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FACT

FUTURE ALL AVIATION CNS TECHNOLOGY

This Final iCNS Functional Architecture is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 894616 under European Union's Horizon 2020 research and innovation programme.

Abstract

The primary goal of the project FACT is to evaluate the feasibility of a Performance-Based Integrated CNS (iCNS) concept, in order to support today's and tomorrow's air traffic challenges in the most cost effective way with equally or better than today performance of the overall operational safety. In particular, the project will focus on selected elements of iCNS concept exploring primarily a potential use of cellular networks (4G and 5G) as a complement to the existing CNS technologies within ATM and U space environment, with a particular focus on GA and drones' operations.

This deliverable describes functional architecture which combines airborne and ground functions to enable building of scalable CNS capabilities/systems tailored for targeted spectrum of airspace users and corresponding operational environments. The architecture is based on the operational needs and system/connectivity requirements described in Concept of Operations (D2.3) and System Requirements (D3.3).

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1 Executive Summary

The primary goal of the project FACT is to evaluate the feasibility of a Performance-Based Integrated CNS (iCNS) concept, in order to support today's and tomorrow's air traffic challenges in the most cost effective way with equally or better than today performance of the overall operational safety. In particular, the project will focus on selected elements of iCNS concept exploring primarily a potential use of cellular networks (4G and 5G) as a complement to the existing CNS technologies within ATM and U space environment, with a particular focus on GA and drones' operations.

This deliverable represents an update of Initial Functional Architecture (D2.2) document considering the outcomes of the first validation phase and progress in the preparation of the operational demo. In this context, it covers overview of the functional architecture with the description of the expected data flows among individual users as well as an analysis of communication requirements of different user groups are analyzed in terms of typical requirement for data rate, latency and type of communication.

This document complements the Final Concept of Operations (D2.3) and System Requirements (D3.3) deliverables. These three documents (D2.3, D3.3 and this D2.4) aims to provide an overview of overall operational, system, and functional definition used as a basis for the second phase of validation activities and the final operational demo to be performed in July 2022.

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List of Acronyms

3GPP	3rd Generation Partnership Project
5GC	5G Core
ABAS	Airborne Based Augmentation System
ACARS	Aircraft Communication and Reporting System
ACAS	Aircraft Collision Avoidance System
ADS-B	Automatic Dependent Surveillance-Broadcast
AFIS	Aerodrome Flight Information Service
AMF	Access and Mobility Management Function
ANSP	Air Navigation Service Provider
AOC	Aeronautical Operational Communications
A-PNT	Alternative position, navigation and timing
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Services
ATSU	Air Traffic Services Unit
AUSF	Authentication Server Function
A2A	Air to Air
A2G	Air to Ground
A2S	Air to Satellite
BVLOS	Beyond Visual Line of Sight
BW	Bandwidth
CEPT	European Conference of Postal and Telecommunications Administrations
CIS	Common Information Sharing
CMU	Communications Management Unit
CNS	Communication, Navigation and Surveillance

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COTS	Commercial Off-the-Shelf
CPDLC	Controller Pilot Data Link Communications
CTR	Controlled Traffic Region
D8PSK	Differential 8-Phase-Shift-Keying
DAC	Digital Automation Cloud
DCDU	Datalink control and display unit
DL	Downlink
DME	Distance Measuring Equipment
DSR	Drone Surveillance Radar
EAN	European Aviation Network
EASA	European Union Aviation Safety Agency
eMBB	enhanced Mobile Broadband
FAA	Federal Aviation Administration
FDD	Frequency Division Duplex
FIS	Flight Information Service
FLARM	Flight Alarm
FMS	Flight Management System
GA	General Aviation
GAMA	General Aviation Manufacturers Association
GBAS	Ground Based Augmentation System
GES	Ground Earth Stationatsu
gNB	5G Network Basestation
GNSS	Global Navigation Satellite System
GSM	Groupe Spécial Mobile
G2A	Ground to Air
G2G	Ground to Ground
HF	High Frequency

ICAO	International Civil Aviation Organisation
IETF	Internet Engineering Task Force
IFD	Instrument Flight Deck
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IPS	Internet Protocol Suite
IRS	Inertial Reference Systems
L-DACS	L-band Digital Aeronautical Communications System
LTE	Long Term Evolution
MCDU	Multi-function control and display unit
MEL	Minimum Equipment List
MIMO	Multiple-input multiple-output
mMTC	Massive Machine-Type Communication
MLAT	Multilateration
MTOW	Maximum Take-off Weight
MTSAT	Multifunctional Transport Satellites
NR	New Radio
NRF	Network Repository Function
OSI	Open System Interconnection
PBN	Performance Based Navigation
PDU	Protocol Data Unit
PSR	Primary Surveillance Radar
QNH	Mean Sea Level Pressure
RAIM	Receiver autonomous integrity monitoring
RNAV	Area Navigation
RNP	Required Navigational Performance
RRH	Remote Radio Heads

SBAS	Space Based Augmentation System
SelCal	Selective Call
SINR	Signal-to-Noise Ratio
SMF	Session Management Function
SSR	Secondary Surveillance Radar
SVFR	Special visual flight rules
SWaP	Size, Weight and Power Consumption
SWIM	System Wide Information Management
S2A	Satellite to Air
TDD	Time Division Duplex
TIS-B	Traffic Information Service – Broadcast
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UAT	Universal Access Transceiver
UDM	Unified Data Management
UDR	Unified Data Repository
UE	User Equipment
UL	Uplink
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communication
USSP	U-Space Service Provider
UTM	Unmanned Traffic Management
VDL	VHF Data Link
VFR	Visual Flight Rules
VHF	Very High Frequency
VLOS	Visual Line of Sight
VoIP	Voice Over Internet Protocol

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VOR	VHF omnidirectional range
WAAS	Wide Area Augmentation System

2 Introduction

This deliverable describes a functional architecture which aims to combine optimally airborne and ground functions in such way to allow build scalable CNS capabilities/systems enabling information sharing among large spectrum of airspace users enhancing thus operational safety and capacity of corresponding airspaces. Within the project FACT, the focus is to demonstrate the approach for General Aviation, rotorcrafts and drones operating in part of controlled and uncontrolled airspaces considered as U space. This functional architecture addresses the operational needs identified in Final Concept of Operations (D2.3) and functional/system requirements proposed in System Requirements (D3.3) documents. These three deliverables are therefore complementing each other and are considered all together as final documentation package for FACT solution(s).

2.1 Document Overview

After the introduction sections 1 and 2, the chapter 3 of this document provides an overview of the overall functional architecture and in particular of the communications between different airspace users and ground services providers. Focus is to analyze individual data flows from the perspective of the type of communication, who must provide the information to whom, and expected performance requirements on the data communications. Together with the system requirements addressed in D3.3, this completes an overview of the overall solution addressed in the FACT project and its final operational demo.

Chapter 4 gives an overview of a 5G network as a promising/recommended candidate for commercial deployment of these functions. In addition, an overview of the information flows explored within the project operational demo is provided at the end of this section. Detailed interfaces definitions for implementation of these data flows in the operational demo are provided in Appendix A of D3.3 (Final System Requirements).

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3 Communication Data Flow for Airspace Users

This introduction part summarizes some information included in D3.3 document to provide a common reference for communication architecture and information flow descriptions in the subsequent sections.

The project FACT focuses on CNS enablers allowing to demonstrate the following applications:

- Situation awareness applications for individual users: enabled by traffic surveillance profiting from new position reporting over cellular network and ADS-B. Possible data integrity enhancements using cellular network positioning will be also explored.
- Conformance monitoring & alerting functions required for efficient use of trajectory-based strategic deconfliction. For the operational demo, strategic deconfliction will be applied only within flight planning phase while the project will focus on performance evaluation of supporting real time functions/enablers critical for definition of safe operational buffers around strategically deconflicted flights: realistic trajectory conformance performance of drones as well as on efficiency and latency of conformance monitoring & alerting.
- Emergency voice link between ATCo and remote pilots.

Figure 1 (adopted from D3.3) shows the simplified functional overview of the two first applications.

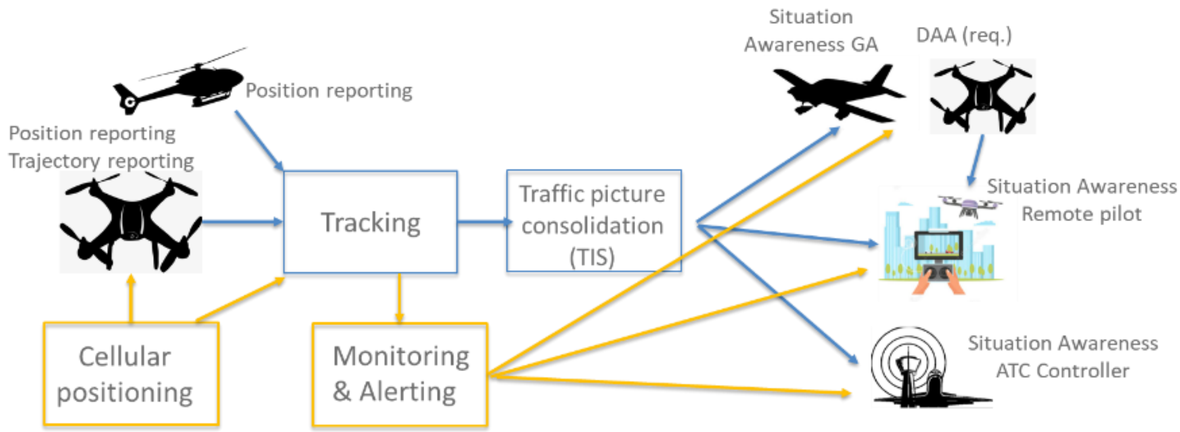

Figure 1: Situational awareness applications with considered enhancements supporting strategic deconfliction.

These applications are enabled by a set of main CNS-based systems/functions which will be included in the project's validations and are schematically shown in Figure 2. Functionally the core elements are:

- Position reporting function – hosted on-board the targeted users – GA, rotorcrafts, and drones;

- Trajectory/intent reporting function – hosted on-board the drones performing automated flights, namely, drones within the FACT project. This information can cover both 3D and 4D (3D + time) information depending on the capability of the vehicle's guidance functions. Considering typical equipment of today's drones, only 3D trajectory information will be used during the project's validation activities.
- Aircraft tracking implemented on the ground.
- Conformance monitoring and alerting implemented on the ground.
- TIS/FIS information provision implemented on the ground
- Situation Awareness processing functions (including TIS/FIS reception) of individual users (GA pilot, remote pilot, ATCo)
- VoIP link between ATC and remote pilots and between pilots (regardless whether local and remote).

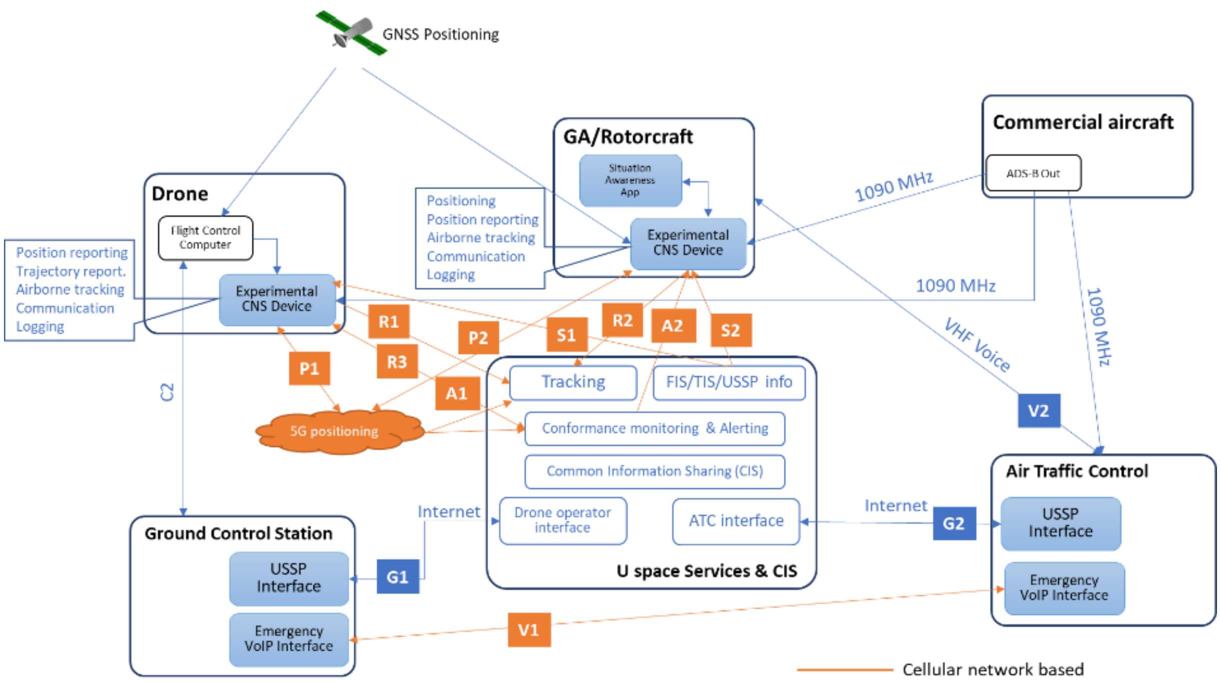

Figure 2: FACT system and functional overview.

These functions are implemented within the following systems (Figure 2) and further described and specified in D3.3. The systems represent communication nodes for the overall communication architecture discussed in this document:

- GA Experimental CNS device (position reporting, communication, SA processing)

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- Drone's Experimental CNS device (position & trajectory reporting, communication, pre-processing of ground data for possible Detect and Avoid implementations)
- USSP/CIS cloud platform (aircraft tracking, conformance monitoring & alerting, TIS/FIS)
- Remote pilot ground control station (SA processing, VoIP)
- ATC controller working position (SA processing, VoIP)
- GA situation awareness device (SA processing function decomposed between Experimental CNS devise and this device).

The main elements of information flow are listed in the following table and further commented in the subsequent sub-sections:

Table 1: The main elements of air-ground information flow.

Target user/system	Source user	Type of data	References in Figure 2	Availability requirements[1]	Data volume	Frequency of data sending	Latency for data packet
Information sharing services: regular/periodic 1:N communication							
GA Aircraft/ Experimental CNS device	USSP platform (for FACT experimental implementation, using ATC data)	FIS-B[2]	S2	Low/medium	150 kB* max	5 min **	<1 min
GA Aircraft, drones/ Experimental CNS device	USSP platform (for FACT experimental implementation, using ATC data)	TIS-B (and similar)	S1 and S2	Medium	150 kB max	1 sec ***	<1 sec
Drones/ Experimental CNS device	USSP platform (service provider)	Geofencing	S1	Medium/high	150 kB max	1-5 sec	<1 sec
Vehicle reporting: regular/periodic 1:1 communication							

[1] Currently only high-level classification of the availability requirements is provided. This approach will be refined later in the project referring also to conventional required communication requirements (RCP) metrics used in aviation.

[2] **FIS –B :** METAR, SPECI METAR, PIREP, TAF, TAF AMEND, Wind & Temp Aloft, AIRMET, Convective SIGMET, SIGMET, NOTAM-D, NOTAM-FDC, SUA, CONUS NEXRAD, Regional NEXRAD, Lightning, Turbulence, Icing, Cloud Tops, Center Weather Advisory, Graphical AIRMET

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USSP / Tracking	GA, Drones/ Experimental CNS device	Position report	R1, R2	Medium	~1 kB	1 - 2 Hz	<0.5s
USSP / Conformance monitoring	Drones/ Experimental CNS device	Trajectory reporting	R3	Low	~1 kB	0.1 Hz *	<5s
Alerting/clearance services: on-demand 1:1 low latency communication							
Drones / Experimental CNS device	USSP platform	Clearances/alerting from USSP/ATC (only dummy clearances for COM testing within the project)	A1	High	~1kB	Situation triggered	<0.5s
GA/ Experimental CNS device	USSP platform (for FACT experimental implementation, forwarding ATC data)	Alerting information aiming to focus pilot\s attention to specific topic/information	A2	High	~1kB	Situation triggered	<0.5s

*   Estimate based on data type and format

** Depends on product type, 5 min is the shortest interval per standard DO-267A

***Optimal value, no strict requirements

Comparing the above latency & throughput requirements with typical cellular network performance characteristics, they seem to be well within the capabilities of the current cellular networks. Nevertheless, practical measurements indicate that the main technical challenge is related to ensuring and guarantee continuity of connectivity/network availability at any moment of the flight.

In addition to the above data link channels, the voice links will be available for emergency/tactical communication between ATC and GA pilot (through conventional VHF radio, labelled as V2 in Figure 2), and ATC and remote pilots (through VoIP channel, labelled as V1 in Figure 2). Finally, specific communications are considered between vehicles (their Experimental CNS device) and ground infrastructure to support cellular network positioning (links P1 and P2 in Figure 2) – however, these links and functions won't be implemented for the project's operational demo and will be explored only technically through complementary activities. Results of the complementary activities will be included in Validation Assessment Report (D5.4).

3.1 ATM Communication Data Flow/Architecture

The current ATM communication data flow is through radio and telecommunication devices, potentially with the help of CPDLC, particularly for the commercial flights. ATC communication exchange for the general aviation traffic is provided by radio frequencies while RTF (radio-telephony) is mainly used for communication with the other operational units.

FACT is aiming to project ATC communication data flow as can be seen in the Figure 3 below. This diagram was created with ATM perspective and controlled airspace in mind considering central role of ATC and including airspace users such as GA traffic (aircraft and rotorcraft), commercial flights, drones and remote operators as well as other ATC units to be coordinated and communicated in the examined airspace (dynamic airspace defined based on the operational scenarios described in the Final Concept of Operations (D2.3), detailed project's validation plan and flight test cards).

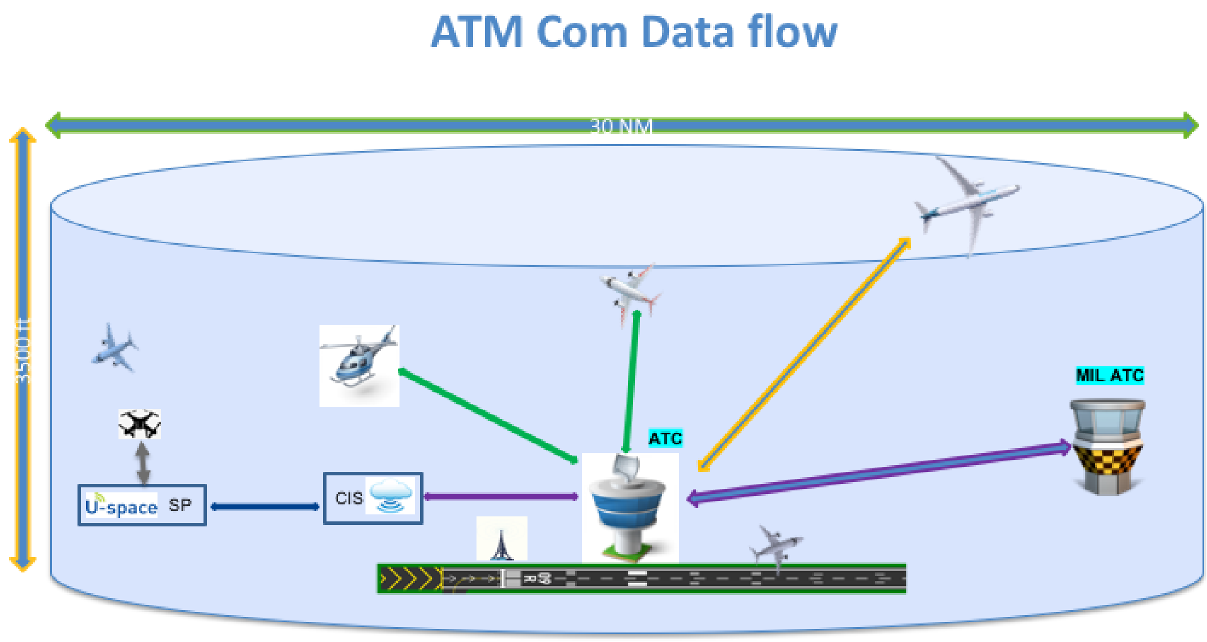

Figure 3: FACT ATC communication data flow.

ATC is at the center of the controlled airspace and has the authority to control the traffic to provide safe and efficient traffic flow including future aspects such as drone flights. The communication data flow starts with the operator flight planning and submission of the flight plans through an online network. The traffic plans are also shared and coordinated with other ATM stakeholders and military ATC authorities for the operated airspace. Communication/interaction between the parties can be detailed as follows:

- **ATC-GA**: ATC provides ATC services for GA aircraft including helicopters in its airspace by conventional means (VHF radio). While controlling GA traffic, aircrafts' position, level and direction along with operational requests are assessed and instructed using proper safety separation standards with phraseology. ATC benefit from access to data about drone traffic in U-Space via CIS.

- **ATC-Commercial Traffics**: ATC provides service to all commercial traffic in its airspace by priority as they are mainly IFR flights. Commercial traffic communication is provided with radios and CPDLC (conventional means). ATC instructions include traffic information about the GA traffic and other essential traffic. ATC benefit from access to data about drone traffic and although active participation (in terms of installing new iCNS equipment onboard) of commercial aircraft is not planned in the project flight demonstrations, there is an option to inform this kind of traffic about unmanned traffic by conventional means if necessary.

- **ATC-CIS**: ATC provide continuously information about detected traffic and instructions by giving the priority to the commercial and general aviation traffic. In opposite direction, ATC obtains processed information from CIS about drone traffic in U-space.
- **ATC-MIL ATC**: ATC coordinates traffic with military ATC units when necessary. The operationally planned and essential traffic and drone information including position, level and profile is shared and coordinated with the Military ATC units by communication channels of RTF and online devices.

FACT projected communication channels will improve air traffic controller's situational awareness and performance of safety and efficiency in their airspace.

In addition, a voice communication channel (through Voice over IP technology using cellular network) between ATC and drone's remote pilot will be available for emergency purposes.

3.2 U-Space Services

As the main purpose of the project is development and evaluation of CNS enablers for both U space and ATM services, a simplified approach will be adopted and the same experimental platform will be used for implementation of digital ground services supporting both ATM users (GA and rotorcraft) and drones.. It does not mean that the project push for such business solution, but it is the most efficient approach how to meet project's objectives. Note, that the ConOps and interfaces for interplay between U space services and ATM are currently under development/definition in the SESAR project PJ.34 and this progress is closely monitored, but the FACT project's activities are focused on technical CNS aspects.

Beyond the high-level functions shown in Figure 2 and already discussed in D3.3, there will be multiple "hidden" low level supporting functions implemented on the ground.

- All the users involved in the validation demo (drones, GA, rotorcraft, remote operators, ATC) will be registered in the project network and appropriate authentication/log in mechanisms will be implemented.
- Group of users will be created to allow manage efficiently the access rights and distribution lists for individual services[3]: group of GA/rotorcraft users, group of U-space users (drones), group of remote operators, ATC[4].

[3] There will be still possible to manage rights individually, but it is not planned to be used.

[4] As the cellular technology currently does not support real "broadcast", the 1 to N communication will be managed through connectivity to the appropriate group of users.

- Tracking function will be the key enabler of all traffic surveillance and will manage traffic tracks based on position reports received via cellular network and/or ADS-B. It will be able provide at any time information about expected position of an aircraft including the information when the last report was received, i.e., how long coasting/extrapolation of its movement is used.

- TIS/FIS services will use traffic and airspace information available in the storage (CIS) and distribute them periodically to the groups of airspace users. While TIS will be common both for GA/rotorcraft and drones, there will be possibility to distinguish FIS data for different users.

- Conformance monitoring & alerting function will be used to monitor capability of drones to maintain shared trajectory and alerting function will be used to test time critical communication channel. This function is intended to complement and support strategic deconfliction function which will be applied during the flight planning.

- Common Information Sharing function is a storage function which will maintain actual traffic (position, flight plan, trajectory (when applicable), constraints) and airspace (airspace allocation, geofence, restricted airspace, weather) information collected from different sources and available to the individual services.

- ATC and remote operator’s interfaces will support situation awareness applications on the users’ side and also enable provision of the operational information from these users.

For FACT operational demo, the services will be run on the PC for reducing system complexity, however the implementation is designed and allows to run them also in the cloud.

3.3 General Aviation

GA aircraft operate in all classes of airspace and represent a wide range of aircraft airspeeds, flight rules, and pilot capabilities. In this context, a performance-based approach to CNS equipage is expected in the future. For the purpose of the FACT operational demo, a mixture of traditional and innovative equipment is planned.

Communication of General Aviation aircraft will be solved by both traditional and innovative means. Traditional means represent VHF radio for voice communication with ATC. An innovative means of communication is the Experimental CNS device that receives, processes, and sends data over a mobile network (among other functions not related to communication) and benefits from obtaining additional digital information from ground services..

Experimental CNS device will transmit position reports through cellular network to U-Space Service Provider. This functionality is principally similar to ADS-B Out in terms of messages content, data volume and frequency of sending. Position reports contains information about own position based on GNSS with envisioned possible enhancement by cellular network. Planned content of data captured in position reports is provided in Appendix A.

Experimental CNS device receives data from Flight Information Services (FIS) and Traffic Information Services (TIS) broadcasted by ground systems to all users in area of coverage. Content and data format are strongly inspired by existing FIS-B and TIS-B realized in the USA through Universal Access Transceiver datalink (RTCA DO-282 Minimum Operational Performance Standards for Universal Access

Transceiver Automatic Dependent Surveillance – Broadcast, RTCA DO-358 Minimum Operational Performance Standards (MOPS) for Flight Information Services-Broadcast (FIS-B) with Universal Access Transceiver). The data are processed by experimental CNS device and provided to mobile situation awareness application for pilot. ADS-B In sensor for direct detection of aircraft equipped by ADS-B Out will be part of experimental CNS device and detected traffic is also provided to situation awareness application.

Performance requirements for communication of GA aircraft are not very demanding in terms of data volume, data rate or latency, but important is primarily network availability.

3.4 Drones

Communication of drone will be also solved by both traditional (command and control link to remote pilot) and innovative means. Experimental CNS device located on drone will be similar to the unit installed on GA aircraft, but not identical. The main difference is in direct connection of the experimental CNS device to the flight guidance computer which results in access to digital position information without need to measure it independently. This position received from the flight guidance computer can still benefit from enhancement by cellular signals when available. Communication function also contains some differences with respect to communication of GA aircraft.

Experimental CNS device installed on drone will provide position reports and trajectory reports to U-Space Service Provider through cellular network. Position reports will conform to EU regulation related to electronic ID of drones. Trajectory reporting is function related to estimated future trajectory. This trajectory report consists of waypoints series. Expected update rate is 10 seconds or triggered by trajectory changes.

Information which drone receives through experimental CNS device will consist of geofencing information and surrounding traffic picture, both provided by U-Space Service Provider. Experimental CNS device will again contain ADS-B In sensor to feed potential Detect and Avoid function (not used within the demo).

For emergency cases, function enabling ATC to reach remote pilot by Voice over IP, is also deployed.

4 Network Functional Architecture

This section focuses on defining functional network architecture for end-to-end applications that provides connectivity based on the requirements described in Chapter 3.

The dimension and conceptual architecture of the cellular ground network will be explained in this chapter. Particular focus is put on the information flow among the specific airspace users to the ground (U-space provider or ATC). Below is a schematic picture of the different data flows.

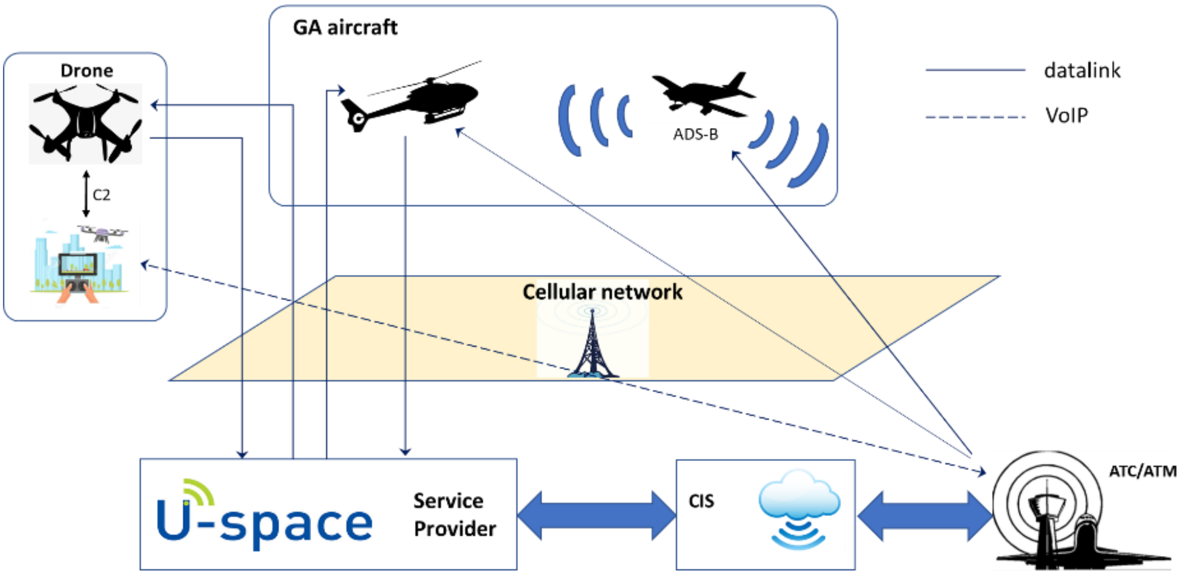

Figure 4: Schematic information flow over the cellular ground network.

Based on the requirements and the interface which are described in section 3 and in the D3.3 the network will provide sufficient capacity and coverage.

In D2.1 different deployment scenarios were described (public versus private network). In the FACT project it is expected that a private (stand-alone) 5G network will be the most suitable business solution satisfying performance requirements of safety critical air traffic applications. In this context the present section is primarily addressing such trial network. However, global situation with suppliers of the chips during the project's execution did not allow to build in time such solution for the project's operational demo and therefore the project's operational objectives will be evaluated within public LTE network deployed in Turkey.

4.1 Principle of Ground Network Architecture

In the FACT project, a 5G network is considered a suitable solution for realizing the communication network enabling the iCNS applications. The reason for choosing a 5G network are the following:

- 5G is the next generation wireless networks with the highest flexibility, which also means the best possibility to find optimized solutions for the aviation requirements.

- In the upcoming standardization several features can be useful for application in the aviation usage, like 5G based positioning.
- Flexibility of the different subcarrier spacing allows better adaptation to higher velocity of airspace user.

The recommended cellular network solution would be based on 5G stand-alone (SA) connectivity in a 5G NR frequency band (depending on available frequency licenses). The core network can be based for instance on Nokia's NDAC platform. The radio access network (RAN) would then comprise a number (say 3-5) of micro or macro outdoor remote radio heads (RRH) connected to Nokia's 5G AirScale System Module.

Nokia DAC is a carrier/industrial grade digital automation service platform providing private 4G and 5G connectivity and a suite of applications for enterprises and verticals. It includes a reliable, secure, and high-performance private wireless network that is scalable according to needs. Nokia DAC offers an easy to use interface for network management tasks, such as managing SIM cards, adding and removing devices and features, viewing real-time information via Nokia DAC Manager (a web based user interface) on the status and utilization of network and devices as well as 5G radio network and Edge cloud health. In a commercial deployment, the Nokia DAC Manager can be used by the customer personnel directly.
Operating a private network requires very limited manual work as Nokia DAC service is orchestrated and maintained from Nokia DAC regional clouds, which are designed with high availability and secure architecture including multiple levels of redundancy, and a continuously increasing level of automation. Cloud-based management is enabled with the connection of the local Edge to the regional cloud through the Internet.

4.1.1 3GPP standardization

5G is standardized by 3GPP in releases. The very first 5G standards were specified in Release 15, which was fully completed in June 2019. Release 15 covers both the so called non-standalone (NSA) and standalone (SA) options. The main use case for NSA architecture is evolution from 4G networks using the existing 4G evolved packet core (EPC), 4G radio layer as the anchor band and 5G radio as the capacity layer based on 4G-5G dual connectivity architecture.
Release 15 also specified SA architecture, which supports pure 5G radio access together with the new 5G core network. The focus of Release 15 was on enhanced Mobile Broadband (eMBB) use cases. Release 16 introduces capabilities for industrial use cases such as Ultra Reliable Low Latency Communication (URLLC). Release 17 focuses on high numbers of IoT devices also known as massive Machine-Type Communication (mMTC). The completion date for Release 16 was in July 2020 and for Release 17 in June 2022.

4.1.2 3GPP 5G SA architecture overview

5G Radio Access

5G SA includes the next generation radio access network (NG-RAN), which connects to the 5G Core (5GC). NG-RAN provides 5G NR (New Radio) connectivity for User Equipment (UE). The 5G NR base station is called gNB in 3GPP specifications.
The high-level NG-RAN architecture is depicted in Figure *3GPP NG-RAN overall architecture [3GPP TS*

38.300]. The focus in this document is on gNBs having Xn interface between them for handovers and generic NG interfaces to 5GC functions. The NG interface can be further split into control plane N2 from gNB to AMF (Access and Mobility Management Function) and user plane N3 from gNB to UPF (User Plane Function) as described in *5G Core*

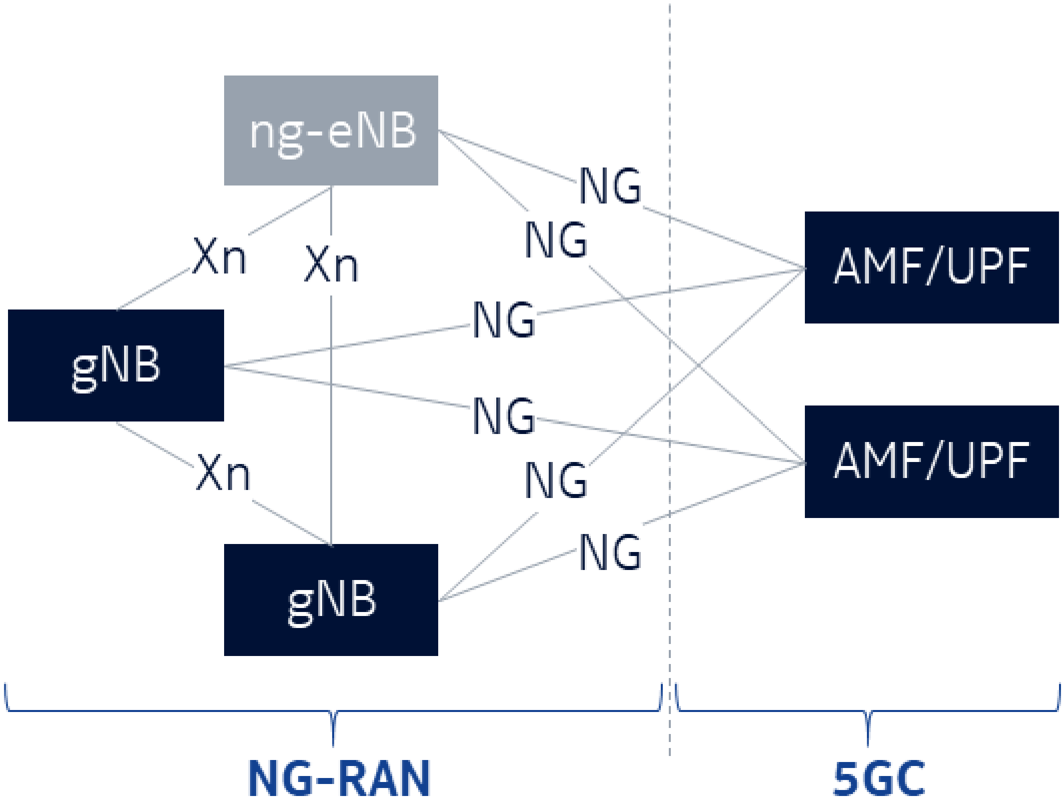

Figure 5: 3GPP NG-RAN overall architecture [38.300].

5G Core

The 5G core (5GC) network has changed from previous generations in a few important principle ways. Firstly, there is clear separation between user plane and control plane functions starting from the very first 5G architecture based on 3GPP Release 15. This enhancement has been also added later to the 4G evolved packet core (EPC). The second significant change is service based architecture for control plane functions. Network functions (NF) expose their services to other NFs to be consumed. 5G system architecture is depicted in Figure *3GPP 5G system architecture with service-based interfaces [3GPP TS 23.501]*. Service based interfaces (SBI) are shown in the figure as “Nxxx” - so N followed by the NF abbreviation in lower case letters (e.g., Nsmf for SMF). The SBIs are based on HTTP/2 protocol with JSON as application layer serialization protocol [3GPP TS 29.500].

The 5G network provides PDU (Protocol Data Unit) connectivity service, which enables exchange of PDUs between UE and Data Network (DN). A PDU session is an association between the UE and a Data Network that provides a PDU connectivity service.

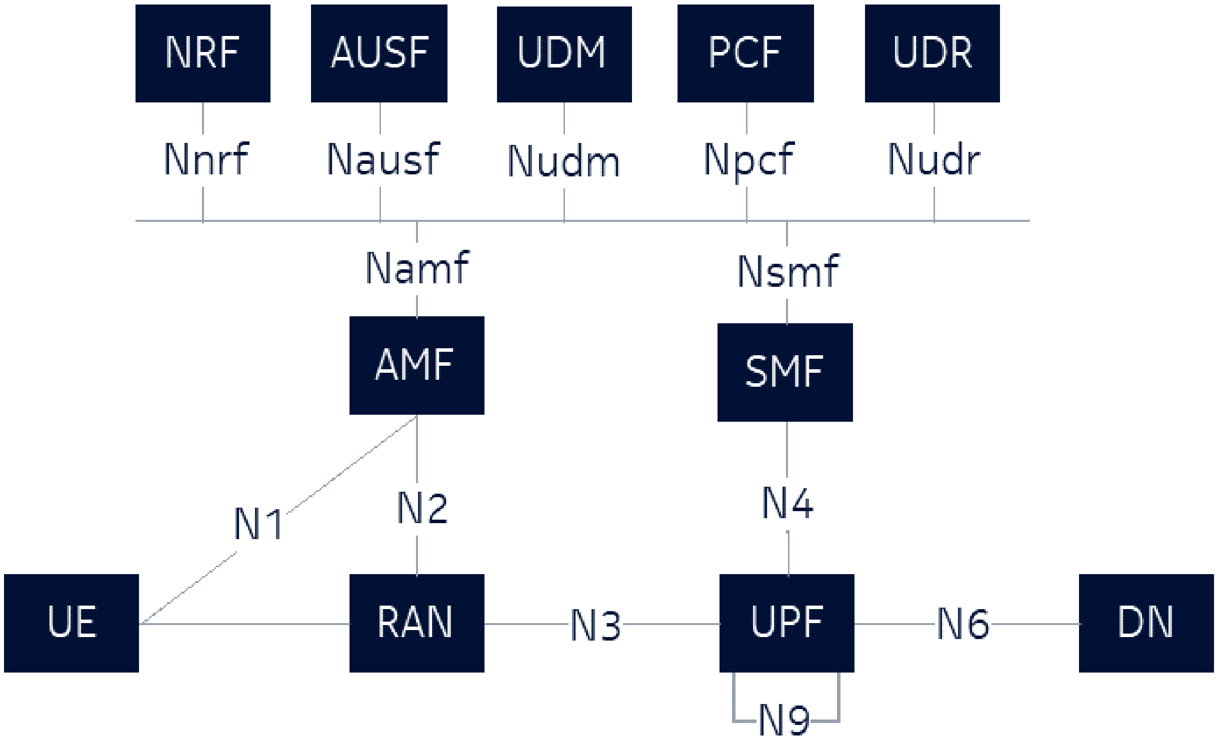

Figure 6: 3GPP 5G system architecture with service-based interfaces [3GPP TS 23.501].

All the specified 5GC NFs are not mandatory in every deployment. The most important functions are:

- AMF: Access and Mobility Management Function
- AUSF: Authentication Server Function
- SMF: Session Management Function
- UDM: Unified Data Management
- UPF: User Plane Function
- UDR: Unified Data Repository (not shown in the figure above)
- NRF: Network Repository Function

Their main roles are as follows:

- AMF terminates NAS signaling from UE (N1 interface) and handles network registration, connection management and mobility management related procedures including authentication supported by AUSF. AMF also interacts with SMF, which terminates the session management part of NAS signaling.
- AUSF provides UE authentication service.
- SMF handles PDU session management and UE IP address management procedures, for example.
- UDM is needed for subscription management and generation for 3GPP AKA authentication credentials.
- UPF takes care of user plane packet routing and forwarding, acts as a mobility anchor point, provides interconnection to the external Data Network (DN) and handles user plane QoS.
- UDR is storage for subscription data used by UDM.
- NRF supports registration and discovery of network functions in the service-based architecture.

4.2 Nokia DAC 5G SA solution architecture

A complete 3GPP 5G SA system can be deployed on the customer premises with 5G gNBs and all 5GC NFs on the edge server, also called the Edge. Thus, the gNBs together with the Edge comprise a fully operational 5G SA network. The Edge is connected to a regional cloud (i.e. Nokia DAC data center, DC), which provides secure cloud-based management functions. 5G SA networks in customer premises are managed via the regional cloud, which provides management tools for operations personnel as well as secure access to a web-based customer portal.

The gNBs connect via the customer IP network to AMF and UPF functions in the Edge. The gNBs also have O&M connection to RAN management service in the Edge.

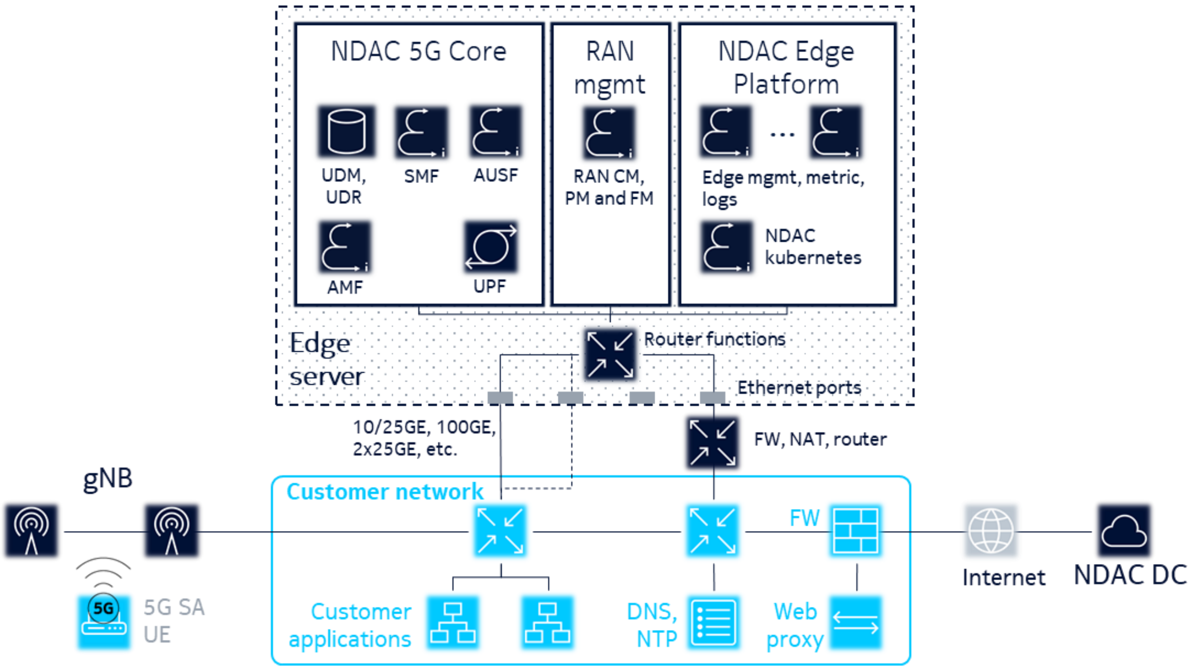

Figure 7: 5G core NFs and support functions in the Edge.

5G SA solution components

This section provides a general overview of the Nokia DAC 5G SA components with selected examples.

4.2.1 Classical 5G gNB architecture

Nokia DAC supports classical gNB architecture comprising Nokia AirScale products both for indoor and outdoor use cases. Nokia's classical 5G gNB consists of AirScale System Module (SM) and various Remote Radio Head (RRH) options for different frequency bands and use cases.

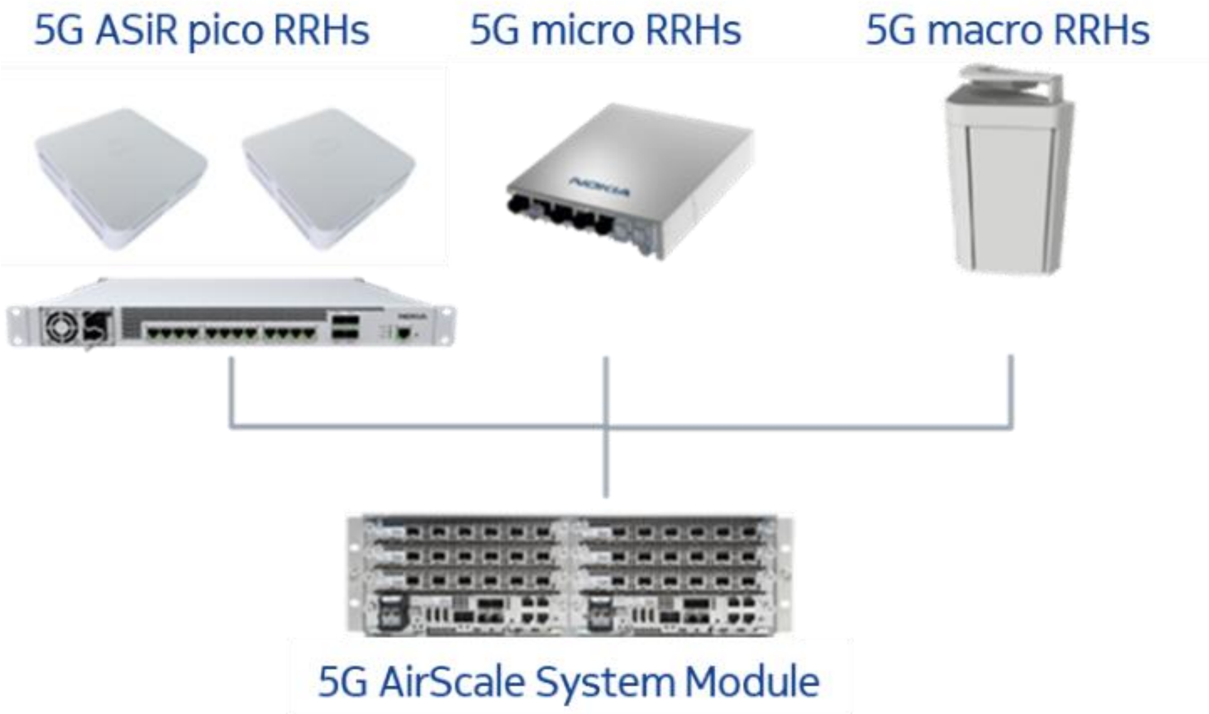

Figure 8: Overview of Nokia AirScale based 5G NR options in Nokia DAC.

4.2.2 Frequency and range consideration

Unpaired radio frequency spectrum with at least 20MHz bandwidth would be required to setup the TDD-based FACT trial network. The proposed frequency band is n38 (2570 – 2620 Hz). Since band n38 falls within the duplex distance of paired band b7 typically used for LTE FDD macro-cellular public networks, there are coexistence aspects to be considered: 5MHz guard interval required and 100m distance between base stations according to CEPT report 19. Preferably the carrier frequency is chosen near the band center to maximize the frequency guard intervals. An alternative frequency band may be n78 (3300 – 3800 MHz) typically used for NR TDD public outdoor networks. However, there are concerns that usage of this band may cause interference to aeronautical radio altimeters operating at 4.2-4.4 GHz.

The maximum radio link distance to be supported is 3000m. Such link distances will not cause link budget issues, since the corresponding free space loss of 101dB is well within the engineered limits of the NR air interface. Link budget examples are presented in Table 2 for 2600MHz carrier frequency, 20MHz bandwidth and 3000m link distance. The ground-to-aircraft link (downlink) applies 2x2 MIMO while the aircraft-to-ground (uplink) applies single stream transmission. The gNB uses directive cross-polarized antennas with 11dBi antenna gain; the antennas will point upwards. The signal-to-noise ratio (SNR) is excellent in both UL and DL, which allows to reduce the gNB transmit power per stream to e.g. 1 Watt (30dBm). Fading margin is ignored due to line-of-sight propagation; losses due to rain and atmospheric absorption are negligible at centimeter wavelengths. The resource utilization assumes allocation of 51 NR frequency resource blocks in 20MHz bandwidth (91.8% BW allocation), allocation of one control symbol per slot in the time domain and 15% pilot overhead. In early trial phase, the maximum link distance may be limited to 1-2km.

Table 2: Link budget examples for ground-to-aircraft (left) and aircraft-to-ground (right) links[5].

DL = ground to aircraft Antenna config: 2Tx 2Rx	2600MHz 3000m
Frequency (GHz)	2,60
Distance (m)	3000,00
DL Tx power per stream (dBm)	**30,00**
Tx antenna gain - cable loss (dBi)	**11,00**
Path loss (dB)	101,07
Fading margin (dB)	**0,00**
Rx antenna gain - cable loss (dBi)	0,00
2Rx combining gain (dB)	2,50
Rx power per stream (dBm)	-57,57
Bandwidth (MHz)	**20,00**
Thermal noise (dBm/Hz)	-174,00
Noise figure (dB)	6,00
Thermal noise (dBm)	-94,99
Implementation loss (dB)	3,00
DL SNR per stream (dB)	**37,42**
Resource utilization	0,725
Shannon rate 2x2 MIMO (Mbps)	331,410
Spectral efficiency 2x2 MIMO (bit/s/Hz)	16,57

UL = aircraft to ground Antenna config: 1TX 2Rx	2600MHz 3000m
Frequency (GHz)	2,60
Distance (m)	3000,00
UL Tx power (dBm)	**24,00**
Tx antenna gain - cable loss (dBi)	**0,00**
Path loss (dB)	101,07
Fading margin (dB)	**0,00**
Rx antenna gain - cable loss (dBi)	11,00
2Rx combining gain (dB)	2,50
Rx power (dBm)	-63,57
Bandwidth (MHz)	**20,00**
Thermal noise (dBm/Hz)	-174,00
Noise figure (dB)	4,00
Thermal noise (dBm)	-96,99
Implementation loss (dB)	3,00
UL SNR (dB)	**33,42**
Resource utilization	0,725
Shannon rate single stream (Mbps)	146,461
Spectral efficiency single stream (bit/s/Hz)	7,32

Coexistence of the considered FACT trial network with public cellular networks in adjacent bands is assessed in Table 2.

It is assumed that the antenna sites are 100m apart and the antennas point to each other. Adjacent channel leakage ratio and adjacent channel selectivity on the order of -50dB can be expected with a frequency guard interval of at least 10MHz. It turns out that adjacent-band interference is minor in either of the systems, even under the unrealistic assumptions that base station antennas would point towards each other.

The maximum velocity of the aircraft shall be 300km/h. The NR air interface provides features to cope with radial user velocities of such magnitude. In early trial phase, the radial velocities may be limited to about 120-150km/h.

[5] Note, that telecommunication industry uses different terminology than is common in aviation: Downlink in telecommunication means from network to the user's device/equipment (here aircraft) while in aviation it represents transmission from aircraft to ground. Similarly, the sense is reversed for uplink. In this section, the telecommunication terminology is used as it refers to general telecommunication characteristics and specifications. Nevertheless, in the chapters and documents focused on aeronautical applications, the usual aviation terminology is and will be used.

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Table 3: Assessment of adjacent-band worst-case interference from public cellular network to FACT trial network (left) and from FACT trial network to public cellular network (right).

Public MNO to FACT trial network	LOS
Distance between sites (m)	100,00
Tx power (dBm)	**46,00**
Tx antenna gain - cable loss (dBi)	**17,00**
Rx antenna gain - cable loss (dBi)	11,00
Path loss (dB)	71,53
Adjacent channel leakage ratio (dB)	-50,00
Adjacent channel selectivity (dB)	-50,00
Received interference power (dBm)	-97,53
Rx bandwidth (MHz)	**20,00**
Thermal noise (dBm/Hz)	-174,00
Noise figure (dB)	4,00
Thermal noise (dBm)	-96,99
Interference to thermal noise ratio (dB)	**-0,54**

FACT trial network to gNB of public MNO	LOS
Distance between sites (m)	100,00
Tx power (dBm)	**33,00**
Tx antenna gain - cable loss (dBi)	**11,00**
Rx antenna gain - cable loss (dBi)	17,00
Path loss (dB)	71,53
Adjacent channel leakage ratio (dB)	-50,00
Adjacent channel selectivity (dB)	-50,00
Received interference power (dBm)	-110,53
Rx bandwidth (MHz)	**20,00**
Thermal noise (dBm/Hz)	-174,00
Noise figure (dB)	4,00
Thermal noise (dBm)	-96,99
Interference to thermal noise ratio (dB)	**-13,54**

4.2.3 5G Data Flow/ Group Communication

Analyzing the requirements of Chapter 3 and considering the information provided in D3.3 we can now dimension the network and map the different data flows over the 5G network. The required data rates and latency per user can be fulfilled with a 5G Release 15 network (which is the status of the first deployments). To transfer data between the flying vehicle and the U space Service and CIS an experimental CNS device is used, which is 5G compatible. For the ground network these devices are connected as one user. The different data flows could be handled as different services with different quality of service requirements. As described in section 3 table 1 the expected data rate is in the range of some 100 kbit/s. The latency requirement is more in the range of seconds. For the dedicated network design also the number of potential users which are simultaneously connected to a specific area needs to be considered. This means that the radio network planning (which allows a dimensioning of coverage and capacity) will consider all these different parameters and will also take into account the bandwidth which can be used for the service.

Another aspect are the different ways of communication like 1 to 1 or 1 to many. The categories can be found in Table 1. To realize this kind of data flow we can use several techniques. One realization we will use during the demonstration is based on so called group communication. A first step is to define groups of users with dedicated requirements. Then it is possible to decide easily to whom the data should be addressed. For example, in case you want to share the information with all the user in a specific area or only with users of a specific type of airspace users. During the next month we will investigate also other option like broadcast techniques (under consideration of the standardization roadmap).

4.2.4 VoIP Link Between ATC and Remote Pilot

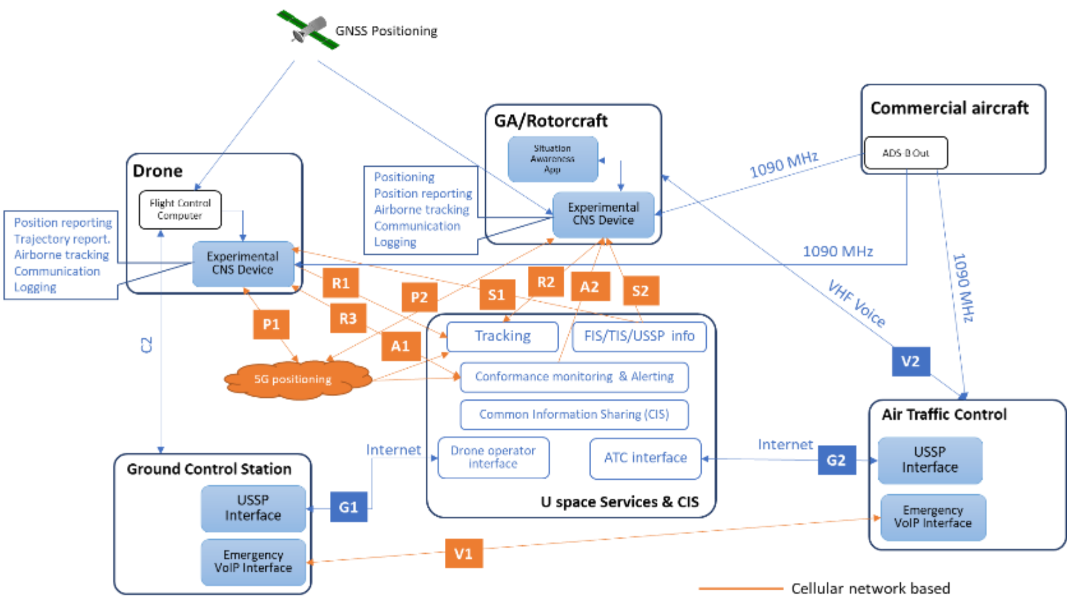
As in D3.3 described the communication between the ground-based remote-control pilot and ATC could be realized by a ground-ground VoIP link. In the trial network we will realize this by providing voice service with the same trial network. In later real deployments the architecture will be based on the existing networks most likely on the application level, because sometimes several communication networks will be used.

4.2.5 Positioning functions of Cellular Network

Cellular network used for the project's operational demo won't support positioning functions. Nevertheless, as described in D3.3 these capabilities will be explored in the project through theoretical analysis and technical measurements of selected parameters in existing (both public and experimental) networks. Overview of main positioning methods used or standardized for cellular networks is provided in Annex C of D3.3 including short description addressing differences in functional architecture.

4.3 Overview of Communication Links Used in Operational Demo

In this chapter the list of links used within the project operational demo (Figure 2 is duplicated here for reference) is provided together with some implementation details.



Label	From – To	Link description	Implementation details
R1	Drone → USSP	Position and status reporting (based on eID/ADS-B) – used primarily by USSP tracking and conformance monitoring functions.	Cellular network communication between on-board user equipment and USSP gate.
R2	GA → USSP	Position and status reporting (based on eID/ADS-B) – used	Cellular network communication between on-

		primarily by USSP tracking functions.	board user equipment and USSP gate.
R3	Drone → USSP	3D trajectory reporting – used by conformance monitoring function.	Cellular network communication between on-board user equipment and USSP gate
S1	Drone ← USSP	Datalink providing snapshot of traffic information for given part of airspace – used by on-board DAA system (only logging for performance evaluation in the project)	Cellular network group communication sending the same information to the defined group of users
S2	GA ← USSP	Datalink providing snapshot of traffic information for given part of airspace – used by on-board situation awareness application supporting pilot.	Cellular network group communication sending the same information to the defined group of users
A1	Drone ← USSP	Datalink providing alerting about detected threats and/or non-conformances detected. Used to evaluate communication performance for potential sending of manoeuvring instructions.	Cellular network communication from USSP gate to on-board user equipment – focus on low latency, high availability.
A2	GA ← USSP	Datalink providing alerting about detected threats and/or non-conformances detected – used by situation awareness application to inform pilot.	Cellular network communication from USSP gate to on-board user equipment – focus on low latency, high availability.
V1	Remote Pilot ↔ ATC	Emergency link supporting direct communication between ATCo and remote pilot of drone.	Ground-ground VoIP link through experimental cellular network
V2	GA ↔ ATC	Conventional voice communication between GA pilots and ATC	Conventional aviation voice link over VHF radio
G1	GCS (remote pilot) ↔ USSP	Datalink between GCS and USSP, within the demo used primarily (beyond mission management) to sending TIS/FIS, geofencing, and potential alerting info to remote pilot.	IP (internet) connection – details to be defined within operational demo preparation

G2	CIS (USSP) ↔ ATC	Datalink providing interface between ATC and USSP/CIS. Within the demo used primarily to provide ATC with traffic information and USSP with ATC instructions (e.g., geofence/geocage requests related to airspace allocation).	IP (internet) connection – details to be defined within operational demo preparation
P1	Drone ↔ Cellular network	Positioning information between drone's modem and cellular positioning functions	Not implemented
P2	GA ↔ Cellular network	Positioning information between GA's modem and cellular positioning functions	Not implemented

5 References

[1] https://www.faa.gov/news/media/attachments/RemoteID_Final_Rule.pdf

[2] https://www.faa.gov/nextgen/equipadsb/capabilities/ins_outs/

[3] RTCA DO-282 Minimum Operational Performance Standards for Universal Access Transceiver Automatic Dependent Surveillance – Broadcast

[4] RTCA DO-358 Minimum. Operational Performance Standards (MOPS) for Flight. Information Services-Broadcast (FIS-B) with Universal Access Transceiver

[5] CORUS U-space Concept of Operations (2019): https://www.eurocontrol.int/project/concept-operations-european-utm-systems

[6] FACT Deliverable D2.1: "Initial Concept of Operations", version 00.01.02, 22.6.2021

[7] FACT Deliverable D2.2: "Initial iCNS Functional Architecture", version 00.01.02, 26.10.2021

[8] FACT Deliverable D2.3: "Final Concept of Operations", version 00.01.01, 2.9.2022

[9] FACT Deliverable D3.3: "Final System Requirements", version 00.01.01, 2.9.2022

[10] FACT Deliverable D5.4: "Validation Assessment Report", to be delivered in September 2022.

Appendix A Additional Details for Information Flows

Detailed description of data interfaces and therefore communication flows implemented in experimental setup used for the operational demo are provided in Appendix A of D3.3. In this section, a description of information flows respecting today's aeronautical standards is provided for reference.

A.1 Position Reporting (GA and drones)

Position reports will contain the following information:

- Time of applicability
- Latitude
- Longitude
- Geometric Altitude
- Pressure Altitude (if available)
- Altitude quantization
- Ground speed
- Heading / Flight Intentions for the next ? seconds (if available)
- NIC – Navigation Integrity Category
- NACP – Navigation Accuracy Category
- Position enhanced by cellular flag (true/false)
- Cellular network status
- For drone
    - Status
    - Drone ID
- For aircraft
    - Callsign
    - Mode S address

Performance requirements are derived from ADS-B Out requirements and from summary of requirements for different types of data in GA, Table 1-2 [8].

Optionally, it is possible to envision additional reporting of operator's private data such as flight time remaining, weather data, etc. This option may be included for analysis of data link characteristics.

A.2 Flight and Traffic Information Services

Flight Information Services broadcast through cellular network is inspired by FIS-B as it's realized in the US for aircraft receiving ADS-B data through 978 MHz Universal Access Transceiver data link (unlike the TIS-B which can be received also through 1090 MHz Extended Squitter). Information collected by more than 500 ADS-B ground stations are transmitted aboard [1]. Location in coverage of any ground station is a condition for obtaining the FIS-B.

FIS-B is focused on weather. Data quality is guaranteed by data source, the FAA and the US National Weather Service. FIS-B data can be displayed on wide range of devices from low cost portable units to certified federated avionics products.

Broadcast is automatic with transmission interval varying from 2.5 to 15 minutes depending on data type. Broadcasted information is summarized in the Table

Table 4: FIS-B Information [2].

Name	Type	Description	Update Rate	Transmission Rate
METAR	Text	Aviation routine weather report	30 min	5 min
SPECI METAR	Text	Unscheduled special weather report	As av.	5 min
PIREP	Text	Pilot Reports	As av.	10 min
TAF	Text	Terminal Aeronautical Forecast	6 hrs	10 min
TAF AMEND	Text	Amended TAF	6 hrs	10 min
Wind & Temp Aloft	Text	Forecast of winds & temperatures aloft	12 hrs	10 min
AIRMET	Text/Graphics	Airman's Meteorological Information: mountain obscuration, icing, or turbulence	As av.	5 min
Convective SIGMET	Text/Graphics	Convective Significant Meteorological Information: severe, extensive, or prolonged thunderstorm	As av., then 15 min for 1 hour	5 min
SIGMET	Text/Graphics	Significant Meteorological Information: turbulence, icing, or IMC conditions.	As av., then 15 min for 1 hour	5 min
NOTAM-D	Text/Graphics	Distant Notice to Airmen: Information to be wide disseminated	As av.	10 min
NOTAM-FDC	Text/Graphics	Flight Data Center Notice to Airmen: Regulatory information	As av.	10 min
NOTAM-TFR	Text/Graphics	Temporary Flight Restriction Notice To Airmen	As av.	10 min
NOTAM-TRA/TMOA	Text/Graphics	Temporary Restricted Area and Temporary Military Operation Area Notice To Airmen: Provided in textual and graphical formats.	As av.	10 min
SUA Status	Text/Graphics	Special Use Airspace Status	As av.	10 min
CONUS NEXRAD	Graphics	NextGen Radar: precipitation and wind in a mosaic map	Approx. 5 min	15 min
Regional NEXRAD	Graphics	Regional NextGen Radar	Approx. 5 min	2.5 min
Lightning	Text	Lightning detected by Vaisala	As av.	5 min

Turbulence	Text	Intensity of turbulence at 12 altitude levels (2,000 – 24,000 ft)	1 hr	15 min
Icing	Text	Icing at 12 altitude levels (2,000 – 24,000 ft), current & forecast	1 hr	15 min
Cloud Tops	Text	Terminal Aeronautical Forecast	1 hr	15 min
Center Weather Advisory	Text	Warning of potentially hazardous conditions not satisfying criteria for AIRMET, SIGMET of Convective SIGMET	As av.	10 min
Graphical AIRMET	Graphics	Potentially hazardous conditions	6 hrs	5 min

A.3 ATC Instructions for GA

ATC will have and provide information for GA traffics by using radio communication and benefiting from new CNS capabilities within the project. Main purpose of the instruction to provide safe separation between obstacles, other traffics and remote aerial vehicles.

While having traffic 3D situation via new device and CNS integration, it will be better for the operator situational awareness for all in the air and on the ground.

ATCo's will instruct by using proper phraseology to instruct and control GA traffics and also provide essential traffic information including items presented in Table 4.