26] as suitable for the operations of UAS, and it is expected that modern cellular technologies built upon 3GPP specifications ensure coverage up to such altitude.

3.2.1.1.2 Aviation policies

ICAO's Unmanned Aircraft Systems Traffic Management (UTM) – A Common Framework with Core Principles for Global Harmonization document, Edition 4, states that:

"A significant amount of UAS operations are expected in the low-level environment and above populated areas, with various types of operations and UA. This will likely include:

- operations at altitudes in the very low-level structure (e.g. below 150 metres or 500 feet above ground level (AGL))"

Thus, VLL operations may be considered those that are conducted within 150 metres or 500 feet AGL.

ICAO's EUR SIGMET and AIRMET guide, Edition 5, 2023 [27], states that: "The main purpose of this document is to provide guidance for standardization and harmonization of the procedures and formats related to the occurrence or expected occurrence of specified hazardous en-route weather conditions that may affect the safety of aircraft and **low-level aircraft operations**, known as SIGMET and AIRMET information".

The following definitions are provided:

GAMET: This is an area weather forecast for low-level flights, typically covering the airspace from the ground up to FL100 (10,000 feet). In mountainous regions, the upper limit can be FL150 (15,000 feet) or higher.

AIRMET is "Information concerning en-route weather phenomena which may affect the safety of low-level aircraft operations".

These advisories are issued for weather conditions that may affect aircraft operations at altitudes below FL240 (24,000 feet). They provide warnings about moderate weather phenomena like turbulence, icing, and visibility issues.

3.2.1.1.3 Aircraft state-of-the-art

Table 4 lists twenty VCA along with their typical and maximum operational altitudes.

#	Aircraft Name	Manufacturer	Typical Altitude (ft)	Max Altitude (ft)
1	BlackFly	Opener	1200	4000
2	SureFly	Workhorse Group	1500	5000
3	Zeva Zero	Zeva Aero	1500	5000
4	CityAirbus NextGen	Airbus	2000	5000
5	VoloCity	Volocopter	1500	6500
6	ALIA-250	BETA Technologies	4000	8000
7	Bell Nexus	Bell Helicopter	4000	10000
8	Aurora eVTOL	Boeing (Aurora)	4000	10000
9	Wisk Generation 6	Wisk Aero	4000	10000

10	AutoFlight Prosperity I	AutoFlight	4000	10000
11	Manta ANN2	Manta Aircraft	4000	10000
12	VX4	Vertical Aerospace	4000	10000
13	Lilium Jet	Lilium GmbH	4000	10000
14	Midnight	Archer Aviation	3000	10000
15	PAL-V Liberty	PAL-V	3500	11480
16	EH216-S	EHang	2000	11500
17	Joby S4	Joby Aviation	4000	15000
18	Pipistrel Nuuva V300	Pipistrel (Textron)	7500	20000
19	TriFan 600	XTI Aircraft	17500	25000
20	QUANT	nanoFlowcell	19061	27230

Table 4: Operational altitudes of existing and expected VCA.

Out of all VCA expected on the market, two have the highest operational altitude. Those are [28]:

- XTI Aircraft TriFan 600, 7620 m (25 000 ft)
- nanoFlowcell QUANT, 8 300 m (27 230 ft)

Even though the average typical operational altitude is 4,813 ft, seventeen out of twenty aircraft intend to operate within 4,000 ft, within the average number. Even though the average maximum altitude is 11,186 ft, fourteen out of twenty aircraft have the maximum altitude within 10 000 ft, under the average number.

It is essential to mention that starting from 10 000 ft MSL, there are some specific requirements for pressurised and unpressurised aircraft for the use and/or supply of oxygen.

3.2.1.1.4 Summary for the altitude within the project focus

The ANTENNAE project continues to research the properties of low-altitude operations. Given the above observations, the current assumption is the following:

1. 10 000 ft MSL is an upper limit for low-altitude IAM operations
2. The focus of the project to operations within 4 000 ft AGL, where the majority of the IAM operation is expected to take place.

Using MSL as the upper limit for IAM operations is required due to the technical capacity of IAM aircraft and specific requirements for operations at higher altitudes.

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

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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 is 500 ft (150 m). As stated earlier, 3GPP specifications ensure cellular network coverage up to 1 000 ft (300 m). The ANTENNAE project will investigate whether the same set of technological solutions can ensure CNS services across the entire operational altitude, up to 1200 m AGL, or if two different solutions will be required to serve the lower and higher ranges of that altitude.

3.2.1.2 Airspace delimitation

In the context of the SESAR 0521 solution, the operational environment can be divided into two sub-categories: within the vicinity of an airport or vertiport, and beyond the vicinity of an airport or vertiport. For these areas, most countries use Class C airspace, as defined by ICAO. An approximation of the size of these areas can be obtained from the Federal Aviation Administration (FAA), which indicate that below an altitude of 1200 ft (~ 366 m), the airspace coverage area should have a radius of 5 NM (~ 9260 m) [29]. In this document, range will therefore be defined as a radius of 5 to 10 km around an airport zone. The differences in the implementation of the solution for these two environments are discussed in section 3.3.2**Error! Reference source not found.** of the document.

3.2.1.3 Airspace traffic

At this altitude, Solution 0521 is built in anticipation of the arrival of a new type of air traffic, UAS and VCA. The evolution of airspace, and more specifically urban airspace in the vicinity of an airport, would tend towards the implementation of a shared airspace between UAS, VCA, helicopters and general aviation. The solution would therefore apply at all times in this context.

3.2.1.4 5G Terrestrial network

In Release 15, the 3GPP laid the foundations of UAS and VCA communications by investigating the use of LTE advanced. In this study findings indicates that ground and aerial users might be differentiated, as the interference affecting the aerial users increase with the altitude due to the exposition to a greater number of Base Station (BS). In later releases, the 3GPP continued to push the development of UAS use cases and standardization of communication interfaces and procedures. Thus, solution 0521 seeks to explore the same ground network framework used in 3GPP TR 36.777 [30] which consists of 25 m BS with down tilted transmitting at power of 43 dBm for users on the ground and aerial users with altitude between 25 m and 300 m, also providing the path loss models for urban macro-BS, rural macro-BS and urban micro-BS. The only difference to this framework is the central carrier frequency, which is the n78 (3.6 GHz) and 20 MHz bandwidth, more suitable for the geographical area the solution targets. Every cell is installed with an antenna that irradiates the radiation pattern as described by the 3GPP in table 7.1-1 of [31]. The propagation channel model proposed by 3GPP for aerial UEs in the Annex B of [30].

3.2.1.5 Non-terrestrial network

High Altitude Platform System (HAPS) services are focused on covering areas where ground networks cannot provide enough coverage. For example, a corridor for low-altitude aircrafts approaching an airport may be covered by HAPS, whose altitudes range from 18 km up to 20 km, much lower than Low Earth Orbit (LEO) satellites. HAPS can reduce the latency and increase the capacity due to the shorter distance, while the deployment and maintenance are less expensive and complex than satellite

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networks. HAPS experience significantly less path loss and Doppler shift compared to satellites. The Solution 0521 aims to exploit HAPS at an altitude of 18 km, a transmission power of 43 dBm in the service link (downlink), an S-band carrier frequency at 2 GHz, and a bandwidth of 20 MHz

Solution 0521 considers a LEO satellite constellation configuration based on a LEO satellite deployment operating in the Ka-band at 20 GHz. Due to the severe path loss, the link performance is compensated with a 400 MHz bandwidth to offer high data rates. The constellation is comprised of 308 satellites on a circular orbit with an altitude of 550 km and 24 orbital planes with an inclination of 53º. The weather effects on the satellite and HAPS links are not considered and the propagation channel model used is Free-Space Path Loss (FSPL) [32] plus atmospheric attenuation, as defined by ITU-R P.618.8 [33].

3.2.2 Roles and responsibilities

Many stakeholders will be involved in the operational implementation of the 0521 Solution. The main roles and responsibilities are listed below. Further details on the implication of SESAR architecture stakeholders are available in appendix A.1.

- **Air Traffic Service Provider (ATSP):** Integrated national Air Traffic Service (ATS) provider responsible for producing part of the data required for ATS, processing and combining this data to make it available to their controllers and using that data to provide ATS to aircraft via datalink. ATSP are usually part of the Air Navigation Service Provider (ANSP) domain.
- **ATM Data Service Provider (ADSP):** Provider of data and applications supporting the provision of ATS and aircraft operation. The ADSP can be part of ANSP domain or be an entity independent to the ATSP. ATM data relies on underlying integration services for weather, surveillance and aeronautical information. Data services include flight data processing functions like flight correlation, trajectory prediction, conflict detection and conflict resolution, arrival management planning, and Aeronautical Information Management (AIM)/Meteorological Information Management (MET).
- **Communications Service Provider (CSP):** The CSP provides communication services for air navigation and operation. This involves providing the network connectivity between ground and/or aircraft located IPS hosts, the movement across the communication infrastructure in the role of Mobility Service Provider (MSP), and security related features. The CSP may also be an Access Service Provider (ASP) to provide access to aircraft, in which case it is called an A/G Communications Service Provider (ACSP). For this purpose, CSPs can establish and manage relationships with ASPs. In the future it is foreseen that the CSP role is to be managed at a common European service provision level, at a minimum for ATN datalink backbone services,
- **Access Service Provider (ASP):** The ASP is the operator of Radio Access Technology (RAT) providing Air to Ground (A/G) datalink communications with aircraft accessing the network. This role is dependent on the functions (medium access, link control, handover, roaming, and Layer 2 security) supported by the specific radio communication infrastructure technology (e.g. L-band Digital Aeronautical Communications System (LDACS), Aeronautical Mobile Airport Communications System (AeroMACS), Internet Protocol (IP) Satellite Communication (SATCOM) or IP Very High Frequency (VHF) Data Link Mode 2 (VDLM2)),
- **Network manager (NM):** The Network Manager manages regional air traffic management network functions as well as scarce resources (e.g., radio frequencies) in Europe. It monitors

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the performance of ATC datalink and reports appropriate statistics for the network datalink to allow stakeholders to understand how well the system is performing on a regional (Europe-wide) basis. The NM will also provide insight as to why the system is performing the way it is and recommendations on how to tackle system-wide issues,

- **Aircraft (A/C):** This actor involves the ensemble of human (flight crew) and automated systems on-board an aircraft operated by an airspace user, communication functions (including radio) and managing applications on Internet Protocols Suite (IPS) hosts within the aircraft mobile subnetwork,
- **Flight Operations Centre (FOC):** This actor represents an airspace user coordination hub centralizing the tasks of flight planning and monitoring. The FOC manages the AOC communication with its operated A/C, and shares ATM information for coordination and situational awareness with ADSP.
- **Remote Control Station (RCS):** A dedicated station which controls and monitors UAS using Command and Control (C2) link.

3.2.3 CNS/ATS description

3.2.3.1 ATM

ATM is an essential component of the aerospace operation, responsible for controlling the safe and orderly traffic flow of aircrafts, with the collaboration of multiple agents, including the flight crew and ground-based functions. The current ATM fragmented architecture results from individual deployments in national borders that do not or barely share information or interoperate among them and the communication is heavily dependent of LOS links which require the aircraft to be in range and sight of the TNs and NTNs. Hence, ATM is only available for high-altitude and controlled airspace aircrafts such as commercial and military airplanes. Mission critical aerial vehicles, for instance, Helicopter Emergency Medical Services, Search and Rescue Aircrafts, and helicopter taxi are also managed by ATM although might be encountered out of controlled areas due to its purpose.

Between the most used communication mediums the VDLM2 provides data connectivity between aircraft and ground networks. Additionally, satellites may act as a relay between aircraft and ground infrastructure to support air-to-ground data links for ATM and expand the coverage to remote areas, especially in oceanic regions, not covered by ground-based infrastructure.

3.2.3.2 U-space/UTM development and implementation

The arrival of UAS in airspace requires the deployment of a new dedicated traffic management ecosystem, the U-space, to ensure the safety and proper conduct of operations. This new system would be found at low altitude, where operations of this type take place. The main objective with U-space is to provide cooperative interaction between UAS pilots, service providers, and aviation authorities to visualize and assess real-time airspace status. The development of U-space must include several communication systems, for example, C2 links between the controller and the UAs, aircraft-to-aircraft between two or more UAs, and between UAs and manned aircraft, application of Detect and Avoid (DAA) and between remote controllers and U-space and ATM.

The resources required to meet the UAS demands may vary according with the nature of the mission being performed, defining connectivity and operation standards, for instance, aircraft separation, airspace restriction, and CNS services. Bi-directional voice communication is seen as necessary, between remote pilot and the ATC unit, except as the appropriate ATS authority may release depending on the type of mission. Operation close or in controlled airspace will require communication with ATC, via air-to-ground networks (VHF/UHF) or other means, such as satellite or terrestrial relays, data communications, internet-based systems. Third-party service providers may be involved in the communication with the ATC, but it must be transparent to the controllers and abide with the Required Communication Performance (RCP), procedures and guidance provided by aviation authority. Likewise, Required Navigation Performance (RNP) and Required Surveillance Performance (RSP) must be provided by the UA embedded sensors and the respective data links, in terms of accuracy, latency, periodicity, and availability, enhancing the situational awareness of the overall airspace and resulting on a safely shared airspace.

Security is essential for U-space given that UAS might be more exposed to malicious attacks to the wireless data links. For instance, GNSS jamming or spoofing might mistakenly conduct the UA to a controlled or restricted airspace bringing danger to the neighbouring aircrafts or mislead the U-space advisories and other aircrafts situational awareness about an UA position and harm with collision resolution. It is worth to remind that GNSS measurement is very vital for Automatic Dependant Surveillance-Broadcast (ADS-B) based surveillance. Another further instance of security threats is the C2 link intrusion or failure, either if it is a proprietary direct link between Remote Pilot Station (RPS) and Remotely Piloted Aircraft (RPA) or a C2 data link service provided by a third-party, which is responsible for guaranteeing such security and provide contingency methods. In urban areas, drones (or UAs) will/might face additional security risks such as cyber-attacks on communication networks and/or unauthorized access to onboard systems that could compromise navigation and operational integrity. Dense environments can also cause multi-path interference, leading to degraded GNSS accuracy and increased vulnerability to spoofing. For such reasons, security issues must be addressed and mitigations proposed, assuring that all involved parts are in accordance with the safety management system approved by the correspondent civil aviation authority.

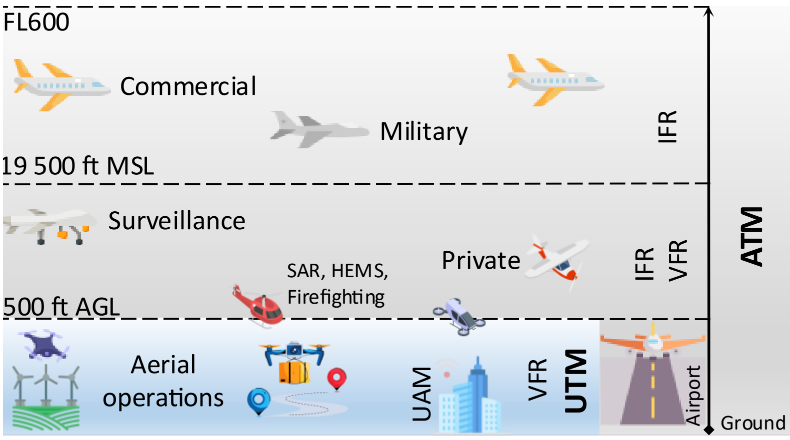

Figure 2: Joint U-space/UTM and ATM organization

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

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3.2.3.3 ATM and U-space/UTM integration

There is an overlap between U-space and ATM, as shown in Figure 3. Their interconnection is crucial and will rely in particular on the use of CNS technologies. An integration between ATM and U-space, as shown in Figure 3, is expected to benefit both systems and potentially enhance the safety of aviation. Such integration requires data exchange between ATM and U-space, which is not yet defined. 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 in a secure way, and relevant U-space data must be available at ATM services to provide the necessary awareness of the U-Space.

Finally, the ATM and U-space services must be viewed as digital data services instead of isolated technologies, allowing interoperability between multiple manufacturers and the automation, and software assistance of low-risk operations. An example of this are 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 industry and academia, the integration between ATM and U-space is seen as further goal on the road to manned and unmanned aircraft coexistence.

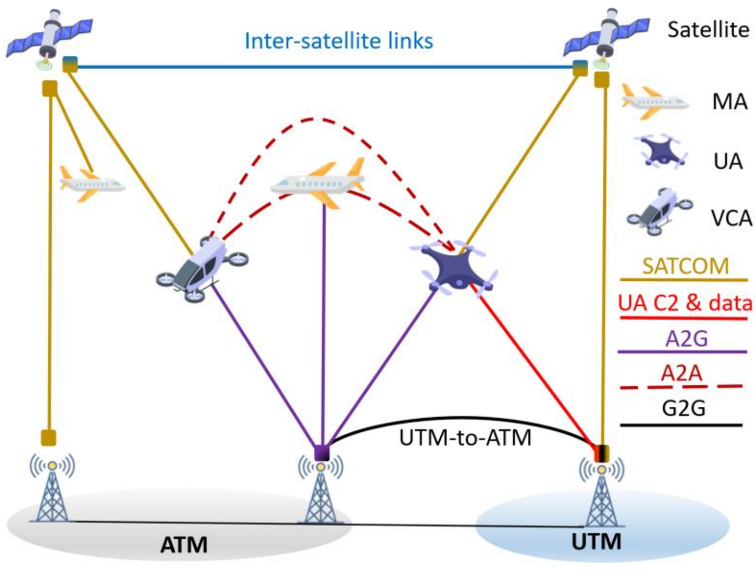

Figure 3: U-space/UTM-ATM integration

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3.2.3.4 Current status of CNS technologies for manned and unmanned aircrafts

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. Likewise, the same technologies are not used depending on whether the aircraft is manned or unmanned, as mentioned in Table 5.

Technology	Manned aircraft	Unmanned Aircraft	Category
Aircraft Communication Addressing and Reporting System (ACARS)	Yes	No	Communication
VHF Data Link (VDL)	Yes	Yes	Communication
Command and Control (C2)	No	Yes	Communication
Control and Non-Payload Communications (CNPC)	No	Yes	Communication
Controller Pilot Data Link Communications (CPDLC)	Yes	No	Communication
Geofencing	No	Yes	Navigation
Inertial Navigation System (INS)	Yes	Yes	Navigation
Global Navigation Satellite System (GNSS)	Yes	Yes	Navigation
Post-Processing Kinematic (PPK)	No	Yes	Navigation
Real-Time Kinematic (RTK)	No	Yes	Navigation
Aircraft-to-Everything (A2X)	No	Yes	Surveillance
Airborne Collision Avoidance System (ACAS)	Yes	No	Surveillance
ACAS Xu	No	Yes	Surveillance
ADS-B	Yes	Yes	Surveillance
Automatic Dependent Surveillance – Contract (ADS-C)	Yes	Yes	Surveillance
Automatic Dependant Surveillance – Light (ADS-L)	Yes	Yes	Surveillance
Distance Measuring Equipment (DME)	Yes	No	Navigation
Instrument Landing System (ILS)	Yes	No	Navigation
Non-Directional Beacon (NDB)	Yes	No	Navigation
VHF Omnidirectional range (VOR)	Yes	No	Navigation
Primary Surveillance Radar (PSR)	Yes	No	Surveillance

Remote Identification of Drones (Remote ID)	No	Yes	Surveillance
Secondary Surveillance Radar (SSR)	Yes	Yes	Surveillance
Traffic Collision Avoidance System (TCAS)	Yes	No	Surveillance

Table 5: Current CNS Technologies and their applicability to manned and unmanned aircraft systems

3.2.3.5 Integrated CNS: principle and vision

Solution 0521 therefore aims to demonstrate the feasibility of an integrated version of CNS, rather than a fragmented one. This system would be implemented using 5G terrestrial and non-terrestrial networks. By taking advantage of 5G's technology, standardized spectrum and compact User Equipment (UE), the solution hopes to bring about interdependence between the 3 domains to take advantage of cross-domain synergies. The advantages and the details of such use are discussed in section 3.3.2.

3.2.3.6 CNS telecommunication technologies

3.2.3.6.1 Terrestrial networks

Aviation's current ground-based communication networks rely on separate datalink technologies that are seen as individual and disaggregated technologies. VHF Digital Link Mode 2 (VDLM2) is a widely used for supporting many legacy aviation communication protocols such as Controller Pilot Data Link Communications (CPDLC) and Aircraft Communication Addressing and Reporting System (ACARS). VDLM2 operates at 136.7 – 136.975 MHz band with 12 channels with 25 kHz bandwidth offering the maximum data rate of 31.5 kbps. LDACS is a potential candidate standard for air-to-ground communication that uses Orthogonal Frequency-Division Multiplexing (OFDM) modulation to support digital data links for ATM functions. LDACS operates at the L-band using 960 to 1164 MHz and offers data rates that can go from 550 kbps up to 2.6 Mbps, depending on the modulation scheme and code rate in use.

Similarly, navigation and surveillance technologies also rely on terrestrial networks. VHF Omnidirectional range (VOR) and Distance Measurement Equipment (DME) are two navigation technologies based on sending beacons to a ground located station, which answer the beacon with a pre-defined delay and then the aircraft can calculate the distance to one station by using the Time Difference of Arrival and its position based on the calculus to multiple stations. Both technologies require dedicated hardware, operating in different spectrum, VOR operates on VHF and DME operates on UHF. Another available technology is Universal Access Transceiver (UAT), which supports the Automatic Dependent Surveillance-Broadcast (ADS-B) protocol, necessary for providing situational awareness information in the surveillance domain. On the other hand, Automatic Dependent Surveillance-Contract (ADS-C) is implemented to use the VHF spectrum to communicate with ground infrastructure. ADS-C and ADS-B send information such as aircraft position, altitude, speed, and meteorological data that will help Air Traffic Services (ATS) and airlines located on the ground to determine if the aircraft is in conformity with the operational and mission standards.

3.2.3.6.2 Non-terrestrial networks

Typically, non-terrestrial networks (NTNs) are the mainly responsible for providing connectivity in remote areas, particularly in oceanic regions, and positioning and timing services. Global Navigation Satellite System (GNSS) is used in many aviation applications for providing positioning and timing for aircrafts systems, being highly accurate and widely used. GNSS can be used in all operational environments including remote and urban areas. Satellite communications can be used for both voice and packet data services for airspace communications, although the latter is still inconsistent due to lack of bandwidth capacity, satellite outages, and insufficient ground stations. These limitations result in interruptions, especially for real-time communications and data transmission during flights. The use of satellites as a bridge between the aircraft and ground infrastructure is the architecture for satellite communication links, using systems such as INMARSAT and IRIDIUM [34]. For example, VIASAT Classic Aero offers communication and surveillance services for packet data including ACARS, ADS-B, and voice services for aircrafts. This service allows continuous tracking, safety reporting, and operational data exchange between the aircraft and ground stations. Another example is the IRIS system [35], a joint program between European Space Agency (ESA) and VIASAT, that provides real-time ATM services via satellite links to offload VDLM2 data links in Europe and support more efficient flight routes and optimised airline operations, reducing cost and CO2 emissions footprint. Therefore, satellite or space-based systems enable efficient airspace operation and management while enhancing flight safety and reducing flight traffic delays.

According to ICAO, satellite communications systems can be categorised into three classes as follows:

- Performance Class C: These are already in use and follow the current SATCOM standards, like INMARSAT Classic Aero, SB Safety, and Iridium.
- Performance Class B: These are improved versions of Class C systems, designed to meet advanced air traffic service (ATS) needs. Examples include INMARSAT SwiftBroadband/Iris and the Iridium NEXT constellation (Iridium Certus service), which are expected to provide AMS® services.
- Performance Class A: These are future SATCOM systems that will enhance and expand Class B systems. They will be developed to meet the aviation industry's future performance requirements.

3.2.3.6.3 Aircraft-to-everything (A2X)

Some actions in the airspace do not depend on a central agent to negotiate or audit it, instead some actions are coordinated between two or more aircraft according with the technology pre-defined rules. A2X links can enable air-to-air communications which can have many functions, including conflicts resolution, trajectory negotiation, and data relaying to increase the communication range and reach the nearest infrastructure. One example of this is ACAS II, a surveillance technology that aims to resolving collision conflicts between two aircrafts equipped with ACAS II gear. ACAS II uses two antennae setups to actively interrogate the transponder of surrounding aircrafts in range in the 1030 MHz frequency (responses occur in the 1090 MHz frequency). Thus, in case a threat has been detected the aircraft with the highest ICAO address coordinates the collision avoidance resolution by sending a traffic or resolution advisory, depending on the level of threat and the aircrafts' 24-bit ICAO identifier [36]. An evolution of ACAS II, ACAS X combines different systems data to leverage situational awareness. Meanwhile its predecessor is deterministic, ACAS X deals with the uncertainty to avoid unnecessary manoeuvres, using a discrete state space and a dynamic programming method to find the lowest cost action for all the parts involved.

The 3GPP introduced A2X in Rel. 18 standard as a 5G sidelink technology. It is designed to enhance collision avoidance mechanisms, ensuring the safety and efficiency of aviation flights. 5G Sidelink technology allows one-hop relay connections, that can be applied to aircraft-to-aircraft and aircraft-to-network connectivity. The former allows that two aircrafts communicate through a third aircraft acting as relay, which increases the range of situational awareness. The latter is focused on extending the network range or providing multi-path robustness, by using an aircraft as relay.

Federal Aviation Administration (FAA) has approved the 5030-5091 MHz band to support UAS control links. Qualcomm is requesting the FCC and advocating the same band for A2X communication with a channel bandwidth of 20 MHz

3.2.4 Applicable standards and regulations

In the context of Solution 0521, the following standards and regulations apply:

- ICAO Annex 2 – Rules of the Air.
- ICAO Annex 10 – Aeronautical Telecommunications Volume III – Communication Systems.
- ICAO Annex 11 – Air Traffic Services.
- ICAO Doc 4444 – Air Traffic Management.
- ICAO Doc 8168 – Aircraft Operations Volume I – Flight Procedures.
- ICAO 9613 - Performance-based Navigation (PBN) Manual.
- ICAO Doc 9924 – Aeronautical Surveillance Manual.
- ICAO Doc 9855 – Guidelines on the Use of the Public Internet for Aeronautical Applications.
- ICAO Doc 9869 – Performance-based Communication and Surveillance (PBCS) Manual.
- Commission Implementing Regulation (EU) 2019/947 – Rules and procedures for the operation of unmanned aircraft.
- Commission Delegated Regulation (EU) 2019/945 – Unmanned Aircraft Systems (UAS) and third-country operator of UAS.
- Commission Delegated Regulation (EU) 2024/1108 - Initial airworthiness of unmanned aircraft systems subject to certification and Delegated Regulation (EU) 2019/945.
- Commission Implementing Regulation (EU) 2024/1110 - Initial airworthiness of unmanned aircraft systems subject to certification and Implementing Regulation (EU) 2019/947.

3.3 Detailed operating method

3.3.1 Previous operating method

As discussed in Section 3.2.3, when describing the CNS and ATM technologies that form part of the context in which the solution is intended to take place, the current vision of CNS is fragmented. This vision was designed and established for manned aircraft and is hardly suited for the VLL in which UAS are expected to operate. Indeed, the three domains are separated in terms of equipment (different transceivers on board aircraft), ground infrastructure and frequency band use, as shown in Figure 4.

As previously mentioned, current telecommunication technologies for CNS are seen as fragmented solutions rather than integrated technologies, which requires multiple equipment. Terrestrial networks (TNs), such as VDLM2 [37], already are in its operational limits in the European continental area, the performance requirements fail to meet the necessary standards in terms of capacity and packet loss due to delays. Likewise, the current non-terrestrial networks require highly directional dish antennas, energy-consuming power amplifiers, and specific service contracts.

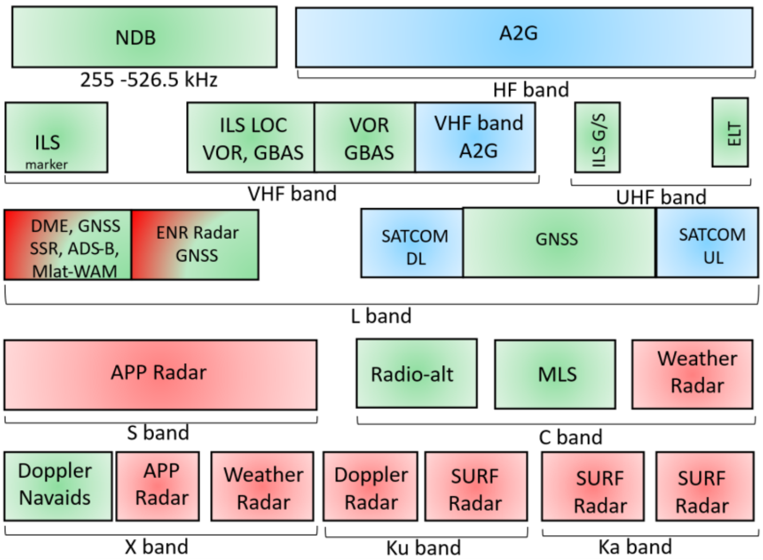

Figure 4: C, N and S domains technologies and spectrum allocation

For UAS, this raises more problems than simply increased costs and inefficient use of the spectrum: weight constraints, limited payload capacity and the energy-use of certain equipment make them difficult to envisage on board such aircraft, especially the smallest. However, it is impossible to imagine a U-space compatible with an ATM without using the same tools. It is also essential to arrive at a solution that offers security and ensures operations run properly: this is the aim of ICNS.

3.3.2 New SESAR operating method

3.3.2.1 5G integrated CNS: operation and improvements

ICNS is based, as its name suggests, on a union of the 3 services, with the aim of offering a performance-based approach for each of these services. To achieve this, Solution 0521 wishes to rely on a hybrid connectivity framework, integrating terrestrial and non-terrestrial 5G networks, as depicted in Figure 5. The role of the TN system will be to provide the primary connection in areas with well-developed ground network infrastructure. NTN, in turn, will support CNS operations in remote regions, i.e., outside of TN coverage, such as oceanic and rural areas. NTN can help to offload the CNS traffic from TN, reducing congestion during peak hours and in high air traffic density areas, such as ESA IRIS system. In case of outage, these networks can act as fallback of each other, strengthening resilience, offering the improved connection availability, service continuity and resilience needed for autonomous operations beyond visual LOS and ATM-U-space integration. Moreover, this integration should extend to the ATM and U-space, increasing airspace safety and U-Space cost-efficiency.

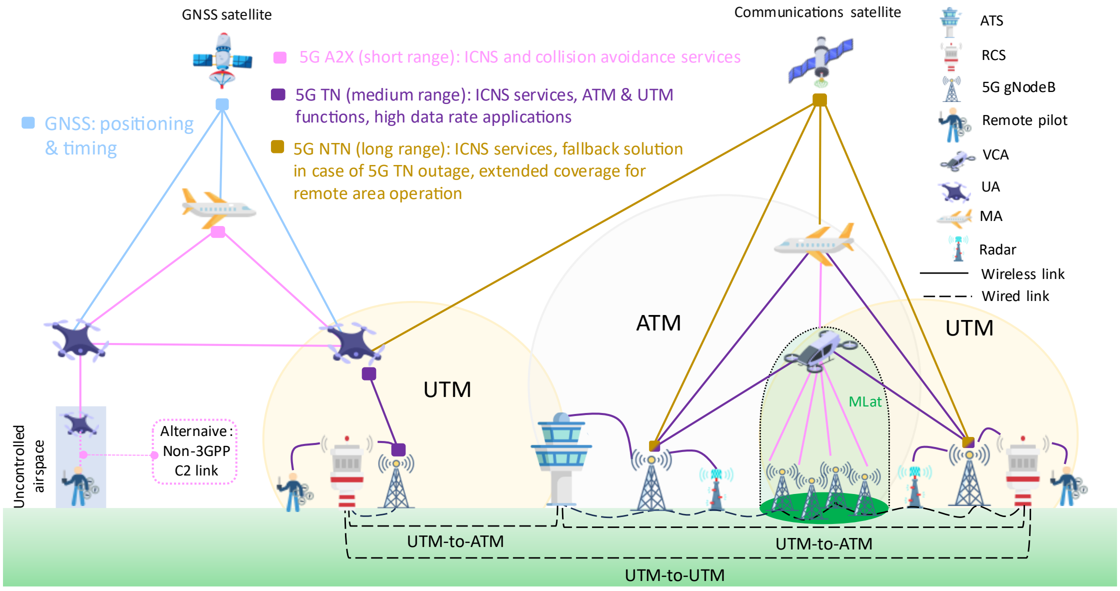

Figure 5: Integrated CNS using 5G terrestrial and non-terrestrial networks

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Such an implementation, based on the single use of 5G, would enable a significant reduction in network complexity and costs, both in terms of spectrum usage, as shown in Figure 6, and in terms of equipment. On the UAS side, the number of on-board hardware devices would also be reduced, consequently reducing weight and power consumption, leading to a reduction in on-board batteries. This solution would also alleviate the jamming and spoofing problems encountered by some widely used equipment (GNSS in particular), since positioning redundancy and cross-check can be providing by using Multilateration (MLAT) solutions and the data privacy can be managed by using secure IP methods. These improvements would offer all airspace users a better quality of service.

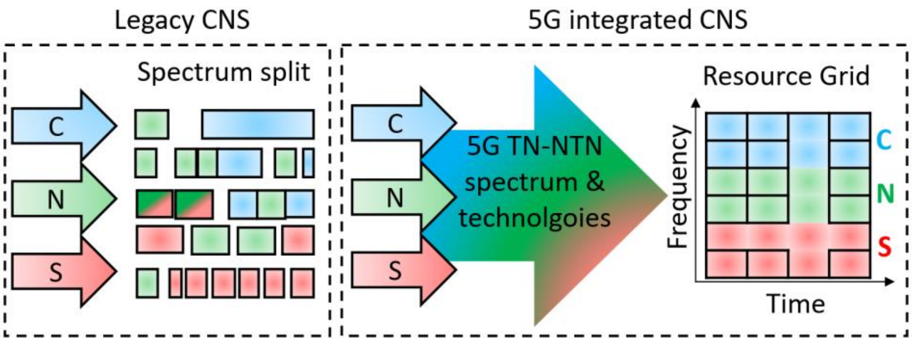

Figure 6: Current CNS system vs 5G integrated CNS system

Present in almost every urban area 5G is a mobile communication technology that offers efficient data rate communications, capable of encompassing CNS services. In addition, other benefits of using these technologies are a large community developing the standard and investigating solutions for the arising challenges, the 3GPP standardization of an interface for A2X communication, and the proposal several use-cases and business models for UAS in recent documents. As a technology that aims to offer multiple use-cases since its beginning, 5G enables Ultra-Reliability Low Latency Communications (URLLC) applications with strict latency (1 ms) and reliability (99.999%) requirements that well suit applications such as intelligent transportation systems and aerospace communications. Additionally, it is possible to mix the three use-cases, URLLC, Enhanced Mobile Broad Band (eMBB), and Massive Machine-Type Communication (mMTC), as depicted in Figure 7. The eMBB is focused on data consuming applications that require massive broadband, such as high-definition video streaming. Targeting the IoT services, mMTC is 5G use-case that attends the IoT demand for a high-density device deployment. These use-cases might be found combined in some applications, for example, intelligent transportation fusion URLLC mMTC application that provides reliable connectivity to a large number of devices to provide road safety and efficiency.

As 5G is under constant evolution, new features and opportunities arise every new release. Introduced in Release 17, Reduced Capability (RedCap) or 5G NR-light, is a low-complexity 5G NR specification targeting IoT devices, for instance, industrial sensors and wearable devices. RedCap introduces energy efficient, less complex, and enhanced performance solution that may be suitable to various applications in the mid-tier broadband IoT segment. Another feature is Access Traffic Steering-Switching-Splitting (ATSSS), which allows to steer the traffic between multiple technologies according to Quality of Service (QoS) requirements. Mainly associated with Wi-Fi, steering refers to the capability of choosing the best link for the QoS, switching describes the possibility of handover between technologies without interruption, and splitting is the capability of using both technologies simultaneously. Thus, this feature might be used to tailor the mechanism for integrating the multiple communication technologies explored in the solution.

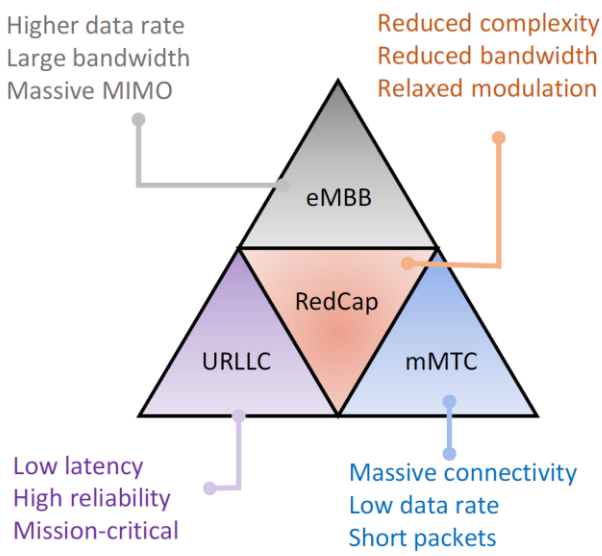

Figure 7: 5G NR use-cases triangle

To help ensuring safety and efficiency on flights, the 5G A2X sidelink technology can be employed. It provides short-range CNS and collision avoidance services to enable aircraft situational awareness in the surrounding area. For example, A2X can support aircraft-to-aircraft and air-to-ground (shortrange) communication for exchanging ADS-B, C2, Remote ID, and ACAS/ACAS-Xu messages. A2X can also be used to broadcast the beacons for MLAT purposes to ensure A-PNT. In the envisioned ICNS framework proposed in this solution, the 5G network can use TN, NTN or A2X to provide highly accurate timing signals to UAS. These timing signals can support RTK-based navigation and geofencing, improving navigation accuracy and surveillance security level.

The major concern with using 5G for aerospace communication is the inter-cell interference. Even with the cells antenna down tilted, in [30] the inter-cell interference perceived by the aircraft flying at low altitude was an issue, hampering the SINR KPI. Besides, the interference caused by aircraft in the ground users also poses a challenge to the Mobile Network Operator (MNO) that must meet both user categories offering the agreed service level performance. Reusing the same spectral resources for coexisting ground and aerial users is beneficial for the MNO and may be offset by the mutual interference they generate. Directionality can also be leveraged at the UE terminal for spatial multiplexing and interference mitigation. These are goals of 5G-and-beyond cellular networks, which aim to employ massive MIMO beamforming technology to ultimately improve the network aggregated capacity.

Moreover, the MNO distribution of the terrestrial BSs might not fully cover the aerial corridor and other areas of interest for crewed and uncrewed aircrafts or yet not offer the service requirements needed in terms of availability, latency, capacity, and reliability. Evaluating whether it is the case for deploying a private 5G network or a hybrid public and private 5G network considering the deployment and operation costs, as well as the resultant performance of each one of these architectures is in the scope of the solution. Due to its flexibility and the recent advancements in wireless Software Defined Networks (SDN), disaggregated and open Radio Access Network (RAN) architectures, cost-efficient and soft management 5G deployments are becoming more and more common.

Typically, aircraft use satellite data links, known as SATCOM, in oceanic and remote areas outside the TN coverage. With the rapid growth of the satellite communications industry, in particular LEO satellites, urban areas, including crowded cities, are now covered by dense low-orbit satellite constellations while complementing TN during congestion and outages. Complementary to the satellites, the HAPS 5G BS can provide temporary coverage in remote areas. Powered with batteries and solar panels or hydrogen tanks, HAPS can provide large area coverage where LEO satellites are not available or when the weather condition are adverse, with 5G connectivity fully compatible with current devices.

3.3.2.2 TN and NTN integration

TNs are used in urban areas due to the ubiquity of 5G ground BS in such areas. To support remote area coverage, NTNs could be used, filling the coverage gaps where 5G ground network is not available because it is not profitable for the network operators. The combined use of TNs and NTNs would enable effective and efficient coverage of territories, reducing costs and the necessity of multiple hardware on board. The recent popularization of LEO satellites pushed by latency-reduced and price competitive communication compared with higher satellite orbits, i.e., Medium Earth Orbit (MEO) and Geosynchronous Earth Orbit (GEO), is considered a mobile communication enabling technology for aerospace services, such as CNS. Additionally, HAPS are also considered to provide coverage on remote areas and redundant connectivity to ground base stations.

However, it should be pointed out that at present, the cellular 4G and 5G devices are not yet capable of communicating directly with satellites. The predominant satellite communication architecture is called "bent pipe" architecture, the satellite acts as a radio relay and the BS is located on the ground. Hence, the higher layer functions, such as handovers, are realised on the ground, increasing the system latency and reducing the architecture flexibility. In this architecture, the satellite simply forwards the received signal to the ground station without processing the data, which limits the ability to handle complex network management tasks in space. Currently, more and more the satellite communication providers are migrating to a regenerative architecture, where the satellite can act as a 5G BS. In this architecture, the satellite is capable of performing signal processing, such as data encoding, modulation, and even routing, directly on board. This architecture also provides satellite-to-satellite communication and better performance in terms of latency and coverage. It is also expected that in the near future the devices will embed the hardware necessary to communicate with regenerative payload satellites and viable solutions are already under test [38], which corroborates to the solution wish to investigate 5G regenerative payload LEO satellite communication.

HAPs also compose the NTNs in the solution, offering a highly configurable connectivity service, that can cover gaps on demand where ground 5G BSs and satellites are not available, for example, when the weather conditions do not favour atmospheric propagation. The cost and availability of HAPs is a concern, however, to design a future-proof solution the addition of this category of wireless communication service is necessary. Nevertheless, HAPs connectivity services currently advertised, by companies as STRATOSPHERIC PLATFORMS [39], are appealing due to its flexibility of deploying multiple mobile communication standards, full compatibility with current devices, satellite-like coverage and tailored deployment.

Moreover, the rules governing handover between TNs and NTNs, and also between different NTNs, have not yet been established. Solution 0521 focuses on exploiting the ATSSS, a 3GPP feature which allows traffic convergence across multiple technologies (including 3GPP and non-3GPP), to evaluate TNs and NTNs integration. Attaining smooth connectivity between the TNs and NTNs networks may provide resilience and redundancy to crewed aircrafts and U-Space CNS services. Also, this integration can foster CO2 emissions footprint reduction due to more direct and efficient flying routes, without the necessity of flying only above the ground network covered areas. Thus, methods to offload the CNS traffic through the network according to the capacity, availability, and cost will be object of investigation of the proposed solution.

3.3.2.3 Alternative Position, Navigation and Timing (A-PNT)

GNSS, although widely used for navigation, has many limitations and vulnerabilities. The risks of interference, jamming and spoofing make it necessary to find alternative solutions to ensure a safe and robust service.

A-PNT relies on the use of other technologies to complement GNSS. Following a similar modus operandi to MLAT, it would be possible for an aircraft to use 5G signals to determine its position. Solution 0521 is therefore particularly well suited to the use of A-PNT for low-altitude operations, increasing the accuracy, availability, continuity and integrity of the navigation system.

3.3.2.4 Alternate Surveillance (A-SUR)

Surveillance is one of the pillars of ATM, referring to all the systems, processes and techniques used. to monitor in real time the position and status of aircraft operating in a given airspace. As air traffic increases, so does the risk of congestion on the 1090 MHz frequency. This frequency is indeed at the core of some of the most widely used surveillance systems, such as ADS-B. It is therefore necessary to develop new surveillance systems to ensure continuity, safety and minimize the risk of information loss.

A-SUR is based on the use of existing links for surveillance, such as SATCOM, VDLM2, LDACS and 5G. By offering the use of I-CNS via 5G, Solution 0521 is particularly well suited to the use of A-SUR to complement existing ADS-B systems for low altitude operations.

3.3.2.5 Use cases

This sub section contains a list of the high level uses cases ICNS will cover. These use cases are examples of the possible applications the solution 0521 might leverage. In this initial version of the document the following list is not extensible and may be modified in the final version of this document.

3.3.2.5.1 Cellular network optimization for aerial users

3.3.2.5.1.1 Cell shaping and coverage optimization for aerial users

A key enabler of connectivity for low level operations is the ability to reconfigure the terrestrial network to support not only ground users but also aerial platforms at various altitudes. Traditional cellular networks are designed with ground-based coverage in mind, using down-tilted antennas and narrow beam patterns to optimize signal strength at street level and reduce interference between neighbouring cells. However, this configuration becomes a limiting factor for aerial connectivity, as most of the radiated energy is focused downward, leaving the sky poorly covered and making aerial link quality highly variable. To address this, cell shaping techniques must evolve to provide 3D coverage, steering a portion of the antenna radiation upwards without compromising ground-level performance. This requires fine-tuning antenna parameters such as the down-tilt angle and the Half-Power Beamwidth (HPBW), which directly impact the coverage footprint and interference profile of each cell. Yet, such tuning is not straightforward, as changing the settings of one BS affects others in its vicinity, turning the problem into a highly coupled optimization challenge.

Current practices often rely on iterative, trial-and-error adjustments using radio planning tools, which are time-consuming and fail to scale for highly dynamic aerial scenarios. Instead, future network deployments will need to embrace data-driven optimization frameworks that can exploit real-time network data and predictive models to dynamically reconfigure antenna patterns. Machine learning approaches, in particular, offer a promising path to automate and accelerate the process, adapting cell configurations to varying densities and trajectories of both manned and unmanned aerial vehicles. By doing so, 3D cell shaping becomes a cornerstone for reliable and scalable aerial connectivity, ensuring that coverage and capacity are maintained across the full vertical dimension of the airspace.

With the cell shaping and coverage optimization for aerial users use case the solution is aiming on:

- Evaluating data-driven machine learning optimization methods for 3D cell shaping in 5G networks for aerial connectivity.

3.3.2.5.1.2 Mobility management for aerial users

As the density of cellular networks increases and their use expands into three-dimensional airspace, handover mechanisms face new levels of complexity. Ensuring seamless connectivity for aerial users—who often move at high speeds—requires a more sophisticated approach to mobility management than that used for ground users. In conventional networks, handover settings such as the A3-offset and Time-To-Trigger (TTT) are statically defined per cell and tuned for ground-level mobility. However, this approach quickly breaks down in large-scale, heterogeneous networks where the mobility patterns of aerial users vary widely and experience the unique characteristics of airspace propagation. Aerial users may be particularly prone to experiencing unnecessary handovers—commonly known as ping-pongs—due to the strong LOS conditions that increase interference from neighbouring cells. At the same time, if handover decisions are delayed, high-speed aerial users may travel too far into a target cell before the handover is completed, resulting in degraded link quality or even Radio Link Failure (RLF). These conditions not only disrupt the quality of service but also lead to excessive signalling overhead, putting additional strain on the network.

To overcome these challenges, mobility management could move beyond static, one-size-fits-all configurations, since a network-wide handover policy may not efficiently support the diverse speed profiles, mobility patterns, and altitudes of aerial users. Instead, a more granular, adaptive approach could be used to tune mobility parameters such as TTT and A3-offset based on both user-specific and cell-specific contexts. This requires a shift toward data-driven optimization techniques capable of handling the complexity and dynamics of real-world deployments.

Finally, we summarise the mobility management for aerial users use case:

- Assess the performance impact of using dynamic optimized handover parameter to improve network mobility for aerial users.

3.3.2.5.2 Hybrid connectivity

3.3.2.5.2.1 Aerial coverage continuity and handovers

The first use case that arises from the hybrid-connectivity framework is ensuring the coverage in areas where the ground network signal is unavailable or insufficient. In such situations the whole CNS services might be shut off due to lack of communication, putting flight safety and ATM efficiency in jeopardize. To avoid this, the current solution is to take flight routes that fly over ground station coverage for as long as possible and switch to SATCOM when necessary, prioritizing safety services since they are fragmented into different transmission methods. This approach is also not feasible for U-space and does not enable ATM-U-space integration. First, because in U-Space CNS case the drones do not have enough physical space, payload, and power supply capability to carry various equipment to generate and transmit CNS information. Second, the fragmented current solution does not consider the numerous drones flying and the dynamic of their flight paths, which requires U-Space automation and precise and highly available CNS services coverage. On the other hand, by integrating TN and NTN and enabling hybrid-connectivity, we aim to not only increase the coverage and provide connectivity in remote areas, but also to increase the overall network capacity and reduce the latency to meet the growing number of manned airplanes and drones, supporting all sorts of business models these aircrafts may leverage.

Likewise, the handovers cannot be neglected in such scenario in order to provide seamless hybrid-connectivity when the aircraft is transitioning between ground BSs, from ground to space BSs, and between space BSs. The vertical handover, from the terrestrial network to non-terrestrial network and vice-versa, is not defined yet in 3GPP standards and current aeronautical communication technology does not provides such kind of handover. By providing a homogeneous and integrated lower layers relying on 5G, the handover policies can be defined by an agreement between stakeholders, for instance, airlines, manufacturers, ATCOs, and ANSPs, when hiring the hyperconnectivity service to meet the demands of ATM performance, safety, and security. This would also eliminate the necessity of having a piece equipment only responsible for switching between the link that is available or that meets the switching rule predefined by the airline or manufacturer. Thus, this solution aims to provide seamless handover by exploring novel handover rules for integrated TN and NTN.

In summary, with the Hybrid connectivity use case the solution will assess the following

- Aerial Coverage Continuity: Capability of a 5G hybrid TN-NTN network to provide continuous and cost-efficient connectivity for ICNS considering the CNS technologies performance requirements.
- Handovers: Novel TN-NTN handover mechanism may provide seamless transition between two integrated 5G networks in the context of aircraft users in network mobility

3.3.2.5.3 Safety applications

The safety applications use cases aim to provide a broad description of the safety CNS services and a thorough system-level analysis to evaluate and fully understand the feasibility of our proposed 5G-aligned CNS solution. The ICNS solution proposes to integrate all three CNS domains and comply with the performance requirements of each one of the technologies that require a datalink, for example, in terms of throughput, latency, and reliability. The performance of the proposed solution must be proven adequate for the use cases, i.e., that a 5G TN-NTN hybrid network can accommodate the aggregated and stricter CNS services requirements, after extensive realization of system level simulations.

3.3.2.5.3.1 Communication

The communication service exchanges information, including the voice, messages and data for aeronautical fixed and mobile services. The main communication application is voice data exchange between airborne crew and the ATM/U-space using amplitude modulated HF/VHF signals. Text data exchange is also important to provide flight information and supplement voice communication, mostly using CPDLC protocol. Finally, ACARS protocol also uses VHF for weather information, aircraft health status, and flight plans. All these three examples use VHF frequency bands, which provides limited data rate and is prone to congestion, but the terrestrial VDLM2 is still the preferred data link. Changing the connectivity paradigm towards a data-driven 5G hyperconnected solution may reduce airborne communication gear complexity, provide link redundancy, using 5G NTN when either in *en route* phase or lacking TN coverage, and seamless switch to 5G TN when in approaching, take off, and landing phases.

C2 link is essential for Beyond Line-Of-Sight (BLOS) UAS operations and requires a dedicated link to allow such remote operation. Besides, voice communication between remote pilot and U-space will also become crucial to UAS services. However, most drones operate in close distance to the remote

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pilot using direct RF links on unlicensed spectrum bands. Such links are range limited, as well as subject to interference, jamming, and spoofing. Safer and cost-efficient solutions are, for instance, U-Space MNO C2 and voice communication service provisioning, exploiting existent cellular networks, and the use of satellite communications. Furthermore, having redundancy is desirable to ensure safe operation without human input in case of link failures and security threats. By integrating a 5G TN and NTN network, with ubiquitous coverage, our solution aims to enable low-cost, high-resilience, and performance-driven C2 links.

Below the communications related use cases are summarised:

- 5G for Aeronautical Communication: Replacing VHF-based systems with 5G improves data rates, reduces congestion, and ensures seamless TN-NTN connectivity for all flight phases.
- Reliable C2 Links for UAS: 5G TN/NTN enhances drone C2 links, overcoming RF limitations with a cost-efficient, resilient, and secure solution for BLOS operations.

3.3.2.5.3.2 Navigation

GNSS is the standard method of acquiring positioning and timing information. Although world-wide available and widely embedded in many devices, GNSS is susceptible to jamming and outage at low altitude. Alternatively, Low-Power Distance Measuring Equipment (DME) can be used at VLL as a ground-based back-up for GNSS [40][41], providing accuracy distance measurement based on UHF beacon transmissions and TDOA calculations to establish the distance to the ground-based infrastructure. However, depending on beacons transmission is viable on crewed aircrafts it may become a problem in energy limited aircrafts such as electric VTOL (eVTOL) and drones. Another important navigation functionality is geofencing for UAS system, which is becoming a factory-installed features by many UAS manufacturers and might drive the feasibility of U-space. Such mechanism relies on position sensors, such as GPS sensors, and is designed to impede those pilots mistakenly entry into controlled or restricted airspace areas, which might be two or three-dimensional area [42].

The previously mentioned navigations technologies are essential to the safety of aerospace operations. Therefore, providing alternative means of acquiring positioning information is one of the goals of the proposed solution. Achieving such status might be possible due to 5G location capabilities, present since Release 16, and elevated LTE location capabilities to increase accuracy and reduce inter-cell interference using multiple transmission of reference signals in the downlink and uplink [43]. This A-PNT capability can be leveraged on TN and NTN network, acting in conjunction to other technologies, such as GNSS and DME, providing centimetre precision, cross-checking in case of jamming or spoofing, and redundancy in case of outage.

Below the envisioned use cases for the navigation domain are listed:

- 5G-Based Positioning: 5G gNodeBs can estimate aircraft positions using time- and/or angle-based location techniques, providing stronger, interference-resistant signals compared to GNSS, especially in urban or low-altitude environments.
- Resilient Backup & Redundancy: 5G positioning enhances navigation reliability by mitigating GNSS disruptions (jamming, spoofing, signal blockage) and leveraging TNs and NTNs for continuous situational awareness.

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3.3.2.5.3.3 Surveillance

This third safety service provides high-accuracy information on the position and movement of the aircraft to ATM and U-space systems for ensuring safe separation between aircraft. In manned aviation, the commonly used surveillance technologies include Airborne Collision Avoidance System (ACAS), Automatic Dependent Surveillance - Broadcast (ADS-B), Automatic Dependent Surveillance - Contract (ADS-C), Primary Surveillance Radar (PSR), and Secondary Surveillance Radar (SSR). Together, these technologies enhance situational awareness and improve the management efficacy of manned airspace.

ADS-B relies on aircraft broadcasting their essential information, such as, identity, position and other information derived from on board systems, such as GNSS. ADS-B signal is transmitted on UHF band, usually via Universal Access Transceiver (UAT) data links, and can be used by ground or on-board other aircraft to improve the traffic situational awareness, spacing, separation and self-separation. ADS-C uses the same systems as ADS-B and transmits similar information but operates under a contract that specifies the terms with ground services, for instance, Air Traffic Services Unit (ATSU) and Aeronautical Operational Control (AOC). ADS-C operates on VHF or SATCOM links, which are integrated by a datalink service provider (DSP) that feed the ADS-C information to ATC and AOC.

To avoid UAS mid-air collisions, UA must feature Detect and Avoid (DAA) technology onboard. ACAS is a DAA system, and it works independently of the ATM system. ACAS Xu is the latest version of ACAS designed for UAS; it enables UA with DAA capabilities [44] by combining traditional ACAS sensor information with other sources of situational awareness like ADS-B. The UAS Remote ID broadcasts UA identification and location information for surveillance [44]. The UA can be equipped with ADS-B and ADS-C, Automatic Dependent Surveillance-Light (ADS-L) and FLARM to provide situational awareness and surveillance services to U-space.

Implementing these technologies through a pervasive data-driven integrated wireless network might bring various benefits for aviation allowing internetworking between the existent and future datalink technologies. For example, this solution aims on reducing the latency and the cost of transmitting surveillance data while increasing the reliability of which these messages are sent. Another example, is the combined use of GNSS and multilateration, increasing the positioning information accuracy and robustness to possible threats such as jamming. Furthermore, the integration with A-PNT mechanisms may result on more accurate, sustainable, and continuous provision of surveillance services that is fundamental for the evolution ATM and U-space. Finally, a data-driven ICNS infrastructure leverages the implementation of an API between the data links the network core, which ultimately can be used to increase situational awareness by crossing navigation and surveillance information provided by the aircrafts and positioning information provided by the network, for a more accurate and informed ATM and U-space.

Below the envisioned use cases for the surveillance domain are listed:

- GNSS + MLAT: GNSS combined with multilateration enhances positioning accuracy and resilience against threats like jamming. Integrating A-PNT further ensures precise, sustainable, and continuous surveillance, vital for ATM and U-space evolution.
- ATM/U-space Impact: A data-driven ICNS infrastructure enables an API between data links and the network core, improving situational awareness by cross-checking aircraft navigation data with network-based positioning for more informed ATM and U-space.

3.3.3 Differences between new and previous operating methods

The main differences between the old and new operating methods, detailed in Sections 3.3.1 and 3.3.2 respectively, are presented in the Table 6. Radars, e.g., SSR and wide area multilateration (WAM), can also be used for the UAS surveillance [44]. PSR might be less accurate in tracking smaller UA at low altitudes.

Activities (in the SESAR architecture) that are impacted by the SESAR solution	Current operating method	New operating method
Use of ICNS	At present, CNS services are fragmented: the 3 domains are very distinctly separate, with few synergies between them, each requiring specific equipment. The consequences can be seen in the inefficient use of the frequency band, with energy and weight costs making it difficult for the smallest UAS to use them.	The use of ICNS offers a performance-oriented approach to the use of services, taking advantage of synergies between domains. This would help overcome the current inefficient management of airspace resources, particularly in terms of spectrum usage and the risk of congestion on certain links.
5G for ICNS	No current operating method.	Using 5G for ICNS would considerably reduce the complexity and cost of networks dedicated to CNS technologies. Its presence in most urban areas and its ability to deliver high data rates with great reliability make it a tool of choice for VLL applications. The scientific community is very active around this technology, and new standards and possibilities are constantly being developed. However, integration between TN and NTN must be considered. As 5G coverage is limited outside urban areas, the use of NTNs is necessary to ensure continuity of coverage.

Table 6: differences between the new and the previous operating method

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4 Key assumptions

4.1 Operational assumptions

In this section we list the operational assumptions considered in solution 0521:

- **5G coverage:** we assume that a 5G network integrates hybrid-connectivity TN-NTN, providing 5G coverage continuity and handover capabilities between the networks. This also implies that the NTN, both satellite and HAP, embeds 5G capabilities and handovers NTN-NTN are seamless and handled transparently to the user. The 5G network, either private or public, is integrated to the ATM and U-space communication service provider, also providing all necessary 5G 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, but 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.

- **ICNS viability:** ICNS is a key enabler of the UAS safety and possible coexistence with large aircrafts. Thus, it is considered in the solution here proposed that the aircrafts, 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 the U-Space traffic services in accordance with the authorities' regulations on U-Space operations and the mission specific UAS requirements, particularly BLOS operation. Besides, the uncrewed aircraft and remote pilot are able to transmit and receive to/from the U-space, supplying the necessary information to ensure a safe coexistence with other aircrafts, for instance voice communication and surveillance data.

4.2 Safety assumptions

Regarding the safety of airspace operations, it is assumed first that the solution is thoroughly compliant with the legislation and rules governing the airspace. In the previous Chapter, the solution architecture was described and details on infrastructure deployment respecting control zones, allowed frequency spectrum, bandwidth, and antenna type, were given. Apart from the concerns raised before, we could not identify any other direct safety issue.

As stated in the previous chapter, security is one of the primary concerns of IAM operations that directly affect safety. Security considerations are out of the scope of this document, while they are in the scope of the security risk assessment. Nevertheless, several assumptions for improving safety are stated below:

- **5G certification:** We assume that aviation and telecommunication authorities would certify 5G as safe for aviation use, particularly the application in safety services such as CNS. This includes the 5G and 5G mobile network providers' conformance in terms of data transmission performance, security and privacy provision, availability, and interference. Also, 5G transceiver devices can be embedded in the envisioned aircraft categories and operate in a broad range of aeronautical missions.

- **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 operations, for example, might be restricted by UAS corridors, where the traffic of this type of aircraft has minimal impact on other aircraft operations and citizens' safety. Furthermore, such areas might be defined in two or three dimensions, according to the aviation authorities and entities.

- **UAS communication security and redundancy:** due to the greater exposure to potential threats and lower robustness, UAS systems are assumed to have the necessary cybersecurity means against jamming, spoofing and integrity threats. This includes the systems that are providing navigation, positioning, and timing to the aircraft as the CNS services in use by the aircraft.

- **UAS geofencing:** Geofencing is by default installed in all UA not permitting the UA to approach restricted and controlled areas without previous permission of the aviation authority and aircraft manufacturer for the mission being executed. Also, the positioning and navigation systems are calibrated and geofencing functions were not altered without consent of authorities. This premise is of utmost importance to ensure that ATSU and aviation authorities are aware of the aircraft entry in a restricted space.

4.3 Performance assumptions

The solution 0521 impacts the following key performance areas (KPAs):

- **Capacity:** With the addition of the UAS air traffic, the capacity of the airspace would need to increase at low altitudes operations. Thus, the solution assumes an increase in the surveillance and traffic management capabilities. Besides, new flight routes might be possible since the 5G 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.

- **Cost efficiency:** The ICNS paradigm may impact directly on the operational costs of UAS operations. An integrated equipment providing all the necessary CNS services plus connectivity via 5G may be less expensive than having several CNS equipment and multiple datalinks. Furthermore, the form factor of the aircraft can be smaller and the structure lighter due to the also lighter equipment payload.

5 References

5.1 Applicable documents

This OSED 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

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Appendix A Stakeholder identification and benefit impact mechanisms (BIM)

A.1 Stakeholders identification and expectations

Stakeholder	Involvement	Why it matters to the stakeholder
European Institutions (SESAR, European commission)	Responsible for the future of European airspace, the European institutions are behind the project, its organization and financing.	As project coordinators, the institutions must be kept informed of project progress. It is therefore essential for them to ensure that the project is running properly, that it is relevant to the ATM master plan, and that it is coordinated with other projects.
ANSPs	Responsible for the organization and structure of airspace, they must ensure the maintenance of an airspace offering adequate capacity, safety, flexibility and responsiveness. The integration of new vehicles into the airspace and the associated standards will be carried out under ANSP supervision.	The solution has a direct impact on the use of CNS services, for a portion of airspace that is still little exploited: low altitude. As airspace organizers, ANSPs have a duty to keep up to date with advances in CNS technologies associated with airspace. The same applies to the emergence of U-space: ensuring reliable, efficient and safe integration with existing ATM is a crucial step for the future of European airspace. Understanding the use of CNS technologies and their operation will play a key role in ensuring this.
Regulators	Regulators are responsible for developing and applying regulations to ensure the safety and efficiency of air traffic. Their role is to ensure that new technologies comply with existing airspace requirements, in order to guarantee quality of service.	The modernization of European airspace and the application of the new standards required by the solution will be carried out by regulators. It is therefore in their interest to follow the development of ICNS, U-space and related technological solutions.
Standards Organizations	Standards organizations are responsible for developing new standards for European airspace, aviation and aeronautical equipment, which are then applied by regulators. As such, their	New standards will need to be developed in order to implement the solution. These new standards will concern both the use of 5G for ICNS and the implementation of U-space.

	expertise is essential to any project requiring changes to regulations.	
Airport Operators	Responsible for managing airport operations and development, they are essential for ensuring the smooth running of these infrastructures, and in particular air traffic, in collaboration with the ANSPs.	The solution focuses in particular on airport areas. areas where the low altitude ICNS proposed by the solution could prove very useful. As key elements in the emergence of U-space, operators will need to adapt these areas to ensure its implementation.
Network Managers	Network Managers are in charge of managing ATM network functions, as well as resource sharing within European airspace. Any new use of these resources will therefore be under their control.	As the solution relies on the use of 5G to deliver a number of important services, Network Managers will have a key organizational role to play in its deployment.
Airspace users	All users of European airspace, from airliners to UAS and military aircraft, must comply with all existing regulations.	As the first to be affected by the implementation of a solution, keeping abreast of its progress and the new features it will bring can facilitate its subsequent implementation.
Aircraft manufacturers	Aircraft manufacturers have a responsibility to design planes that comply with the safety and performance standards required to operate in European airspace.	The implementation of ICNS will lead to changes in standards, and in avionics architecture to make aircraft compatible with them. In this respect, aircraft manufacturers need to closely monitor developments and advances relating to the solution.
UAS manufacturers	UAS manufacturers have a responsibility to design aircraft that comply with the safety and performance standards required to operate in European airspace.	As this solution directly concerns UAS, manufacturers are well advised to keep abreast of its progress. The development of ICNS using 5G will make a major contribution to the implementation of U-space. By keeping abreast of the changes, the solution will bring to UAS systems, manufacturers can also prepare for the necessary adaptations to come.
Scientific community	By regularly contributing new advances in the fields related to the development of the solution,	For the scientific community, the advances proposed by the solution can

	the work of the scientific community indirectly helps and participates in its development.	serve as a basis for future innovation and research.

Table 7: stakeholders' expectations and involvement

A.2 Benefits impact mechanisms (BIM)

The aim behind the ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521) is to leverage terrestrial and non-terrestrial 5G networks to achieve an integrated version of CNS technologies, particularly applicable for low-altitude operations. These include general aviation take-off and landing operations, as well as UAS operations. The development of such a solution is particularly well suited to the development of U-space and its integration with pre-existing ATM, leading to the deployment of U-space, as outlined in European ATM plans.

The use of ICNS for low-altitude operations would offer many advantages. Table 8 describes the benefits of Key Performance Indicators (KPIs) in terms of their Key Performance Areas (KPAs).

KPA	KPI	KPI Definition	Benefits
Capacity	CAP1 (Airspace capacity)	Terminal manoeuvring area throughput, in challenging airspace, per unit time.	The use of ICNS at low altitudes would increase the capacity of European airspace. Firstly, because its use would open up new possibilities for the emergence of U-Space, which would increase the number of UAS. Secondly, because the technology is ideally suited to challenging low-altitude airspace, offering a form of A-SUR that can offset the emerging risk of congestion in certain surveillance technologies (ADS-B in particular). Moreover, the new coverage provided by TN and NTN integration would enable the development of new routes than those currently used by aircraft. Finally, the use of 5G would also make it possible to avoid interfering with the CNS technologies currently in use, which are sometimes close to saturation.
	CAP3 (Airport capacity)	Peak Runway Throughput (Mixed mode).	
Cost-Efficiency	CEF3	Technology Cost per flight	The use of ICNS through 5G would reduce the amount of equipment normally required to operate the associated technologies. This would translate into lower costs, both in terms of ground infrastructure and on-board equipment. The solution is also designed

			to use established standards, resulting in lower development and deployment costs than competing approaches.

Table 8: ANTENNAE solution (ANTENNAE-01, STELLAR Solution ID 0521) benefits related to KPI

The solution also contributes to other KPAs:

- Safety: The introduction of new positioning and surveillance systems will help to increase safety. In particular, the solution will provide alternatives to overcome the vulnerability of GNSS and the risk of ADS-B congestion,

- Security: The solution is based on the use of 5G, a technology whose associated standards are already established, and highly tested against security risks. In addition, the solution would enable the use of alternative means of navigation, reducing the risks associated with GNSS (jamming and spoofing),

- Environment: Solution 0521 could help reducing the CO2 emission in different ways. The use of ICNS would largely use existing telecommunications infrastructures, limiting the number of new ones to be deployed. Then, the additional coverage offered by the hybrid 5G TN-NTN may enable more efficient shorter aircraft flight routes. Additionally, enabling the use of electricity-powered UAS to perform cargo delivery missions and eVTOL air taxis can reduce the number of car and helicopter travels, respectively.