EXPLORATORY RESEARCH

Technical Enablers and Initial System Requirements

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FACT

FUTURE ALL AVIATION CNS TECHNOLOGY

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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 without negatively affecting the overall operational safety.

This deliverable provides description of the main CNS technical enablers addressed in project FACT as well as initial version of related System Requirements. Because project FACT covers a whole range of operations with different airspace users, the appropriate functional architecture is the key pre-requisite for successful system definition. This document is therefore very closely connected to deliverable Initial iCNS Functional Architecture (D2.2) and together with initial Concept of Operations (D2.1) they represent the overall description of the project FACT technical and operational eco-system.

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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 without negatively affecting the overall operational safety.**

In this context, a coexistence of drones and GA including rotorcrafts within the controlled and uncontrolled airspace is the primary focus, the particular attention being paid to possible use of existing and future cellular network infrastructure and how to combine it with other aeronautical technologies. While the project is addressing technical enablers of multiple U-space and ATM services, it investigates more in detail position and trajectory reporting together with associated tracking & monitoring, and provision of information through traffic and aeronautical information sharing services.

This deliverable provides description of the main CNS technical enablers addressed in project FACT and explains how they contribute to targeted end-to-end CNS applications. Initial version of performance requirements for these applications is proposed through adoption/adaptation of the requirements for existing ADS-B applications with similar objectives.

Because project FACT covers a whole range of operations with different airspace users, the appropriate functional architecture is the key pre-requisite for successful system definition. This document is therefore very closely connected to deliverable Initial iCNS Functional Architecture (D2.2) and together with initial Concept of Operations (D2.1) they represent the overall description of the project FACT technical and operational eco-system.

1.1 Definitions

Aerodrome Flight Information Service (AFIS) is the provision of information useful for the safe and efficient conduct of aerodrome traffic at those aerodromes designated for use by international general aviation where the appropriate air traffic services authority determines that the provision of aerodrome control service is not justified, or is not justified on a 24-hour basis [18].

Common Information Service (CIS) is entity enabling real time sharing of information between ATM and U-space as well as among individual U-space services providers. According EASA Opinion [20], it will be certified and unambiguously assigned by an authority defining the specific U-space (typically State). It consolidates actual traffic data and other airspace related information (such as geofencing zone, restricted airspace, etc.) from all USSPs and ATC / AFIS, and provides access to this information to the relevant stakeholders [17]

Controller Pilot Data Link Communications (CPDLC) is a two-way data-link system by which controllers can transmit non urgent 'strategic messages to an aircraft as an alternative to voice communications. The message is displayed on a flight deck visual display. The CPDLC application provides air-ground data communication for the ATC service. It enables a number of data link services (DLS) that provide for the exchange of communication management and clearance/information/request messages which correspond to voice phraseology employed by air traffic control procedures. [15]

Flight Information Service (FIS) is a service provided for the purpose of giving advice and information useful for the safe and efficient conduct of flights [17]. It is available to any aircraft within a 'Flight Information Region'. The details of FIS may vary throughout Europe due to different national regulations. The core tasks are published in ICAO-documentation (e.g. Annex 11 & Doc 4444) and include the provision of pertinent information in regard to the following elements: weather conditions. Availability of radio navigation services, changes in condition of aerodromes, etc. [14].

Traffic Information Service (TIS) is a service providing provides traffic advisory information to aircraft. within a specified service volume. It is realized in the USA as part of the FAA's Next Generation Air Transportation System (NextGen).

U-Space airspace is UAS geographical zone designated by Member States, where UAS operations are only allowed to take place with the support of U-space services [12].

U-Space Service is a service relying on digital services and automation of functions designated to support safe, secure and efficient access to U-space airspace for a large number of UAS [12].

U-Space Service Provider supports the safe and efficient movement of drones in the U-space airspace and ensure coordination with manned aircraft. These organizations must be certified to provide U-space services in one or more European member states. To become certified, organizations are required to provide four mandatory U-space services: network identification, geo-awareness, traffic information, and UAS flight authorization.

1.2 List of Acronyms

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
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
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
COTS	Commercial Off-the-Shelf
CPDLC	Controller Pilot Data Link Communications
CTR	Controlled Traffic Region

DAA	Detect and Avoid
D8PSK	Differential 8-Phase-Shift-Keying
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
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
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
MLAT	Multilateration
MTOW	Maximum Take-off Weight
MTSAT	Multifunctional Transport Satellites
NR	New Radio
OSI	Open System Interconnection
PBN	Performance Based Navigation
PSR	Primary Surveillance Radar
QNH	Mean Sea Level Pressure
RAIM	Receiver autonomous integrity monitoring
RNAV	Area Navigation
RNP	Required Navigational Performance
SBAS	Space Based Augmentation System
SelCal	Selective Call
SINR	Signal-to-Noise Ratio
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
UE	User Equipment
UL	Uplink
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
VOR	VHF omnidirectional range
WAAS	Wide Area Augmentation System

1.3 List of Figures

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2 Introduction

This deliverable provides description of the main CNS technical enablers addressed in project FACT as well as initial version of related System Requirements. Because project FACT covers a whole range of operations with different users of airspace, it is important to correctly distinguish the boundaries of the individual functional units. This document is therefore very closely connected to deliverable Initial iCNS Functional Architecture (D2.2) and together it forms functional and system description of the project FACT technical eco-system.

Approach adopted for development of initial system requirements is based on the following steps:

1. Definition of main end-to-end applications to be enabled by the considered iCNS architecture (which is described more in detail in D2.2 deliverable);
2. Development of functional requirements for each application;
3. Definition and description of associated technical enablers.
4. Definition of system requirements starting from overall requirements drive by end-to-end applications from which the requirements on the individual systems/technical enablers will be derive. Only the first step is described in this document as the second step will take into account the results of first validation activities and is planned for refined system requirements deliverable D3.3.

2.1 Document Overview

After introduction sections in Chapter 1 and 2, an overview of targeted End-to-End Applications is provided in Chapter 3 together with associated background. Section 4 provides system view on these applications complemented with functional and integration requirements. It includes both already installed capabilities that are planned to be used for project's purposes and the new systems/functions to be developed/installed. Section 5 is focused on definition and discussion of performance requirements. As the performance-based approach is adopted, the requirements are focused on application level, not on individual system components. In addition, the performances of some existing technological solutions are provided in this section as reference. Main interfaces among systems are discussed in Appendix A, nevertheless this list is not completed and all interfaces are covered more in detail in D2.2 (Initial Functional Architecture) document.

3 End-To-End Applications Overview

This section presents overview of end-to-end applications driving the assessment of CNS technical enablers for low altitude operations. Interoperable, accurate and reliable traffic surveillance is one of the key challenges for low altitude airspace with heterogeneous traffic as it is an essential pre-requisites for any efficient traffic management – whether through distributed on-board functions such as Detect and Avoid (DAA) or using different types of ground services.

In this context, situation awareness applications using traffic surveillance based on vehicle's position reporting are used as the basic capability to be supported by CNS enablers considered in FACT. In addition, several CNS enhancements are considered to support strategic deconfliction as a next-level application with different performance requirements.

Beyond the above, direct communication between ATC and remote pilots is considered as another type of end-to-end application for the FACT activities.

3.1 Traffic Surveillance and Situation Awareness Applications

Traffic surveillance is a common enabler of all situation awareness applications considered in this document. For the purpose of project's CNS performance evaluations existing traffic surveillance technical means (e.g., ADS-B, SSR) are complemented with an airborne position reporting function installed in all low altitude vehicles without ADS-B Out capability. This function transmits the position reports (similar to ADS-B Out reports) over the cellular network. The transmitted information is received, consolidated, and potentially complemented with additional information (e.g., weather, airspace restrictions) by ground functions and transmitted to the situation awareness applications of different end users. In this way a complete and consistent situation awareness is achieved for all involved stakeholders.

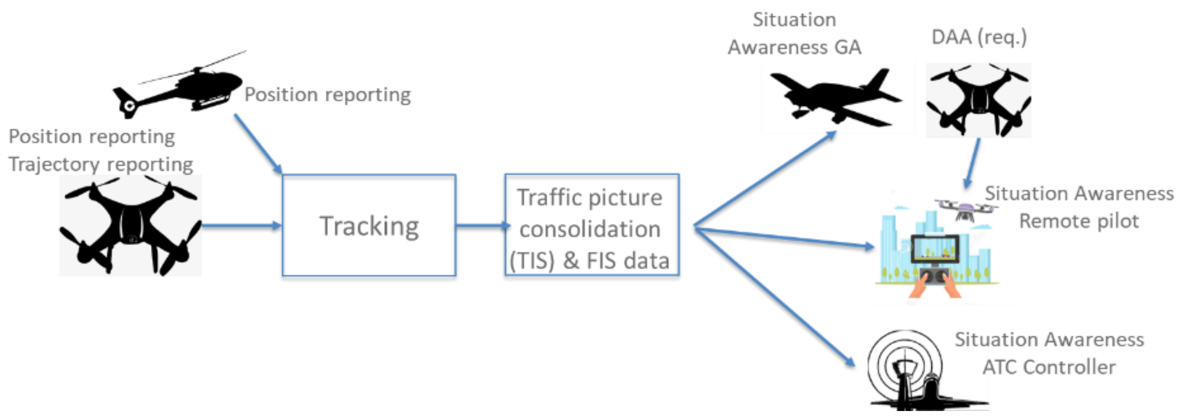

Figure 1: Traffic Surveillance System View

Figure 1 provides description of traffic surveillance from the origin of data by position and trajectory reporting through ground functions responsible for data processing and consolidation to the use of traffic surveillance data in different end applications.

Within the project, the following variants of situation awareness functions are considered:

- Situational awareness for GA Pilot
- Situational awareness for ATC
- Situational awareness for remote pilot of drone

In addition, the use of such traffic surveillance for on-board DAA function is also considered.

The proposed traffic surveillance is very similar to ADS-B and it will be used to draft initial performance requirements using the analogy with standardized ground and airborne ADS-B applications. For European ADS-B Out mandate see [18].

Situational awareness application for GA pilot will be realized as portable application. It is important to mention that although pilot will be provided by additional traffic information, his obligation to perform see and avoid for preventing the collision with other aircraft is still valid. This will result in lower performance requirements on associated traffic surveillance.

It is considered that Traffic Situational Awareness system with Alerts (TSAA) as standardized within RTCA DO-317B can be used as inspiration for initial performance requirements as this application is also intended for GA and it is based on processing incoming ADS-B messages.

Situational awareness for ATC

There are two main benefits associated with the proposed traffic surveillance application. First, it will provide ATC with information about traffic (including unmanned) without transponder or ADS-B Out, and secondly, it would provide information about traffic even in the airspace currently without ground surveillance (SSR, primary radar) coverage. In particular, low altitude airspace outside of airports has typically very limited ATC surveillance coverage today.

In addition, the proposed situation awareness application will allow to receive additional information from U-space services providers about organization of unmanned traffic.

Situational awareness for remote pilot

Situation awareness application for remote pilot will provide traffic surveillance data complemented with information from U-space service provider. The remote pilot is responsible for performing safe flight and compliance with instructions from USSP, and traffic surveillance picture can support him in these tasks. In addition, remote pilot can be interacting with DAA and also in this case the reliable and accurate traffic surveillance information is essential.

A specific type of information to be considered for situation awareness is when remote pilot (based on the EASA U-space regulation) is communicating with ATC about dynamic airspace allocation for unmanned flights in controlled airspace. Dynamic airspace allocation is an example of low-latency application. Airspace allocation will be transmitted to USSP via and USSP is responsible for updating geofencing information and inform remote pilots based on this allocation. Because this chain of information is quite long, the option of reaching drone operator directly by ATC via voice over IP as an tactical tool should be explored for cases when situation changes quickly.

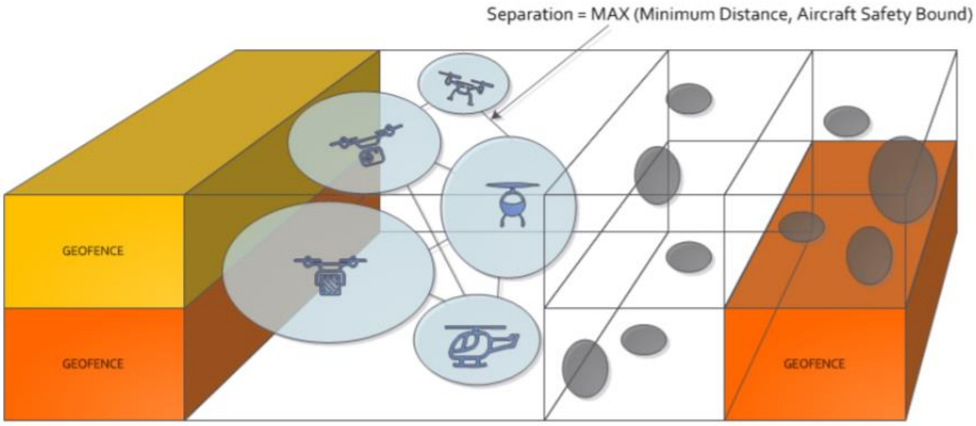

Figure 2: Dynamic airspace allocation example [4]

Traffic surveillance for Detect and Avoid

Although the FACT project does not intent to implement Detect and Avoid system on the drone, and this system will primarily rely on data from on-board sensors, availability of traffic surveillance picture also from ground services is also considered as a way hot increase the performance of the system.

Use of ground surveillance data is considered for instance for ACAS sXu system which can be used as inspiration for drafting performance requirements. ACAS sXu is a Detect and Avoid system which is being developed under The Federal Aviation Administration's (FAA) Traffic Alert and Collision Avoidance System (TCAS) Program Office. ACAS sXu requirements will be documented in a Minimum Operational Performance Standard (MOPS) developed in RTCA SC-147 (in cooperation with EUROCAE WG 75) and expected in 2024.

3.2 CNS Performance Enhancement supporting Strategic Deconfliction

There are two types of CNS enhancement considered in the project to support/enable efficient strategic deconfliction:

- Positioning through cellular network infrastructure to complement GNSS
- Trajectory reporting and related conformance monitoring & alerting.

3.2.1 Cellular positioning

Cellular network – in particular within 5G – offers advanced possibility to determine vehicle's position using ground infrastructure. From application's perspective, the two types of enhancements can be considered:

- Improving the on-board positioning function (navigation) which can increase quality of position reporting (and therefore traffic surveillance described in previous sections), as well as capability of the on-board automation to follow accurately the planned trajectory/mission. There are two options for on-board enhancement:

  - Hybrid navigational solution where advantages of complementarity of cellular and GNSS positioning are used
  - Independent cellular positioning serving as backup for cases of GNSS unavailability

- Providing an independent localization function to ground services processing traffic information. This can allow verification/accuracy improvements of the traffic surveillance data, as well as implementation of various monitoring/alerting functions handling the situations when some deviations between reported and measured data are observed.

Assumed approach for realistic use of cellular network data for positioning purposes is sketched in Appendix C where different options are described in more detail.

It is important to mention that currently envisioned architecture of 5G experimental network for project final validations will not directly support positioning service. Due to this fact, concept of possible use of cellular network for positioning will be prepared theoretically and supported by a series of indirect network measurements. For evaluation of realistic performance, measurement of individual parameters affecting positioning accuracy is planned to be performed by leveraging the opportunity to do the evaluations within other trial (for 5G) and public (for 4G) networks available in Europe. Evaluated parameters will be either directly related to positioning service (positioning reference signals if available, timing advance) or to relevant network performance (signal quality indicators, information about primary and neighbour cells).

3.2.2 Trajectory Reporting & Conformance Monitoring

For the vehicles with automated guidance, such as majority of commercially used drones, the sharing of planned trajectory can enable implementation of strategic deconfliction. This can result in more efficient strategic deconfliction increasing thus airspace capacity and access. The key pre-requisite of such approach is sufficiently high conformance of the vehicles with planned/shared trajectory.

The two enablers of the latter are reliable and accurate on-board navigation and quality of the automated guidance function. In addition, trajectory conformance monitoring will need to be implemented to continuously monitor if the vehicle is adhering to its assigned/planned flight trajectory (used for strategic deconfliction) and immediately alert relevant stakeholders when not.

Per current state of the art in the area of drone autopilots, there is not commonly available support of 4D trajectory (position + time predictions). Due to this fact, only 3D trajectory will be considered within the project.

The simplified overview of basic situation awareness applications as well as considered enhancements is shown in Figure 3.

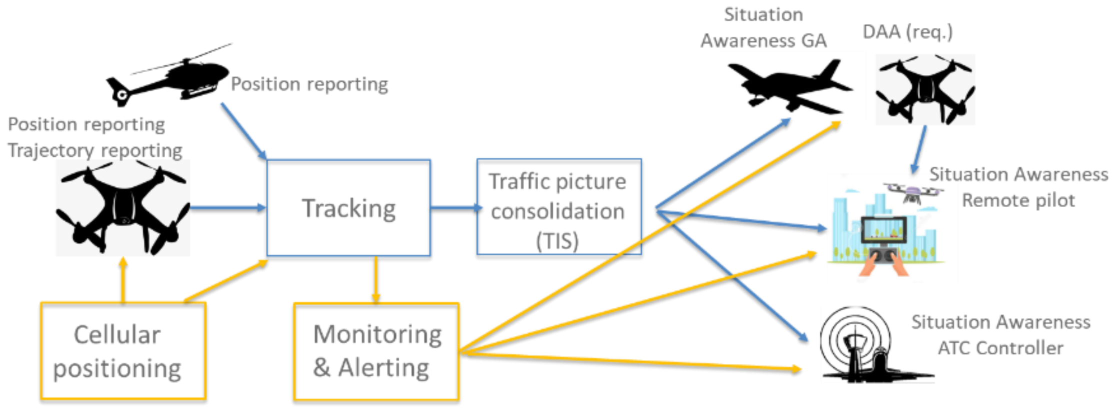

Figure 3: Situational awareness applications with considered enhancements

3.3 Emergency link ATC – Remote Pilot

This application enables direct communication between Air Traffic Controller and drone operator. There is an assumption that it won't be necessary in nominal situations, but it is intended to use during emergency.

Main performance requirement is then related to reliability (continuity of the service). Technology considered for this application in FACT project will be Voice over IP.

4 System Overview – Technical Enablers

The overall system architecture is shown in Figure 4. Beyond the communication infrastructure realized by cellular network which is described more in detail in D2.2 (Initial Functional Architecture), the technical enablers are essentially:

- Systems installed onboard GA aircraft: Experimental CNS device and situation awareness application
- Systems installed on-board drones: Experimental CNS device
- Experimental implementation of selected U-space services. (see Section 4.4 for more details)
- Enhancements of the remote pilot's ground control station
- Enhancements of the ATCo working position.

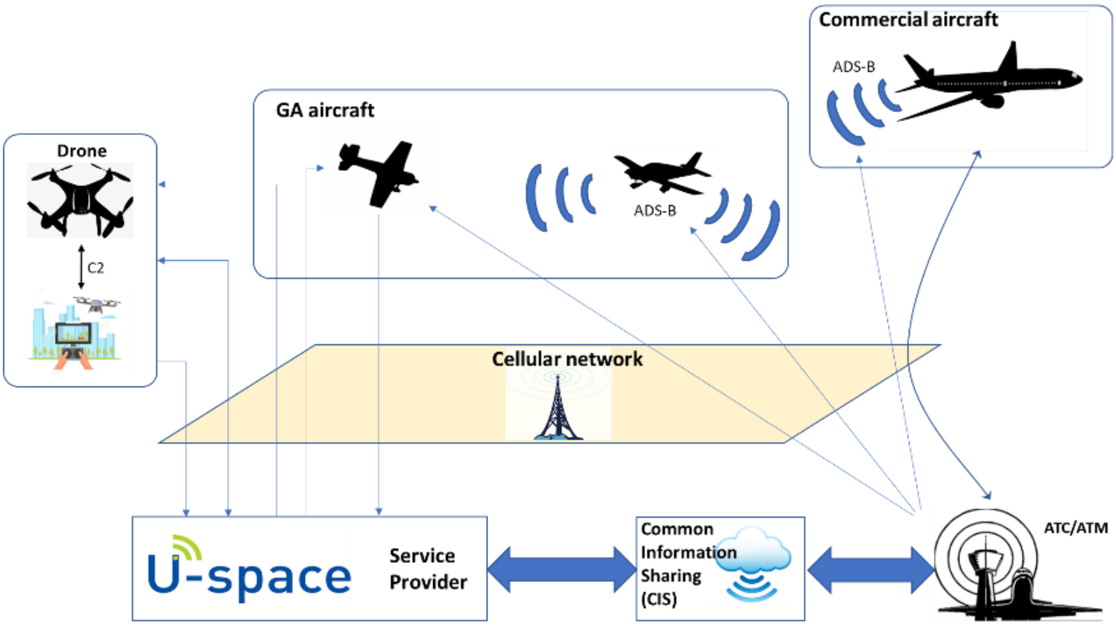

Figure 4: System overview

4.1 General Aviation – Technical Enablers

The purpose of technical enablers on-board the GA aircraft is to:

- Regularly report aircraft position to support traffic surveillance services to support situation awareness of other airspace users and service providers.
- Benefit from enhanced ground FIS/TIS services to increase flight safety through improved situation awareness of GA pilot by presenting received actual information about airspace, weather, and surrounding traffic.

For this purpose, two onboard systems are planned to be installed (they will represent stand-alone units) in the aircraft: experimental CNS device and situation awareness display (mobile installation).

4.1.1 Already Installed Capabilities – Assumptions

GA aircraft is expected to be equipped as necessary for today's operations in the targeted airspace. The equipment will allow to perform safely the planned flights, but this equipment is not expected to be used for evaluation of CNS capabilities.

4.1.2 Experimental CNS Device

The CNS experimental device will be designed as a stand-alone system without any direct connection to integrated aircraft avionics. It will be powered by its own battery. It will contain own GPS to provide position information and cellular chip for communication and positioning support. Requirements related to CNS device at GA aircraft will be marked by 1-X (X conforms to number of requirement).

4.1.2.1 Functional Requirements

The CNS experimental device will provide the following main functions:

<u>Positioning</u>

Positioning function means providing of position data including estimation of quality indicators (accuracy, integrity, etc.) of the reported position information

REQ-FUNC-1-1 Positioning function **shall** be based on GNSS with potential enhancements (depending of the airspace and available infrastructure) using additional technologies such as supporting data from cellular network.

REQ-FUNC-1-2 Position information **shall** be complemented with quality indicators specifying at least the position accuracy and integrity. Structure of information contained in position reports is derived from ADS-B standards enhanced by status of cellular network data.

<u>Position reporting</u>

This function means position and aircraft status report generation function.

REQ-FUNC-1-3 Position reports **shall** contain data specified in the Section A.1.

<u>Communication function</u>

Communication function is responsible for providing all interfaces of the CNS experimental device.

REQ-FUNC-1-4 Position reports **shall** be provided over cellular network with update rate of 2 Hz. (Rate requirement is based on DO-260B requirements for rate of ADS-B messages).

REQ-FUNC-1-5 Device **shall** receive ADS-B data from surrounding traffic.

REQ-FUNC-1-6 Device **shall** receive traffic information from ATC/ATM about traffic.

REQ-FUNC-1-7 Device **shall** transmit consolidated traffic picture by wireless technology with update rate of 1 Hz.

On-board traffic detection function

This function consolidates traffic data for wireless transmission to pilot's mobile device.

REQ-FUNC-1-8 Device **shall** consolidate received ADS-B data with traffic data obtained from ATC/ATM.

REQ-FUNC-1-9 Situational awareness **shall** include the following information about vehicles in region of interest:

- Time of applicability
- Drone ID/ aircraft ICAO address / other IDs
- Bearing (relative angle to ownship)
- Range (relative ground distance to ownship)
- Altitude (relative to ownship)
- Heading (if available)
- Ground speed
- Vertical trend (level / climb / descent)
- Altitude quantization
- Status code

REQ-FUNC-1-10 Device **shall** process received ADS-B data for purpose of situational awareness function.

Logging function

REQ-FUNC-1-11 Device **shall** log following data

- Transmitted position reports
- Received traffic information
- Consolidated traffic picture sent to situation awareness display.

(Optional) Low power ADS-B Out function may be provided for some scenarios.

4.1.2.2 Installation Requirements

Installation will consist of mechanical fixation of the device inside the vehicle and installation of antennas (GNSS, cellular network, ADS-B).

4.1.3 GA Situation Awareness Application

Purpose of the mobile application is to demonstrate benefits for GA pilots resulting from information available due to the enhanced CNS capabilities of mixed traffic and availability of supporting ground services. Requirements related to GA Situation Awareness Application at GA aircraft will be marked by 2-X (X conforms to number of requirement).

4.1.3.1 Functional Requirements

The mobile application is intended to provide following functions:

Communication function

REQ-FUNC-2-1 The application **shall** receive consolidated traffic reports by wireless technology.

REQ-FUNC-2-2 The application **shall** receive flight supporting information by wireless technology.

Displaying Traffic Information

REQ-FUNC-2-3 The application **shall** display traffic data to be consistent with DO317B, Section 2.3 Cockpit Display of Traffic Information (CDTI) Subsystem Requirements.

REQ-FUNC-2-4 The application **shall** be able to display following elements if available:

- Ownship symbol
- Traffic symbol
- Traffic Air/Ground Status
- Differential ground speed
- Traffic relative altitude
- Traffic vertical trend
- Traffic identification
- Traffic ground speed
- Traffic category
- Traffic horizontal velocity vector
- Display range
- Traffic coasting indicator
- Traffic range

REQ-FUNC-2-5 The application **shall** be able to display planned trajectory for neighbor traffic when this information will be available.

OPTIONAL: The application may include traffic alerting.

Displaying Flight Information

Function is responsible for displaying of available flight relevant information like weather, restricted airspace etc. This information is consumed from CNS experimental device.

REQ-FUNC-2-6 The application **shall** be able to display information about airspace restrictions received from FIS/AFIS ground services.

REQ-FUNC-2-7 The application **shall** be able to display weather information data to be consistent with DO317B, Section 2.3.8.1 Multi-function Display.

System status

REQ-FUNC-2-8 The application **shall** display available information about potential system failure or connectivity issues.

4.1.3.2 Installation Requirements

No specific installation requirements, only WI-FI/Bluetooth connectivity with CNS experimental device needs to be verified.

4.2 Drones – Technical Enablers

The purpose of technical enablers on-board the drone is to:

- Regularly report drone's position to support USSP and traffic surveillance services in order to contribute to situation awareness of other airspace users.
- Regularly report drone's flown trajectory to support USSP and potential strategic deconfliction services as well as to contribute to situation awareness of other airspace users
- Profit from enhanced ground FIS/TIS services to feed future on-board DAA and mission management functions with actual information about airspace, weather, and surrounding traffic.

4.2.1 Already Installed Capabilities – Assumptions

Drone is expected to be equipped as necessary for today's VLOS operations and for automatic flight along pre-defined 3D trajectory. The following capabilities are considered to be used for project's activities:

- Navigation (GNSS+INS)
- Autopilot & flight guidance – capable to follow pre-defined 3D trajectory
- C2 link with Ground Control Station (GCS)
- GCS with capability to create/modify trajectory (FPLN) to be uploaded and flown by the autopilot.
- Health monitoring & fail safety – Emergency landing and return to home
- Logging flight data

4.2.2 Experimental CNS Device

The CNS experimental device will be connected to flight guidance computer using Mavlink protocol over a serial link and powered by drone's batteries. Requirements related to CNS experimental device at drone will be marked by 3-X (X conforms to number of requirement).

4.2.2.1 Functional Requirements

The CNS experimental device will provide the following main functions:

<u>Position and drone status report generation function</u>

REQ-FUNC-3-1 Positioning report generation function **shall** read position information from flight guidance computer with potential enhancements (depending of the airspace and available infrastructure) using additional technologies such as supporting data from cellular network.

REQ-FUNC-3-2 Position information **shall** be complemented with quality indicators specifying at least the position accuracy and integrity.

REQ-FUNC-3-3 Position reports **shall** contain data specified in the Section A.1.

REQ-FUNC-3-4 Position reports **shall** conform to EU regulation 2019/945, requirements for an electronic identification of drones.

REQ-FUNC-3-5 Transmitted position information **shall** not be older than 400 millisecond. This time represents time difference between when a position is measured and when it is emitted

Rationale: FAA Final Rule for Remote ID [1]) states requirement for freshness of the position to one second. Because the reported position is intended to use for dynamic airspace allocation, the requirement was tighten to 400 msec as it is required at ADS-B Out.

<u>Trajectory report generation function</u>

Trajectory reports contain planned future trajectory.

REQ-FUNC-3-6 The trajectory report **shall** be updated each 10 seconds or when modified.

REQ-FUNC-3-7 The trajectory report **shall** contain the following information:

- Drone ID
- Time of applicability (time for which the trajectory estimate is valid)
- Series of waypoints specified by
    - Latitude
    - Longitude
    - Geometric Altitude
    - Heading
    - Ground speed

<u>Communication function</u>

Communication function is responsible for providing all interfaces of CNS experimental device.

REQ-FUNC-3-8 The device **shall** consume data specified in Section A.5 from flight control computer of drone.

REQ-FUNC-3-9 Position reports **shall** be provided over cellular network with update rate of 2 Hz. (Rate requirement is based on DO-260B requirements for rate of ADS-B messages – it should be updated taking into account the transmission characteristics of the cellular network).

REQ-FUNC-3-10 Trajectory reports **shall** be provided over cellular network with update rate of 0.1 Hz or within 1s after a FPLN change.

REQ-FUNC-3-11 The device **shall** consume traffic data received through cellular network from U-Space Service Provider.

REQ-FUNC-3-12 The device **shall** receive ADS-B data from surrounding traffic.

On-board Traffic Detection

REQ-FUNC-3-13 Device **shall** process received ADS-B data for purpose of potential use by detect and avoid function.

Rationale: Inputs to DAA function addressed in the project are ADS-B traffic detected onboard and traffic data received from the U-Space Service Provider.

Logging function

REQ-FUNC-3-15 Device **shall** log following data

- Transmitted position and trajectory reports
- Received traffic information
- Consolidated traffic reports prepared for potential DAA use.

4.2.2.2 Installation requirements

Installation will consist of mechanical fixation of the device, serial connection to flight computer, connection to power management (battery), and installation of antennas (cellular, ADS-B).

4.2.3 Ground Control Station Enhancements

The Ground Control Station will be connected to Drone using Mavlink protocol over a dedicated C2 link and to ground cloud services (& CIS) using Wi-Fi/Bluetooth connection in order to access U-space services. The main purpose of GCS software is to provide pilot's/operator's full control over the Drone. In this project, the essential enhancements will be applied to an ordinary Drone GCS. Requirements related to Ground Control Station Enhancements will be marked by 4-X (X conforms to number of requirement).

4.2.3.1 Functional Requirements

The GCS software is intended to provide following enhanced functions:

Communication function

REQ-FUNC-4-1 The GCS software **shall** receive consolidated traffic reports by CNS experimental device.

REQ-FUNC-4-2 The GCS software **shall** receive flight supporting information by CNS experimental device.

REQ-FUNC-4-3 The GCS software **shall** send pilot/operator credentials and operated drone identification data

REQ-FUNC-4-4 The GCS software **shall** receive pilot/operator authentication and drone-pilot allocation acknowledge.

Displaying Traffic Information

REQ-FUNC-4-5 The GCS software **shall** display traffic data.

REQ-FUNC-4-6 The GCS software **shall** be able to display following elements if available:

- Ownship symbol
- Traffic symbol
- Traffic Air/Ground Status
- Differential ground speed
- Traffic relative altitude
- Traffic vertical trend
- Traffic identification
- Traffic ground speed
- Traffic category
- Traffic horizontal velocity vector
- Display range
- Traffic coasting indicator
- Traffic range

REQ-FUNC-4-7 The GCS software **shall** be able to display planned trajectory for neighbor traffic when this information will be available.

OPTIONAL: The application may include traffic alerting.

<u>Displaying Flight Information</u>

Function is responsible for displaying of available flight relevant information like weather, restricted airspace etc. This information is consumed from CNS experimental device.

REQ-FUNC-4-8 The GCS software **shall** be able to display information about airspace restrictions received from FIS/AFIS ground services.

REQ-FUNC-4-9 The GCS software **shall** be able to display weather information data.

<u>Displaying Airspace</u>

REQ-FUNC-4-10 The GCS software **shall** display the airspace information (geofence/geocage zone, restricted airspace) data.

4.2.3.2 Installation requirements

No specific installation requirements, only connectivity with CNS experimental device needs to be verified.

4.2.4 Ground Control Station: VoIP Communication with ATC

The VOIP communication with ATC feature of GCS Software enables direct communication between Air Traffic Controller and drone operator in emergency cases. Main advantage of VoIP over regular telephone line is quality of audio call and cybersecurity, especially possibility of advanced authentication and encrypting of the communication.

Requirements related to VOIP communication with ATC feature will be marked by 5-X (X conforms to number of requirement).

4.2.4.1 Functional requirements

REQ-FUNC-5-1 The VOIP feature **shall** enable receiving incoming calls form the ATC.

REQ-FUNC-5-2 The VOIP feature **shall** enable calls to the ATC.

REQ-FUNC-5-3 The VOIP feature **shall** provide echo-free and real-time/low-latency voice communication.

REQ-FUNC-5-4 The VOIP feature **shall support protection against cybersecurity threats such as advanced authentication and encryption of the communication.**

4.2.4.2 Installation requirements

No specific installation requirements, only Internet connectivity needs to be verified.

4.3 Network Infrastructure – Technical Enablers

This section provides functional requirements and some additional considerations regarding the network infrastructure to complete overall system description. Nevertheless, more detailed technical description covering architecture and implementation details are provided in deliverable D2.2.

As described in D2.2, different types of traffic has to be handled over the 5G network. In addition, the overall system/functional requirements are captured and translated into wireless communication requirements in that document. From functional perspective:

- The network will provide the capability to use different bandwidth, depending on the spectrum availability and throughput requirements. The dimensioning will also be influenced by the number of airspace users. 5G networks can provide service to several hundreds of users in one cell. Therefore, the dimensioning of the network will depend on balancing all of this parameters and can be different for specific areas. Wireless networks are very flexible and can be also later adapted in case more capacity is needed. Reason could be the increased number of users or additional application with increased data demand. Therefore, the project's approach considers that the proof-of-concept implementation addressed in the project's demo can be adapted to future operational needs by changing the network on the ground without changing radio equipment on the flying vehicle.

- Beside the classical 1 to 1 communication like typical calls, the wireless network can provide features for a kind of group communication. Here the information will be shared with the group of users which can be semi statically defined. Depending on the changing requirements we can improve later these kinds of solutions to tailor it for evolving operational needs.

- FACT project does not consider only the air-ground communications, but also ground communication between a remote-control pilot of a drone and ATC. One proposal is to use VoIP which can be realized by the wireless communication network.

To summarize, the 5G network provides a lot of flexibility for future adaptation to the specific aviation use case requirements. Furthermore, the ongoing standardization will provide additional features which will improve the performance of the applications.

Requirements related to network infrastructure will be marked by 6-X (X conforms to number of requirement).

4.3.1 Functional requirements

REQ-FUNC-6-1 The network infrastructure **shall** provide 1-to-1 connection for all vehicles equipped with experimental CNS unit with ground services platform which will allow regular position and trajectory (when applicable) reporting.

REQ-FUNC-6-2 The network infrastructure **shall** support creation of users group to enable 1-to-N communication.

REQ-FUNC-6-3 The network infrastructure **shall** enable 1-to-N communication to send regularly traffic and airspace information from ground services platform to the selected group(s) of users.

REQ-FUNC-6-4 The network infrastructure **shall** enable 1-to-1 low latency high availability communication (detailed perf. requirements will be specified later) to enable alerting/clearance/acknowledgement communication between the selected user and ground services platform.

REQ-FUNC-6-5 The network infrastructure **shall** enable secure authentication of registered users before login them to the experimental network.

REQ-FUNC-6-6 The network infrastructure **shall** contain adequate (detailed requirements will be specified later) to maintain communication within the experimental network secure against external threats.

4.3.2 Installation requirements

Installation details for ground infrastructure are addressed in D2.2 document.

4.4 U-Space Services – Technical Enablers

U-space services will be implemented as a set of cloud SW modules interfacing with cellular network and providing interfaces to drones' operators and for ATC. The purpose of the implementation is not to represent deployment-ready U-space services but to enable evaluation of feasibility of such services through explored CNS enablers, in particular cellular network. In this context, implementation of services have to mainly introduce realistic latency (associated with ground processing of received data) into overall end-to-end traffic surveillance applications, and provide core functionality to support demonstration of benefits to different stakeholders.

Intended function:

The core of the system will be a cloud storage maintaining actual snapshot of the traffic (position, trajectories (when available) and airspace information. This storage system will be complemented with the following main functions:

- Tracking function processing position reports received via cellular network
- TIS/FIS reports generation and transmission function

- Dummy function emulating outputs of separation management for evaluation of clearance communication loop
- Communication functions supporting external interfaces with remote operators and ATC.

Simplified overview of the ground services to be implemented for the purpose of the FACT validation activities is shown in Figure 5.

Requirements related to U-space services will be marked by 7-X (X conforms to number of requirement).

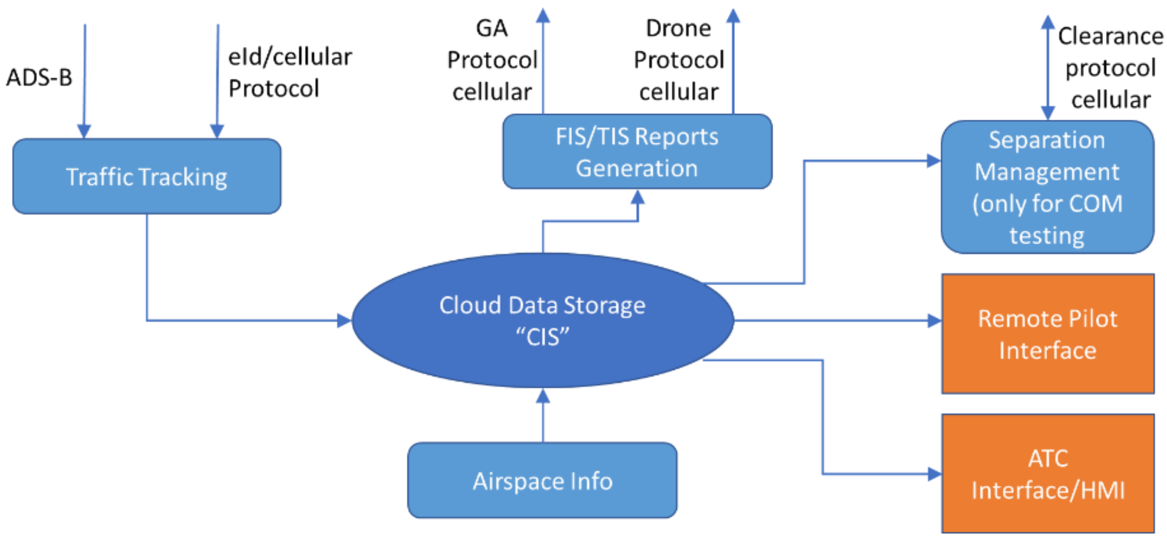

Figure 5: Overview of Ground Services

4.4.1 Functional Requirements

The mobile application is intended to provide following functions:

Tracking function

REQ-FUNC-7-1 The function **shall** create, manage, and update tracks based on position reports received via ADS-B and cellular network in compliance with the ADS-B tracking requirements from [X}.

REQ-FUNC-7-2 The active tracks **shall** be stored in the common cloud storage (playing role of CIS).

TIS/FIS report generation

REQ-FUNC-7-3 The function **shall** create each second the snapshot of traffic based on all active tracks maintained by tracking function.

REQ-FUNC-7-4 The function **shall** create the FIS and TIS reports and transmit them via cellular network with the rate of 1Hz.

Communication functions

REQ-FUNC-7-5 The function **shall** read the airspace information (geofence/geocage zone, restricted airspace) for given scenario from input JSON file and store it in the common cloud storage.

REQ-FUNC-7-6 The function **shall** provide interface to the drones' operators and meet all associated requirements from section 4.2.3.

REQ-FUNC-7-7 The function **shall** provide interface to the ATCo and meet all associated requirements from section 4.5.1.

Separation management function

REQ-FUNC-7-8 The function **shall** transmit the sample clearance to the selected airspace user.

The purpose of this function is not to provide separation management but only support the evaluation of data-link performance for the clearance type of communication.

4.5 ATCo – Technical Enablers

The purpose of technical enablers supporting ATCo is to:

- complement their existing traffic surveillance (mostly depending on ATCRBS transponder equipment of aircraft) means by providing traffic information about unmanned traffic and GA
- provide direct communication link with remote pilots for the emergency purposes.

4.5.1 U-Space Situation Awareness HMI for ATCo

The U-Space Situation Awareness HMI for Air Traffic Control will consist of independent application not intervening with other ATCo systems. Purpose of the application is to demonstrate for ATCo benefits enabled by information available due to the enhanced connectivity and availability of supporting ground services.

While the current concepts of operations typically assumes that ATC will need/want to see drones' flights only in case of non-nominal situations, e.g., when they deviate from the plan, FACT project assumes that information about drones occurrence should be **available** for ATCo regardless if it is currently provided on the display at controller's working position as it can be used by potential safety backend functions. Detailed implementation depends on human factors evaluation, HMI design and specific procedures. Nevertheless,, availability of actual drones position to ATC brings without doubts significant safety benefits.

The application will be able to provide following information on map base

- Actual overview of traffic flying in the U-space part of airspace
- Drone's 3D trajectories (when requested)
- Geofenced areas (when requested)

- Warning in cases of non-conform behavior of U-space participant.

Requirements related to ATC application will be marked by 8-X (X conforms to number of requirement).

4.5.1.1 Functional Requirements

The situation awareness application is intended to provide following functions:

Communication function

REQ-FUNC-8-1 The application **shall** read consolidated traffic picture from the CIS (cloud storage).

Displaying Traffic Information

REQ-FUNC-8-2 The application **shall** display traffic data to be consistent with DO317B, Section 2.3 Cockpit Display of Traffic Information (CDTI) Subsystem Requirements.

REQ-FUNC-8-3 The application **shall** be able to display following elements if available:

- Ownship symbol
- Traffic symbol
- Traffic Air/Ground Status
- Differential ground speed
- Traffic relative altitude
- Traffic vertical trend
- Traffic identification
- Traffic ground speed
- Traffic category
- Traffic horizontal velocity vector
- Display range
- Traffic coasting indicator
- Traffic range

REQ-FUNC-8-4 The application **shall** be able to display planned trajectory for selected traffic when this information will be available.

REQ-FUNC-8-5 The application **shall** provide warning in case of vehicle not satisfying assigned geofences.

System status

REQ-FUNC-8-6 The application **shall** display available information about potential system failure or connectivity issues.

4.5.1.2 Installation Requirements

No specific installation requirements, only WI-FI/Bluetooth connectivity with ground cloud services needs to be verified.

4.5.2 VoIP to Remote Pilots

The voice communication will be performed over the internet protocol between air traffic controllers and remote pilots in case of urgency. The VoIP will serve as last resort tool for disruption of safe operations.

Main advantage of VoIP over regular telephone line is quality of audio call and cybersecurity, especially possibility of authentication and encrypting of the communication.

Functional requirements related to VoIP communication with drone remote pilot are already covered in section 4.2.4.e

4.5.2.1 Installation requirements

No specific installation requirements, only Internet connectivity needs to be verified.

5 End-to-End Applications Performance Requirements

This section focuses on defining initial performance requirements for end-to-end applications that were introduced in the Section 3. It is done using performance requirements for existing applications of a similar nature or purpose.

Performance-based approach aims to minimize the strict allocation of performance requirements at individual components staying at the specification of overall operational performance which needs to be achieved by the whole system. This offers additional flexibility for implementation of larger spectrum of possible technical solutions.

Such approach is also followed by the project FACT and in this document. Focus is thus on specifying performance requirements for end-to-end applications but to the assignment of needed performance to individual functions is not done. Nevertheless, the performances of some existing solutions for selected functions are provided for reference to offer further insights on feasibility.

5.1 Traffic Surveillance

The basis of the performance requirements consideration for traffic surveillance are standardized ADS-B applications both for the ground (ADS-B-NRA, ADS-B-RAD) and the aircraft (TSAA, ATSA-AIRB). This is motivated by the fact, that ADS-B surveillance is based on the same principles (position reporting → traffic processing) as traffic surveillance addressed in the FACT project, only the technological solution is different.

In addition, working assumptions used currently within ACAS sXu development are used as initial estimate for DAA application, as this is one of the first DAA systems expecting systematic use of ground surveillance data.

5.1.1 Definitions of Terms and System Interfaces

Following definitions are retrieved from [7].

Total Latency is the total time between the availability of information at an lower interface 'X' to the time of completion of information transfer at an upper interface 'Y'. Total Latency is the sum of Compensated Latency and Latency Compensation Error.

Compensated Latency is the part of Total Latency that it is compensated for to a new time of applicability, valid at an interface 'Y', through data extrapolation aiming at reducing effects of latency.

Latency Compensation Error (formerly referred as 'Uncompensated Latency') is that part of Total Latency that is not compensated and/or under-/overcompensated for. The value is usually positive but overcompensation might produce negative values as well.

Time of Applicability at an interface 'Y' is the TOA as valid at a lower interface 'X' plus the amount of Compensated Latency applied to and valid at an upper interface 'Y'.

System interfaces denoted by letters from A to G are defined at Figure 6 for Airborne Surveillance Applications and at Figure 7 for Ground Based Surveillance Applications.

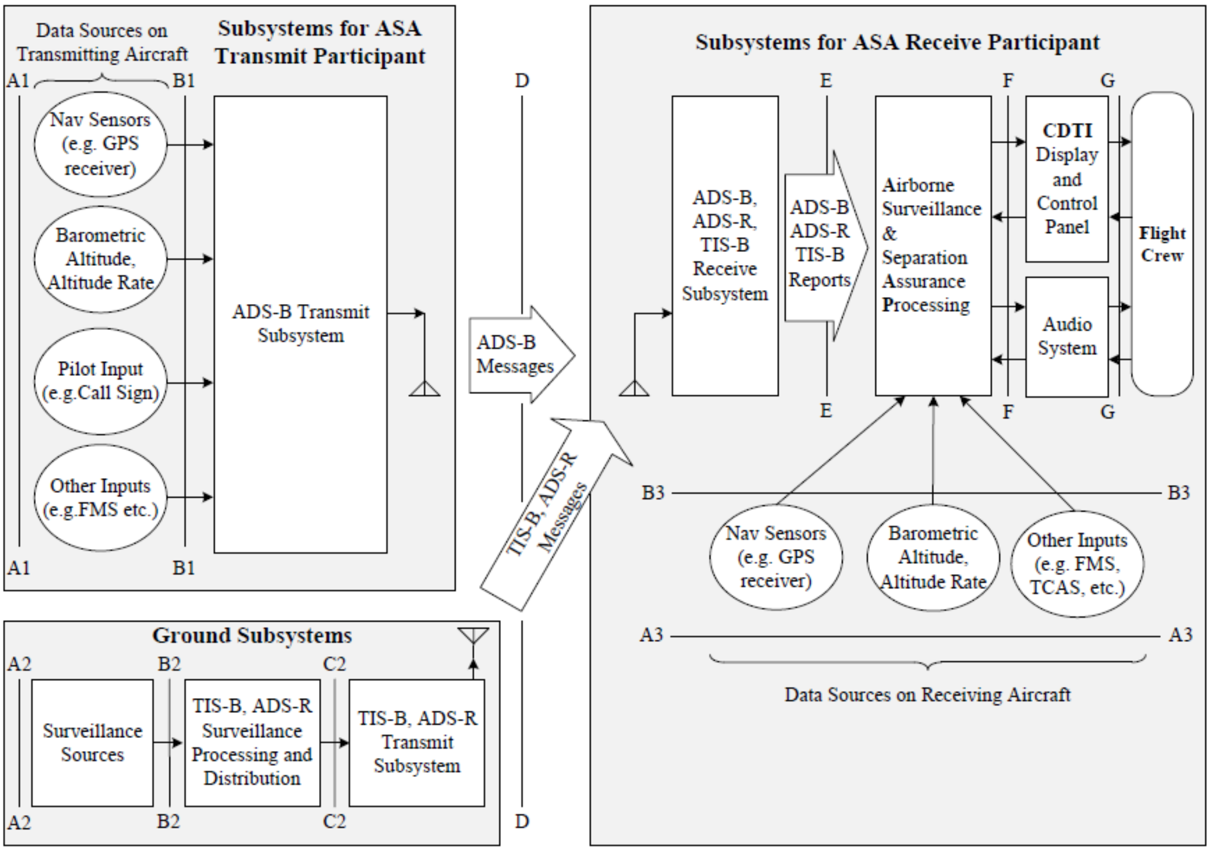

Figure 6: Interfaces and subsystems for Aircraft Surveillance Application System [7]

Figure 6 provides overview and interfaces for Aircraft Surveillance Application. Subsystems responsible for aircraft transmitting traffic information and ground source of traffic provide input data to receiving aircraft. There is analogy with application for GA pilot being developed in the FACT project. Position reports will be based on electronic ID through cellular network and ADS-B.

5.1.2 Situational Awareness for GA and Remote Pilot

Traffic Situation Awareness with Alerts (TSAA) is used as a basis for definition of initial performance requirements for GA and Remote Pilot situation awareness applications. These requirements are documented in RTCA DO-317B, Minimum Operational Performance Standards for Aircraft Surveillance Applications (ASA) System [7]. Relevant requirements for application used for project FACT purposes are presented here.

REQ-PERF-1-1 The ownship position **shall** to be updated at least once per second.

Rationale: This requirement is based on section 1.5.1.1, [7].

REQ-PERF-1-2 The latency compensation error **shall** be less than 600 ms.

Rationale: This requirement is based on section 1.5.1.1, [7]. It describes latency between data sources on aircraft (times of measurement). This latency is applicable for interface between A3 and B3 from Figure 6.

REQ-PERF-1-3 The total latency of horizontal position data from traffic **shall** be less than 2 seconds (measured from interface A1 to interface D).

Rationale: This requirement is based on section 1.5.1.2.1, [7].

REQ-PERF-1-4 The total latency compensation error between interface A1 and interface D **shall** be less than 600 ms.

Rationale: This requirement is based on section 1.5.1.2.1, [7].

REQ-PERF-1-5 Traffic obtained through consolidated traffic picture **shall** not add more than 1.0 second and more than 0.1 second of Latency Compensated Error to the Total Latency of the traffic horizontal position data.

Requirement: This requirement is based on section 1.5.1.2.2, [7].

Summary of ownship and traffic Total Latency to the Situational Awareness Application for GA pilot is provided in the table below.

Ownship			
A3-B3	B3-F	F-G	Total
1.0s	2.0s	0.5s	3.5s
Traffic			
D-E	E-F	F-G	Total
0.5s	2.5s	0.5s	3.5s

Table 1: Total Latency allocation

Note, for remote pilot there is a possibility to apply requirements from DAA MOPS (RTCA DO-365B) rather than adopt the requirements for GA pilot. This option will be further explored for D3.3 (final system requirements).

5.1.3 Situational Awareness for ATCo

Performance requirements for the Situational Awareness application for ATC are based on ADS-B Non-Radar-Airspace (NRA) Application and the related RTCA DO-303, Safety, Performance and

Interoperability Requirements Document [9].

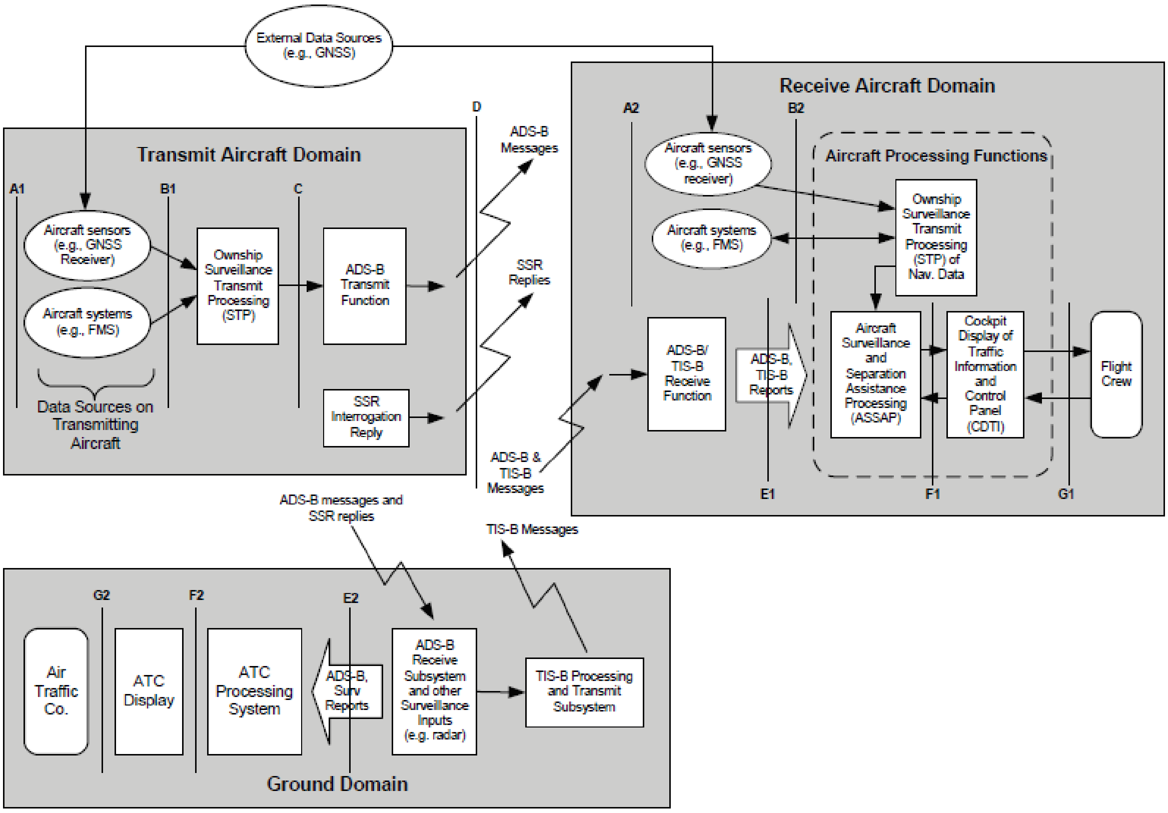

Figure 7: Assumed Airborne & Ground Generic Functional Architecture [9]

Figure 7 provides overview of interfaces between system components.

The [9] also presents assumptions related to positioning quality at transmitting aircraft. First assumption is that failure rate of the horizontal position source is no more than 10-4 [9], ASSUMP-28. Second assumption [9], ASSUMP-29 is that the failure rate, in terms of loss of the system, where multiple aircraft are affected, for any GNSS system used as position source is no more than 10-5 per hour.

Performance requirements defined in [9] for airborne accuracy and position integrity requirements for 3 NM separation in Terminal Airspace are presented in the Table 2. These assumptions and performance requirements for airborne transmit function can represent base for derivation of project FACT requirements for enhanced positioning performance.

Relevant requirements from [9] are stated below:

Airborne Requirements	Applicable Interface	Requirement	Requirement Source
Horizontal Position Accuracy	A1 → D	**SPR 5 :** For 3 NM separation, the 95% accuracy of the horizontal position measured at D shall be less than 0.3 NM (i.e., $NAC_P \geq 6$)	CR-4 (PR 8 :) -
Altitude Accuracy	A1 → D	**SPR 6 :** Altimeter accuracy – including accuracy of measurement and accuracy of reported value through use of encoding - shall be at least as good as Mode C provisions in ICAO Annex 10 which specifies 38.1m (125ft). *Note: These are minimum accuracy requirements for altimeters, and are dependent on the type of airspace. Many airspace regions, such as RVSM, will require better altimeter performance than specified in this table.*[6]	PR 10 :
Position Integrity	A1 → D	**SPR 7 :** For 3 NM separation, the likelihood that a position error exceeds the maximum 1.0 NM containment radius without detection shall be less than 1e-5 per flight hour. (i.e., NIC ≥ 5 & SIL ≥ 2)	CR-2 (SR 10)
	A1 → B1	**SPR 8 :** The time to alert regarding a change of the position quality indicator value shall be no more than 10s when the new value is 0, and no more than 2s in other cases *Note: For equipments and circumstances where the values above can not be met, a more detailed safety analysis will be required for considering the simultaneous loss of integrity together with a transmitted erroneous position.*	Annex I

Table 2: Airborne Accuracy and Position Integrity Requirements for 3 NM Separation in Terminal Airspace [9]

REQ-PERF-2-1 The 95% latency for position reports measured between points D and E2 **shall** not be greater than 0.5 seconds.

Rationale: This requirement is based on SPR19, [9].

REQ-PERF-2-2 The likelihood that Situational Awareness applications for ATC and remote pilot does not provide updated position report for more than one aircraft from which position reports are being received **shall** not be more than 5e-6 per hour.

Rationale: This requirement is based on SR 6, [9].

REQ-PERF-2-3 The likelihood that Situational Awareness applications for ATC and remote pilot does not updated position report for one aircraft from which position reports are being received **shall** not be more than 1e-4 per hour.

Rationale: This requirement is based on SR 4, [9].

5.1.4 Situational Awareness for DAA

As explained in the Section 3.1, detect and avoid system ACAS sXu can serve as example for derivation performance requirements. MOPS for sXu is not approved yet, but working assumptions are available.

Performance requirements for sXu GPS-based surveillance are suggested as follows:

	Nominal Performance
Ownship	NACp: 10 NACv: 3
Large Intruder	NACp: 8 NACv: 1
Small Intruder	NACp: 10 NACv: 2

The minimum quality requirements are expressed via performance indicators Navigation Accuracy Category for Position (NACp) and Navigation Accuracy Category for Velocity (NACv). Definitions of NACp and NACv are summarized in the Appendix B. NACp value of 10 means requirement for 95% horizontal accuracy error below 10 meters. This requirement corresponds, for example, to the WAAS system and therefore requires an enhancement of the GPS functionality.

Those minimum requirements are expected to be more stringent for sXu than Xu (detect and avoid system for larger UAVs) because of increased accuracy needed for dealing with the smaller sUAS platforms and smaller sXu protection volumes.

Concerning the latency requirements, ACAS sXu already consider the use of ground surveillance data for some intruders. Simplified current working assumption about the acceptable total surveillance latency is 3.5s.

REQ-PERF-3-1 The nominal performance of mobile network aided positioning SHALL be at level defined by

- Navigation Accuracy Category-Position of 10 as minimum
- Navigation Accuracy Category-Velocity of 3 as minimum

5.2 VoIP Link Between ATC and Remote Pilot

The ICAO Aeronautical Communication Panel Working Group I adopted the standard for VoIP as part of their own Internet Protocol Suite (IPS). The standard consists of three documents:

- VoIP ATM System Operational and Technical Requirements (ED136)

- Interoperability Standards for VoIP ATM Components (ED137B)
- Network Requirements and Performances for VoIP ATM Systems (ED138).

Especially the ED-138 will serve as baseline for derivation of the performance requirements.

5.3 Overview of Existing Datalinks Used in General Aviation

Performance requirements for communication and position quality are derived from requirements for related applications (see Section 5.1). Due to the use of a different physical layer, the throughput needs must be estimated. To determine the throughput requirements, a overview provided in [7] can provide suitable baseline. It summarizes different data types used in GA (both communication and navigation data is included).

Propagation modes are defined as follows:

- *Ground-to-Ground (G2G):* the communications with the aircraft when it is taxiing or parked in the airport.
- *Air-to-Ground (A2G):* the communications from the flying aircraft to the ground access nodes (AN) and control stations
- *Ground-to-Air (G2A):* the communications from the ground access nodes and control stations to the flying aircraft.
- *Air-to-Air (A2A):* the communications between two or more flying aircrafts
- *Satellite-to-Air (S2A):* the link from the navigation or communication satellites to the aircraft
- *Air-to-Satellite (A2S):* the link from the aircraft to the navigation or communication satellites

The multilink capability refers to the situations when there is more than one communication link available between the aircraft and the corresponding network (with ground or satellite transmitters). If multilink is present, an important question to address is how to maintain and optimize the end-to-end communications in a dynamic environment (i.e., aircraft moving). With the exception of GNSS-based navigation, all the aviation data link types support a multilink capability. Thus, the issue of the optimal connectivity settings and control is an issue that must be addressed within any future solution [7].

Propagation modes	Data link type	Current solutions	Relevance to low-altitude GA/R	Throughput needs	Latency needs	Mobility support needs	Multilink capability
G2G, A2G, G2A, S2A	ATS communications - broadcast mode	ACARS ADS-B EAN Gogo TAG L-DACS	High	1 Mbps	<1.2 s	160 km/h	Yes
G2G, A2G, G2A	ATS communications	ADS SelCal	High	7-10 Mbps	<0.5 s		Yes

	- dedicated mode						
G2G, A2G, G2A, S2A	ATS – Positioning, Navigation and Tracking of aircraft	GNSS Radar	High	N/A[1]	<0.3 s		No
G2A, A2G	AOC, e.g., pilot & weather reports	weather radar	Medium	360 kbps	<0.3 s		Yes
A2G, G2A, G2G	AAC, e.g., Flight data delivery at the airport	manual	High	11 Mbps	< 1 s		Yes
G2G, A2G, G2A, possibly A2A, S2A	APC, e.g., on-board entertainment	EAN Globestar Gogo TAG Inmarsat Iridium MTSAT	Low	>100 Mbps	<0.1 s		Yes

Table 3: Summary of requirements for different types of data in GA (both communication and navigation data are included here) [7]

Abbreviations of data link type are provided in List of Acronyms.

[1] Not Available (N/A) because the navigation and tracking of aircraft is currently based on GNSS and not on cellular solutions. It is an open research topic what the required amount of signalling for positioning purposes will be if the navigation and tracking will be based on cellular communication signals.

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Appendix A System Interfaces

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 (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].

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 USA 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

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

Table 4: FIS-B Information [2]

A.3 ATC Instructions for GA (for tech evaluation only)

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.

A.4 USSP Instructions for drone (for tech evaluation only)

Position hold and land commands may be evaluated as USSP instructions for emergency cases.

A.5 CNS device interface with drone's flight guidance computer

Detailed information about interface may differ in dependency on drone type, but the preferred way is to use MAVlink protocol. Overview of MAVlink messages is presented in the Table 7. Detailed description is provided at [3].

Message	Description
GPS_RAW_INT (#24)	Raw GPS sensor values
GLOBAL_POSITION_INT (#33)	Processed GPS position
ATTITUDE (#30)	Attitude (roll, pitch, yaw).
HEARTBEAT (#0)	Message shows that a system or component is present and responding
SYS_STATUS (#1)	General system state
SYSTEM_TIME (#2)	Time of the master clock

Table 5: MAVlink messages to be obtained from drone's flight guidance computer

Appendix B Navigation Accuracy Quality Indicators

B.1 NACp

Navigation Accuracy Category for Position is defined as follows:

NACp	95% Horizontal Accuracy Bound (EPU)	Comment
0	EPU ≥ 10 NM	Unknown accuracy
1	EPU < 10 NM	RNP-10 accuracy
2	EPU < 4 NM	RNP-4 accuracy
3	EPU < 2 NM	RNP-2 accuracy
4	EPU < 1 NM	RNP-1 accuracy
5	EPU < 0.5 NM	RNP-0.5 accuracy
6	EPU < 0.3 NM	RNP-0.3 accuracy
7	EPU < 0.1 NM	RNP-0.1 accuracy
8	EPU < 0.05 NM	e.g., GPS (with SA)
9	EPU < 30 m	e.g., GPS (SA off)
10	EPU < 10 m	e.g., WAAS
11	EPU < 3 m	e.g., LAAS

Table 6: NACp Definition [10]

B.2 NACv

Navigation Accuracy Category for Velocity is defined as follows:

NACv	Horizontal Velocity Error
0	Unknown or ≥10 m/s
1	< 10 m/s
2	< 3 m/s
3	< 1 m/s
4	< 0.3 m/s

Table 7: NACv Definition [10]

Appendix C Use of Cellular Network Signals for Positioning

C.1 Positioning Methods Overview

The main methods to estimate the position in cellular networks are:

- **Cell-ID:** The position of a UE connected to a specific base station (BS), which is identified by its cell ID, is determined by the location of the BS itself (proximity). This is a very rough method of positioning which can be improved by considering the center of gravity of multiple BSs seen by the UE (up to 7 in GSM);
- **RSSI:** received signal strength indicator (RSSI) measurements can be used to infer the distance between the UE and the BS. Unfortunately, propagation effects make the correlation between RSSI and distance weak thus leading to errors in the order of 150-200 meters. RSSI measurements can be exploited for trilateration or in fingerprinting techniques, or radiofrequency pattern matching (RFPM), where RF maps can be created by an advanced radio propagation prediction software, possibly refined by surveying, and exploited through pattern matching algorithms to determine the UE position. Fingerprinting can be in principle very accurate but it requires frequent RF maps updates and it is very sensitive to changes in propagation conditions;
- **Mobile-Assisted time-of-arrival (TOA):** In GSM a rough measurement of the signal round-trip time (timing advance (TA)) is provided in order to synchronize the UE with the BS timing of slots. When combined with Cell-ID, such measurements can slightly increase the positioning performance even though TA is available only during the call at the UE.
- **Assisted - GNSS:** Cellular network standard protocols have allocated resources to carry GNSS assistance data to GNSS-enabled mobile devices in both GSM and UMTS networks. The purpose is to assist the receiver in improving the performance in terms of startup time, sensitivity and power consumption.
- **OTDOA:** The observed time difference-of-arrival (OTDOA) is the time-difference between the system frame numbers (SFNs) generated by two BSs as observed by the UE. These measurements, together with other information concerning the position of the involved BSs and the relative time difference (RTD) of the actual transmission of the downlink signals, is used to estimate the position of the UE. Since each OTDOA measurement related to a pair of BSs describes a line of constant TOA difference, yielding a hyperbola in two dimensions, UE position is determined by the intersection of hyperbolas of at least two pairs of BSs. Clearly, OTDOA is a UE-based positioning method which requires a specific implementation at the UE. It requires access to information about network time synchronization and precise BTS positions (both to be obtained from mobile network operator)[2]. OTDOA then requires that

[2] This most promising method can be updated during project research

user equipment is capable to detect used bandwidth and measure reference signal time difference (RSTD).

- **UTDOA:** Uplink Time Difference of Arrival is principally similar to OTDOA, but realized in opposite direction. UTDOA is a network-based localization technique introduced in Release 10 of the 3GPP LTE specification. In the UTDOA technique, the time difference of LTE uplink signals sent from the User Equipment (UE) to a set of several eNodeBs (base stations in LTE) are used as the means to estimate the UE's position.
- **CellLocate:** Proprietary method by U-Blox, embedded in 2G, 3G, LPWA and LTE CAT-1 modules [4]. Method based on historic observations of cell visibility and estimations.

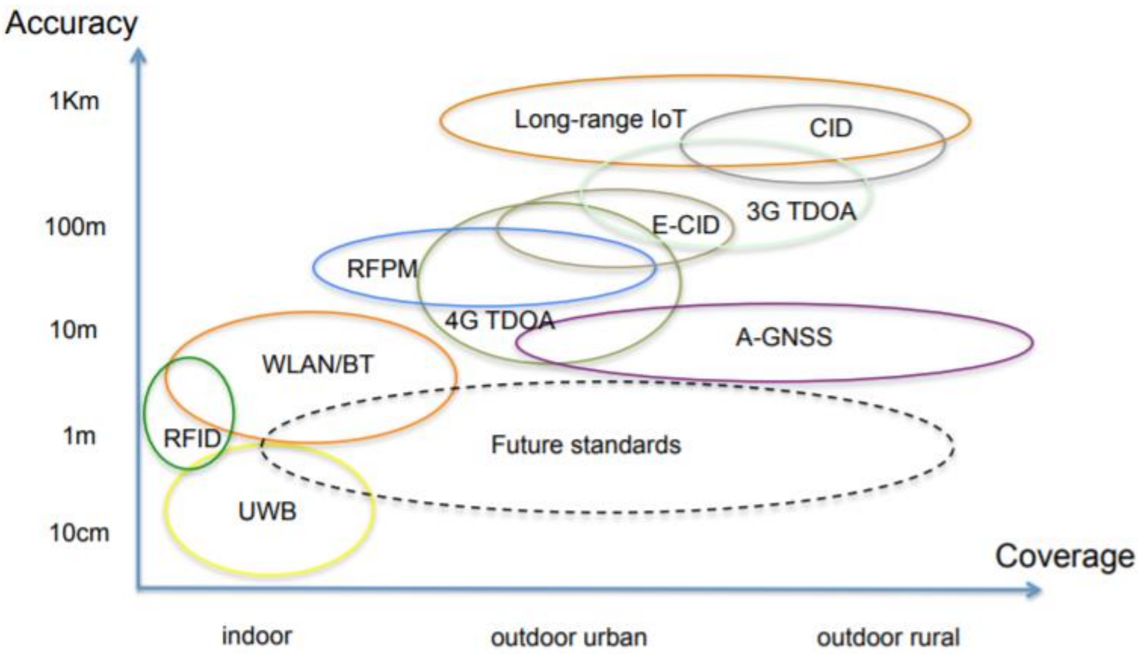

Figure 8: Accuracy of selected methods overview [19]

Accuracy of OTDOA depends on:

  - Bandwidth
  - Time synchronization in network
  - Released functionalities
  - Precise knowledge of antennas location
  - Multipath
  - Geometry of base stations

- Other methods for NG – RAN: network-assisted GNSS methods;
  - Barometric pressure sensor positioning
  - WLAN positioning
  - Bluetooth positioning
  - Terrestrial beacon system (TBS) positioning
  - Hybrid positioning using multiple methods

OTDOA method (see explanation below) will be highly affected by access to all required parameters an their quality (level of time synchronization primarily).

When en-route positioning is discussed, the fact that the public network configuration will be very changeable in different locations has to be taken into account. Dedicated aeronautical network with service-level agreement (SLA) represents a preferred option, but the deployment of such services depend on network operator and its business preferences. Wideband signals offer better time resolution and robustness to multipath thus improving the performance of OTDOA/UTDOA schemes, as well as paving the way to new positioning methods such as multipath-assisted localization exploiting specular multipath components to obtain additional position information from radio signals.

From the positioning point of view, the main differences of 5G are employment of massive multiple-input-multiple-output (MIMO) beamborming and millimeter wave signals.

Use of mmWave brings even large bandwidth and the possibility to place larger number of antenna elements in small dimensions.

C.2 Potential User – Drone

Most basic and cheapest navigation solution for drone represents stand-alone GPS. Generally, there are no relevant issues with performance of cheaper receivers observed. Price affects quality of internal clock at most, but this error probably won't exceed ten meters. Currently common operations have no troubles because the LOS to satellites is clear. In future, automated operations in city environment are expected in much larger extent – GPS issues caused by loss of LOS, buildings, multipath etc. will appear especially at flying at very low altitudes. Next issue related to GPS is that there is significant trend of rapid increase of jamming and spoofing incidents, generally interference incidents (both intentional and unintentional). Number of such incidents were observed , e.g., jammer in car of a professional driver parking near the airport and causing GPS outages.

C.3 Potential Users – General Aviation Aircraft and Manned UAM

Aircraft which are not equipped for IFR has no special requirement for navigation avionics devices. GA pilots typically use stand-alone non-certified GPS units or even simple GPS receivers not intended for aviation (available at cellphones or tablets). Generally, it can be said that GA pilots use whatever they consider beneficial for them - solution must not be certified to be successful and widely used. GA market is also very cost sensitive.

GA aircraft flying close to the defined U-Space airspace will be required to report own position – this reporting can be realized through ADS-B or in the similar way as the UAVs – by the electronic identification. Although quality of onborad derived position is not so crucial for conducting the flight, quality of reported position is important for U-space traffic management. This implies an option to check or increase accuracy of position on ground.

C.4 Overview of Main Technical Use Cases

C.4.1 Hybrid Navigational Solution

Hybrid navigational solution expects synergic use of GNSS and LTE/5G positioning. Assumption is good quality of LTE/5G cellular network (parameters affecting OTDOA accuracy are especially precise time synchronization of network and knowledge of base stations precise positions) and the candidate method is fusion of 5G OTDOA and GNSS navigational solution, potentially also with inertial sensors. Generally, fusion methods makes sense when characteristics of individual methods are complementary which is satisfied in this case. GNSS performs well in the air with line of sight to satellites, OTDOA is capable to provide good results in urban area with higher density of eNB).

Performance requirements are dependent on the type of operations and environment but for advanced operations can be relatively high and those were estimated as:

- Accuracy of 3 meters horizontally, 1 meter vertically
- Availability of 99%
- Update rate 0.5 sec

C.4.2 Backup position information

Backup position information represents solution for emergency backup navigational solution in case of GPS outage. It will serve for mitigation of larger errors caused by GNSS jamming or spoofing. In case of GNSS outages it can provide partial backup information. There is also beneficial that information about poor quality of ownsip reported position can be transmitted to other U-space users or to ATC in case of GA aircraft.

Performance requirements are again varying considerably with type of operations/environment and were estimated for most demanding use cases as:

- Accuracy of 3 meters horizontally, 1 meter vertically
- Availability of 99%
- Update rate 0.5 sec

C.4.3 Raw Check of Primary GPS Position

Raw check of primary GPS position represents solution for independent verification of position reported by drone or GA aircraft. Method should be also GNSS independent, but complete position is not required.

Moderate performance requirements were estimated as:

- Accuracy of 50 meters
- Availability of 95%
- Update rate 2 sec