Design and architecture of the ICARUS system & services

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ICARUS

INTEGRATED COMMON ALTITUDE REFERENCE SYSTEM FOR U-SPACE

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Abstract

This document specifies the overall ICARUS architecture with a particular focus on the architecture of the proposed micro-services that constitute the ICARUS contribution to the definition of U-space services. Moreover, this document specifies the operational and functional relationship between the ICARUS micro-service components, the other UTM/USSPs and the ATM. This specification is based on the analysis of the ICARUS operational scenarios and use cases, and development of the ICARUS concept definition, that was described in ICARUS deliverable D.3.1.

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1 Introduction

The many activities for which unmanned aircraft systems (UAS) are used can lead to their sharing airspace with “manned” [1] aircraft especially in VLL airspaces. To safely and efficiently manage all air traffic in this airspace, it is essential that the altitudes of all of the aircraft involved be known unambiguously.

In manned aviation, an aircraft’s altitude is determined using various pressure altitude difference measurements. For the en-route phases of flight the barometric altimeter is set on the international standard atmosphere. Conversely, in the terminal areas at low level, the setting of based on the day pressure, communicated by ATS at the aerodrome. However, since small drones can take off and land almost anywhere, including far from any aerodrome, some of these settings aren't as significant in unmanned aircraft flights.

The common altitude reference problem affects not only the UAS flights, but also some ultra-light and general aviation manned flights that will potentially share the same airspaces, not to mention aerial work or transport by manned helicopters, including for emergency or public purposes.

In other words, although rule SERA 5005(f) [2] prescribes a minimum height of 500 ft AGL out of metropolitan areas, the rule allows “exceptions by permission from the competent authority” and in practice there are several of such exceptions, leading to significant General Air Traffic (GAT) [3] in addition to possible State flights.

New methods and procedures are therefore needed for large numbers of drones. The EU-funded ICARUS project has the ambition to propose an innovative and feasible solution to address the novel challenge of the Common Altitude Reference inside very low-level (VLL) airspaces with the definition of new U-space services and their validation in a real operational environment.

The ICARUS project has strong links both with the previous SESAR 2016 Exploratory Research studies and with the currently ongoing SESAR projects such as DACUS and BUBBLES.

The Common Altitude Reference System (CARS) document developed by EUROCONTROL and EASA provides the starting point for ICARUS’ investigation. In their discussion paper EUROCONTROL and EASA published some potential options for the resolution to the common altitude reference problem for drones. The conclusion of the study outlined three options covering different approaches to address the problem (GNSS, barometric or mixed approach). ICARUS represents the follow up to this analysis, with the demonstration of the CONOPS proposed in a relevant operational scenario.

The solution to the problem introduced above is described in following chapters and is illustrated in Figure 1-1. It shows how and when CARS services will be used from the perspective of different airspace users and different airspaces categories. As indicated on the diagram, CARS will be used as a service of choice for UAS and other airspace users flying in a GNSS-Altitude Mandatory Zone (GAMZ). On the other hand manned traffic will rely on existing Airborne Collision Avoidance Systems (ACAS) solutions. Whenever a UAS flies above the GAMZ, it will need to use certified ADS-B out transponders to provide location awareness of its position to manned traffic.

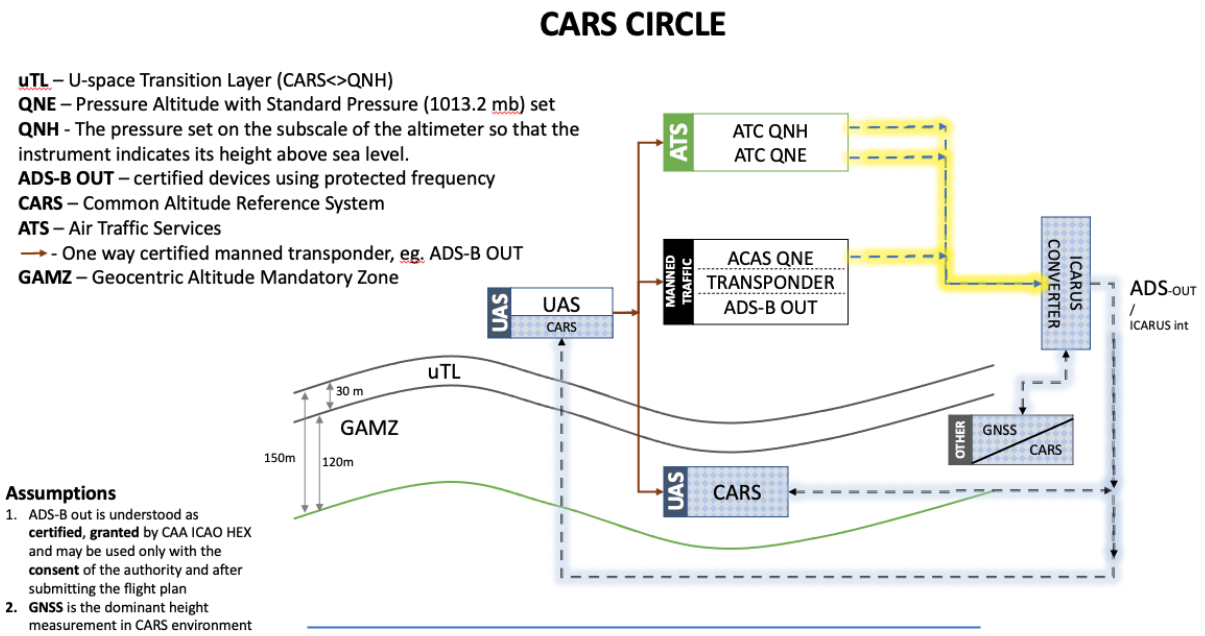

Figure 1-1 CARS "Circle" - flow of information between different users and airspaces

1.1 Purpose of the document

The principal objective of this document is to describe the design of an architecture for the ICARUS U-space service. It contains the overall system architecture, the micro-service architecture and Application Program Interface (API) definitions.

This document gives the fundamental basis for demonstration scenarios, which will be deployed in a prototype environment under WP 5: "Development of Simulated environment, defining the architecture of the system and also the network architecture".

This document is composed of the following chapters:

- Overall ICARUS service architecture and data flows
- Geo-information (GI) Service architecture and data flows
- GNSS Service architecture and data flows
- Vertical Conversion Service (VCS) architecture and data flows
- Vertical Alert Service (VALS) architecture and data flows

The first Chapter presents the overall system and service architecture then in the following chapters this overall architecture is broken down through the architectural design of the individual micro-services composing the proposed ICARUS set. Each micro-service is analysed and characterised not only through its architecture but also through its operational and functional specifications.

Moreover, this deliverable covers, in their respective chapters:

- the applicable standards for terrain and obstacle data management;
- the applicable standards for GNSS positioning, augmentation and integrity services;

- the applicable standards for manned and unmanned communications and data exchange;
- the interface supporting manned and unmanned aviation for altitude reference definition to enable a better architecture design.

1.2 Acronyms

Acronym	Meaning
API	Application Programming Interface
ARAIM	Advanced RAIM
ATC	Air Traffic Control
ATM	Air Traffic Management
ATZ	Aerodrome Traffic Zone
BKG	Bundesamt für Kartographie und Geodäsie
BNC	BKG NTRIP Client
BVLOS	Beyond Visual Line of Sight
CARS	Common Altitude Reference System
CIS	Common Information Service
CTR	Control zone
DAA	Detect And Avoid
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
DOP	Dilution Of Precision
DSM	Digital Surface Model
DTM	Digital Terrain Model
EASA	European Union Aviation Safety Agency
EDAS	EGNOS Data Access Service
EGNOS	European Geostationary Navigation Overlay Service

EGNSS	European Global Navigation Satellite System
GA	General Aviation
GAMZ	Geometric Altitude Mandatory Zone
GI	Geo Information
GNSS	Global Navigation Satellite System
GO	Ground Obstacle
GPS	Global Positioning System
HPL	Horizontal Protection Level
ICAO	International Civil Aviation Organisation
ISA	International Standard Atmosphere
ISM	Integrity Support Message
ISO	International Organisation for Standardisation
MCMF	Multi-Constellation Multi-Frequency
NTRIP	Networked Transport of RTCM via Internet Protocol
PL	Protection Level
PVT	Position Velocity and Time
QFE	Query Field Elevation
QNH	Query: Nautical Height
RAIM	Receiver Autonomous Integrity Monitoring
RIMS	Ranging Integrity Monitoring Stations
RNP	Required Navigation Performance
RTCM	Radio Technical Commission for Maritime Services
SORA	Specific Operations Risk Assessment
TCU	Telespazio's Computing Unit
TSE	Total System Error
UA	Unmanned Aircraft

UAS	Unmanned Aircraft System
USSP	U-Space Service Providers (alias UTM service provider)
UTM	Unmanned aircraft system Traffic Management (alias U-space)
VLL	Very-Low-Level
VLOS	Visual Line Of Sight
VPL	Vertical Protection Level

Table 1-1: Acronyms list

2 Overall ICARUS service architecture and data flows

This chapter is dedicated to the design and presentation of the overall ICARUS system and service architecture.

2.1 High Level System Architecture

The heart of the ICARUS proposal and innovation lies in defining a GNSS-based altimetry system that provides information to UAS pilots and pilots of manned aircraft in VLL airspace on:

a) the actual vertical distance from the ground, in real-time during the flight;

b) barometric/GNSS-based altitude reference conversion, in real time;

c) ground obstacles and buildings during the flight planning phase.

All this information can be provided to users through a "micro-services architecture", where each service has its own specific task but is directly connected to the others.

The micro-services architecture is an architectural style that structures an application as a collection of functions that are:

- Highly maintainable and testable
- Loosely coupled and therefore largely technology-agnostic
- Independently deployable
- Independent of business models (e.g. the information during the flight planning phase might be distributed to UAS operators by a specific U-space service provider (SP), or sent by an ICARUS SP to a U-space information SP for further distribution, or integrated into the function offered by a U-space SP (USSP) offering a range of U-space services).

The micro-services architecture enables the rapid, frequent and reliable delivery of large, complex applications and for these reasons it has been chosen for ICARUS prototyping. As already stated, the system will be built according to the modern programming paradigm based on micro-services through division into the following macro-blocks:

1. Front End

This will interface the ICARUS system with the USSP and ATM platforms, acting as an access point to the services offered.

2. API Gateway

The Application-Programming Interface (API) gateway allows services (or micro-services) to be visible to the outside world in a structured way. It is an application that acts as a proxy with respect to client queries, monitoring and managing call traffic to the back end.

3. Back-end

A pool of micro-services conceived as specialised components in the performance of single functions that communicate with each other and with the API.

The proposed architecture is shown in the following figure, where it is assumed that ICARUS information would be delivered to another USSP, who would further distribute it to end users, including UAS operators.

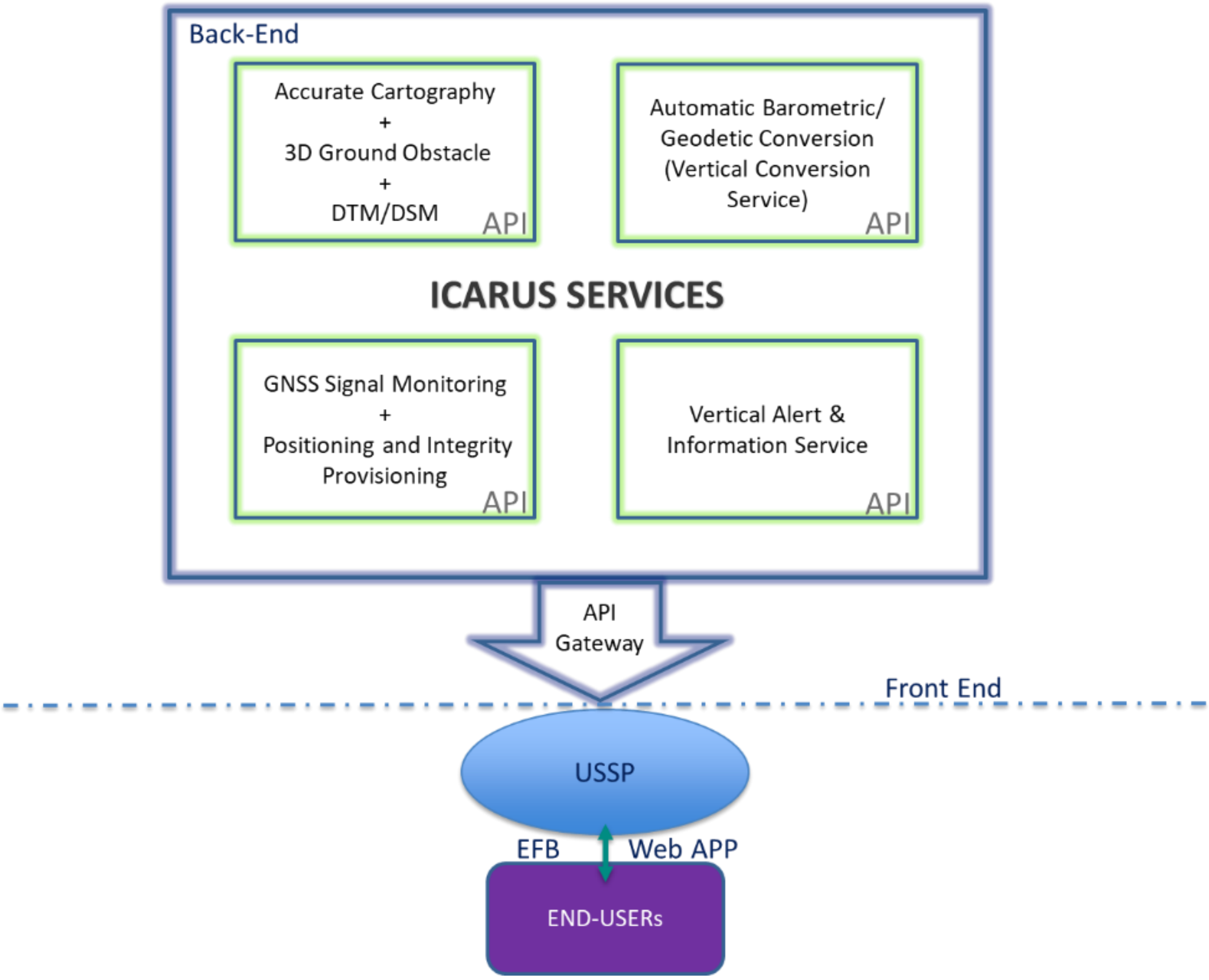

Figure 2-1: ICARUS high-level micro-service architecture

ICARUS could thus be distributed as an add-on to existing U-Space platforms. Pilots would receive the information through an Electronic Flight Bag (EFB) /web application, directly inside the cockpit of manned aircraft and through equivalent displays in case of remote pilots, possibly integrated with respective Command Units [4].

The APIs would provide ICARUS U-space micro-services, which can be related to CORUS proposals and to current standardisation work in ISO as presented in the following table:

Service					Description
ID	ISO [5] Id.	CORUS [6] Id.	Safety Criticality	Proposed for certification by authority [7]	
GIS	Geospatial Information Service (GIS)	Geospatial Information Service	Safety-related	NO	(GIS): Accurate cartography, DTM / DSM, 3D model of the terrestrial obstacle provisioning service during strategic phase of flight (i.e. flight planning)
RGIS	Not mentioned	Not mentioned	Safety-critical	NO	(RGIS = Real-time GIS): Accurate cartography, DTM / DSM, 3D model of the terrestrial obstacle provisioning service during the execution of flight (tactical phase), to provide real-time information of vertical distance to ground.
GAW	Geo-awareness (GAW)	Geo-awareness	Safety-critical	YES	Information service, warning manned aviation pilot(s) of crossing (or being in proximity of) the limit of a new "Geometric Altitude Mandatory Zone" and related advice
VCS	Not mentioned	Not mentioned	Safety-related or critical depending on airspace and flight rules	NO	Vertical Conversion Service, providing automatic translation and readings of barometric height to altitude), conversion of reference systems (barometric to geodetic and vice-versa)
VALS	Not mentioned	Not mentioned	Safety-critical	NO	Vertical Alert service, over the common reference system, alerting drones and manned aviation of current vertical distance from ground.

Service					Description
ID	ISO [5] Id.	CORUS [6] Id.	Safety Criticality	Proposed for certification by authority [7]	
EMS	Electro-Magnetic Interference Information Service (EMS)	Electromagnetic interference information	Safety-related	NO	GNSS Signal Monitoring and Positioning + Integrity service reporting enhanced accuracy, performance estimation and integrity to UAS pilots or drones.

In summary, three services (i.e. EMS, GAW, GIS) encompassed by the ICARUS architecture are already identified by CORUS and ISO. Conversely three new services are proposed: RGIS, VALS and VCS.

The benefits of decomposing an application into different smaller services are numerous:

- Modularity: this makes the application easier to understand, develop, test, and more resilient to architecture erosion [9]. This benefit is often compared with the complexity of monolithic architectures.[10]
- Scalability: since micro-services are implemented and deployed independently of each other, i.e. they run within independent processes, they can be monitored and scaled independently.[11]
- Integration of heterogeneous and legacy systems: micro-services are considered as a viable means for modernising existing monolithic software applications [12][13]. There are experience reports of several companies who have successfully replaced (parts of) their existing software by micro-services, or are in the process of doing so [14]. The process for software modernisation of legacy applications uses an incremental approach [15].
- Distributed development: development is parallelised by enabling small autonomous teams to develop, deploy and scale their respective services independently [16]. The architecture of an individual service is also allowed to emerge through continuous refactoring [17]. Micro-service-based architectures facilitate continuous integration, and continuous delivery and deployment [18].

Archiving of events

- All enquiries and communications will be archived in a dedicated, secure database. Deletion of data will, by definition, not be allowed, and all data manipulation events will be logged.

The guidelines set out in EASA U-space regulations were used when developing the high-level concept. It must be noted that the U-space concept is still under development and may change. However, the ICARUS project has been developed following discussions with many ANSPs and CAA in Europe, as well as using the experience of consortium members. The concept is supported by credible requirements from the beginning and uses existing standards and best practices from in manned aviation, as well as IT aspects related to high performance, cybersecurity and data integrity.

Figure 2-2 illustrates the high-level architecture concept from the point of view of the entire U-space eco-system. This architecture focuses on the functions and services offered by ICARUS, and should not, therefore, be considered a reference for other areas.

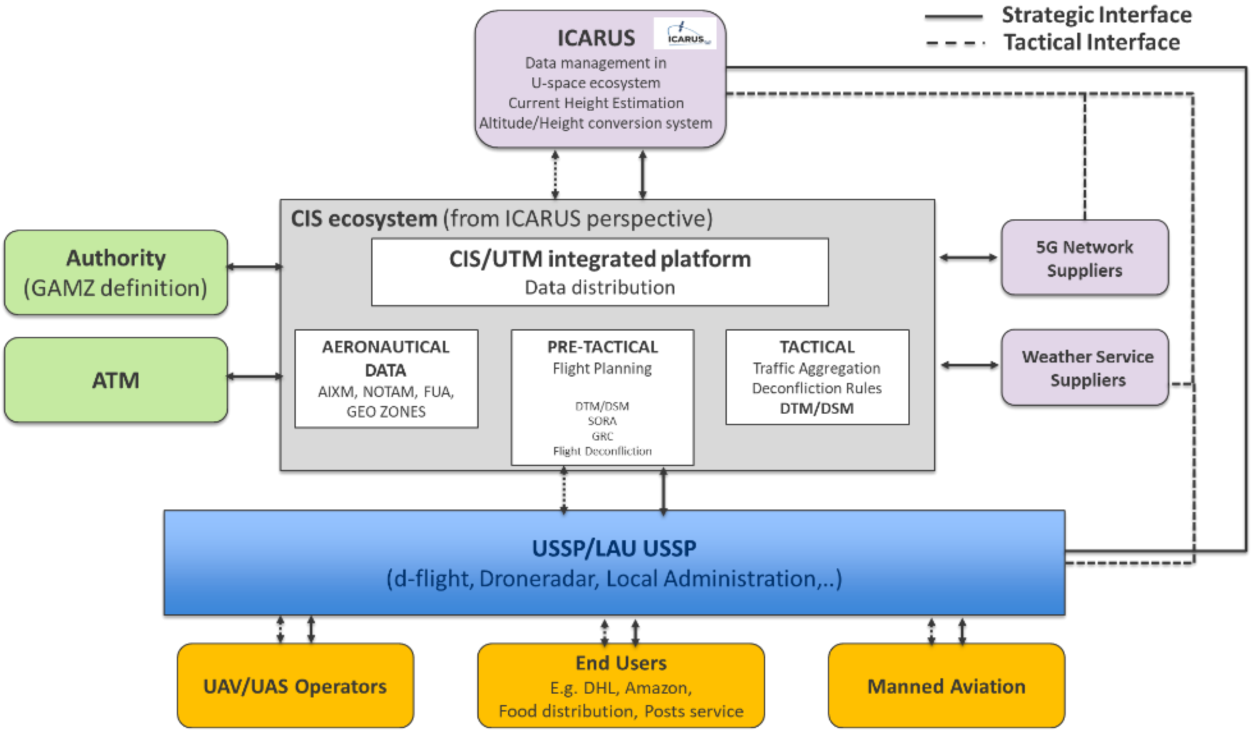

Figure 2-2: U-space eco-system high-level concept of architecture

The services provided by ICARUS will interface with weather and 5G network suppliers: the first, to retrieve the weather data necessary for the height / altitude conversion services; the second, to support real-time/near real-time data exchange between the entities involved in the system, including USSP and consequently the drone operators / end-users.

In addition, the ICARUS services will also be sent to the CIS (Common Information Service), that will enable the exchange of information between the U-space service providers (USSPs), UAS operators, air navigation service providers (ANSPs), and any other actor involved and shown in the figure above.

As the nerve centre of U-space system communications, the CIS provider will use (open) communication protocols to allow information exchange between USSPs and ANSPs using simple, well-defined interfaces.

It is important to underline that the aviation weather information needed for the VCS is a service provided to ANSPs and pilots by weather service providers, generally local to the state overflown (e.g. UK Met Office). It is essential that values used by UASs be the same as those used by manned aviation in the same area to enable coherent altitude/height conversion (hence defining a standard for the QNH data accuracy).

Moreover, thanks to the CIS, the information related to manned aviation (ICARUS Vertical Conversion and Vertical Alert services) can be transferred between ANSPs and USSPs in a bi-directional manner.

From an implementation perspective, it should be noted that the ICARUS solution should be designed from the outset as a distributed service and micro-service architecture with the capability of seamlessly switching from one CARS service instance to another. This requirement is derived from the fact that both air traffic services and U-space services are regionalised on a country level as well as on international level, so the system should support switching between them as illustrated on Figure 2-3.

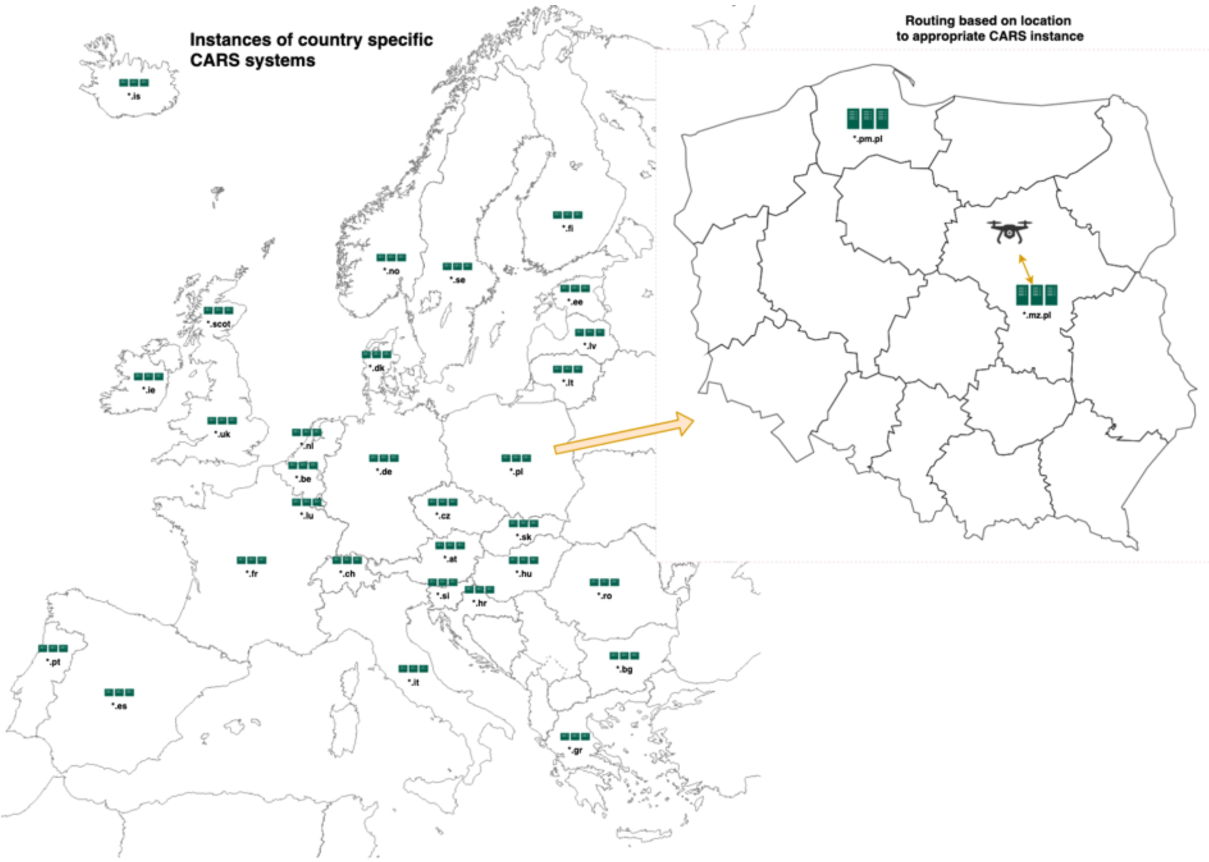

Figure 2-3 Structure of regional CARS instances

Such a structured architecture will also be beneficial from the a processing power perspective, reducing the required minimum performance for serving ICARUS services requests. As the system will run on geographically distributed servers, the traffic will be distributed accordingly.

Additionally, the amount of air traffic to be served has to be taken into account when choosing appropriate CARS area size.

Additional factors influencing the definition of CARS regions such as QNH regions used for CTR, MCTR and ATZ, both those used daily and backups, including local ones, should also be considered.

The appropriate instance might depend on the location of the content requested (where longitude and latitude are provided). There should be routing service deployed to distribute the request to the right CARS instance. The communication is conducted with a regional instance afterwards until the switchover to another instance of the CARS system is required.

There also needs to be a service to manage and control these switchovers between CARS instances. For instance, the CARS should be aware of their regional neighbours. The aircraft handover is performed within transition zones defined on the border between adjacent regions.

2.2 Functional Architecture

Figure 2-4 shows the architecture through a functional break-down of the services that compose it and their system and interconnections.

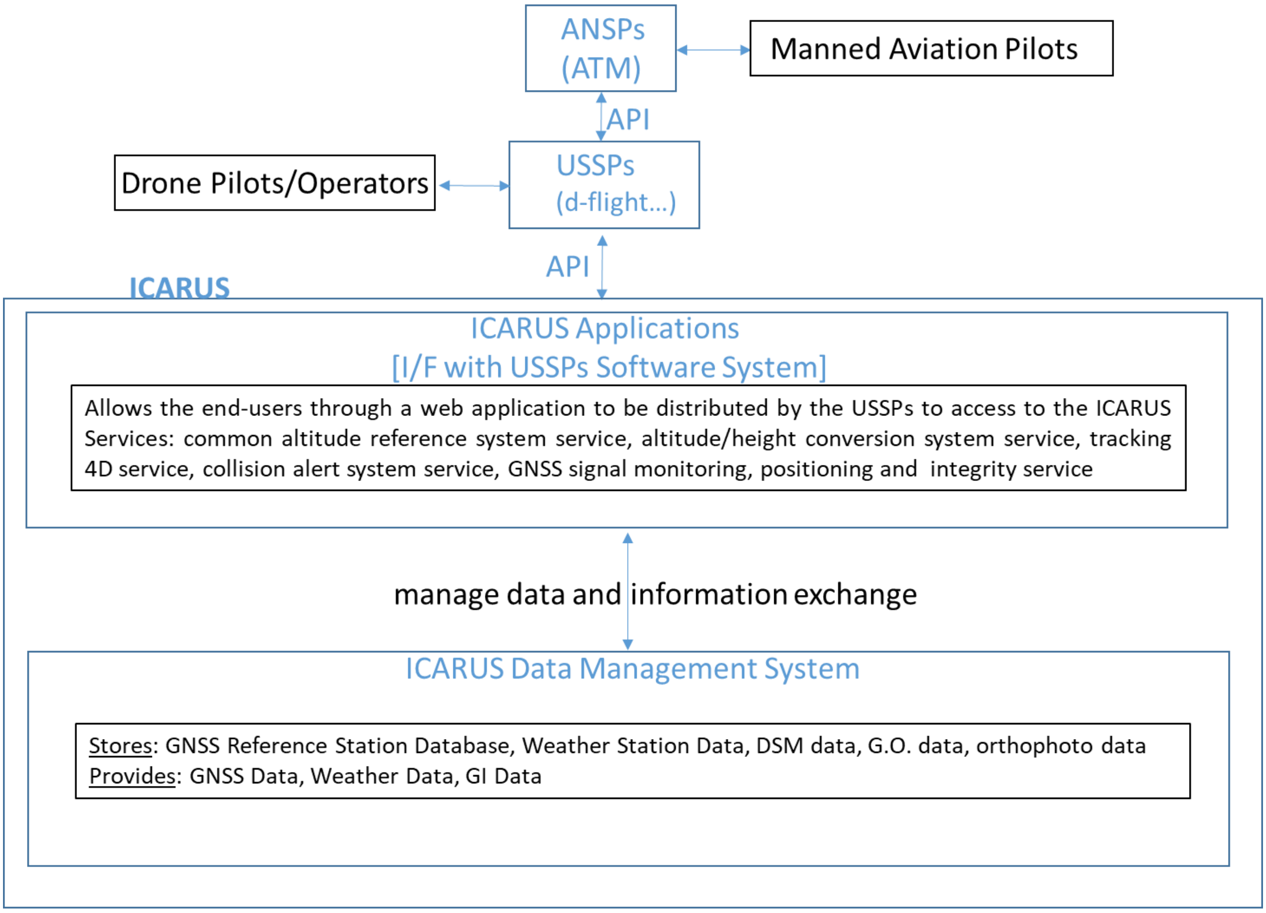

Figure 2-4: ICARUS System Diagram

The ICARUS System Diagram (Figure 2-4) includes all the players involved in ICARUS. These players exchange information between them to perform their functions. They are as follows:

- **Drone Operator:** the 'Operator' is the person or entity responsible for the overall management of his/her U-space operations. The Operator meets regulatory responsibilities, plans flights/operations, shares operational intent information, and safely conducts operations using all available information. Use of the term 'Operator' in this document includes airspace users who decide to participate in U-space, including manned aircraft Operators, except when specifically specified as a manned or UAS Operator.

- **Drone/G.A. Pilot:** is the person who manipulates the flight controls of an aircraft during flight.
- **U-Space Service Provider (USSP):** is any entity providing services to the Operator to support the safe and efficient use of airspace and to meet the operational requirements of U-Space.
- **Air Traffic Management (ATM):** The ATM system is based on the provision of integrated services. These are delivered considering seven operational conceptual components: airspace organisation and management; aerodrome operations; demand and capacity balancing; traffic synchronisation; airspace user operations; conflict management; and service delivery management.
- **Data Provider**: These are the external data service suppliers that must be certified and share coherent information as requested by ICARUS; in particular: GNSS data, weather data, Geo-information data, QNH data, and GAMZ-related information.

The ICARUS System is composed of two macro blocks:

1. ICARUS Data Management System
2. ICARUS Applications System

The first stores all the relevant data necessary for the provision of the service. In particular, it collects all the GNSS reference station data, the weather reference station data, the digital surface model (DSM), GAMZ zone definitions (area polygons), QNH reference data, ground obstacle, and ”orthophoto” data to be provided to the ICARUS applications. There is also an on-line database, a real-time positioning database that keeps the current locations of the monitored aircraft.

The ICARUS Application System is the core of the system where all the micro-services are stored, deployed and run. All the micro-services are structured into Application Programming Interfaces (APIs) which are provided as ICARUS APIs to users (USSPs/ATM) who will share the service with the final end-users (drone pilot/operators, GA pilots) through a tablet (EFB), electronic devices or web application.

Every micro-service has its own function, but it also interacts with the other micro-services exchanging data and information. There are also micro-services that implement interfaces with external systems. The application handles requests (HTTP requests and messages) by executing business logic, accessing a database, exchanging messages with other systems, and returning an HTML/JSON/XML response.

The architecture structures the application as a set of loosely coupled, collaborating services. Each service implements a set of narrowly-related functions. Services communicate using either synchronous (e.g. HTTP/REST) or asynchronous protocols. Moreover, each micro-service has its own database in order to be decoupled from other services.

Icarus applications run on a commercial cloud infrastructure, which has the advantages of being well secured, compliant with data-privacy requirements, scalable and extendible to user needs.

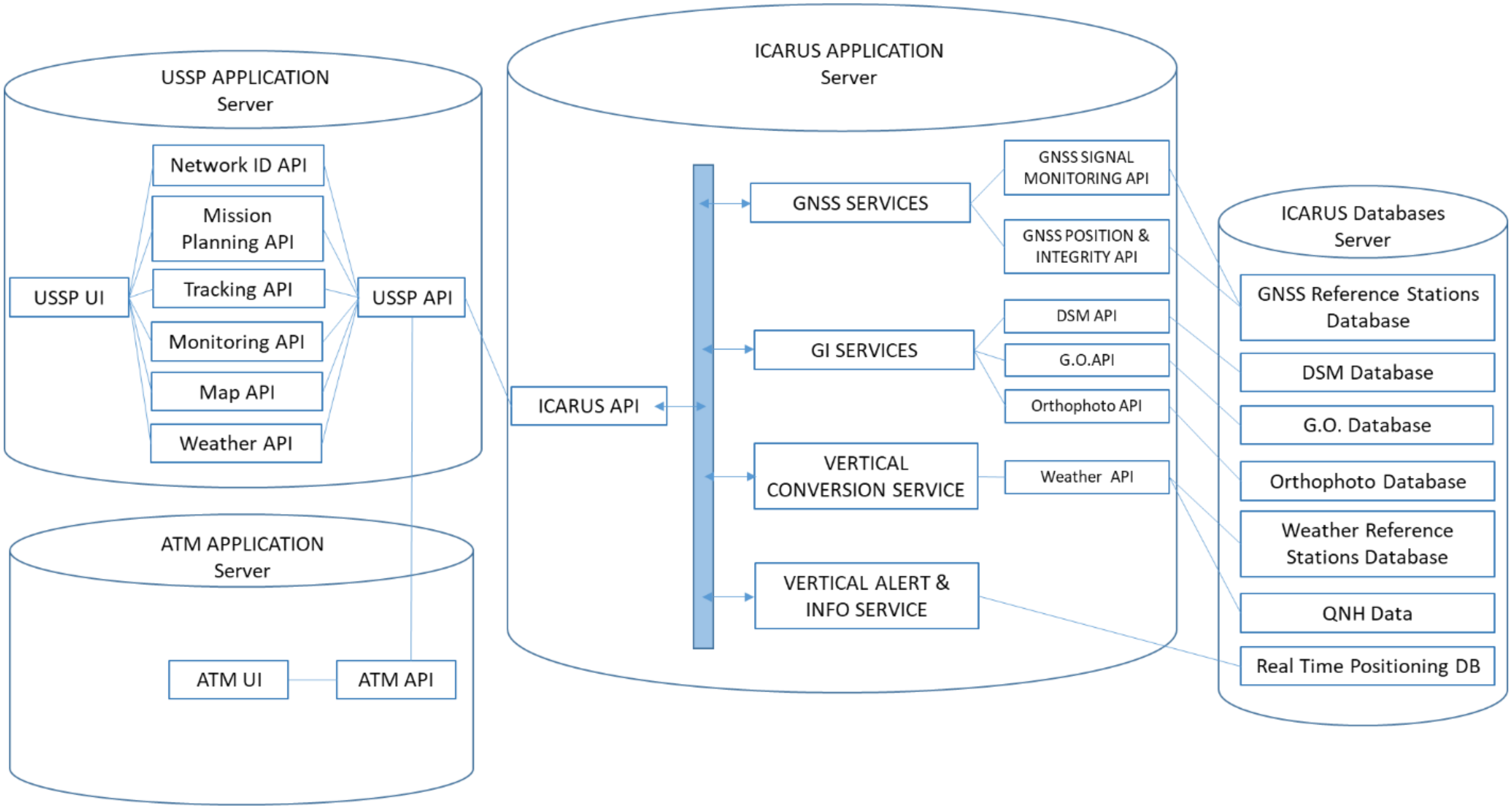

Figure 2-5: ICARUS Components and Micro Services

The main modules of the system illustrated in Figure 2-5 are briefly indicated in the following sub-paragraphs. In particular, the following subsystems are analysed at a higher level of detail than is given in Figure 2-4:

- ICARUS database server:
    - Database of GNSS reference stations
    - DSM database
    - Ground obstacle (GO) database
    - Orthophoto database
    - Database of weather reference stations
    - QNH reference data
    - GAMZ area definitions
- ICARUS Application Server:
    - GNSS Services (i.e. EMS):
        - GNSS signal monitoring API
        - GNSS position & integrity API
    - Geo-information (GI) Services (comprising GIS, RGIS & GAW):
        - DSM API
        - GO API
        - Orthophoto API
    - Vertical Conversion Service (VCS):
        - Weather API
    - Vertical Alert & Information Service (VALS)
        - Real-time positioning DB
- USSP Application Server:
    - Network ID API
    - Mission planning API
    - Tracking API
    - Monitoring API
    - API Map
    - Weather API
    - USSP API
- ATM Applications Server
    - Atm API

The ICARUS database has three basic functionalities:

1. Data ingestion
2. Data repository
3. Data request

Typically, the data ingestion is triggered by the occurrence of an event that can be scheduled. This allows for acquiring and storing data in a systematic and completely automatic way. The typical sequence of operations is:

1. Data ingestion is triggered by a temporal event that also provides information on the type of interface to activate
2. Data is physically transferred from external interfaces
3. A formal check (format check, etc.) is performed on the ingested data
4. The data is possibly renamed if necessary
5. The data is physically inserted into the local data storage

Data ingestion is responsible for managing interfaces with external systems providing data to ICARUS. So the task that triggers the start of an automatic ingestion function must also define the location where the data to be ingested are located, e.g. FTP server, user account, directory, etc.

The format check function performs a formal and quality check on the data entered into the system. The checks to be carried out can be generic or defined ad-hoc. The generic ones are encoded in a series of rules such as:

- Format control
- Naming control convention
- File size control

Specific controls can be defined ad-hoc for each file type. This will allow a series of quality controls to be defined for a given type of file (on a quality flag, or by reading specific fields of the header of a data item), and to define a series of data acceptance rules within the system to guarantee perfect data integrity.

The storage function is the last macro-step of the data ingestion process. It is a communication between data ingestion and the data repository. The repository provides a set of APIs to use. Ingestion into the repository consists of carrying out two types of operation:

- Extract a set of metadata to be included in the central catalogue for ad-hoc searches
- Physically insert the file, or a representation of it, into physical storage.

The Repository is the access point for all data used by the system. The Repository keeps all the data used by ICARUS, which includes input data used by the processors, output data produced, and possibly intermediate results. It also has the task of querying the database.

The Data Request component, manages the procurement of the data necessary for the work of ICARUS. While data ingestion physically carries out the transfer and insertion of data into the ICARUS system, data request operates upstream and deals with dialoguing with the data providers to request the necessary data.

Since there are few types of data necessary - GNSS data, GI data, weather data, QNH data, etc. - the data request component will have to interface with the suppliers of such data, which will then be entered into the ICARUS Application Server.

Once the data have been obtained from the GNSS, weather and GI data providers, they are used as input into the ICARUS Application Server. All the ICARUS micro-services are contained within this server and are composed of various APIs as mentioned above (Figure 2-5).

The **GNSS service** retrieves data from EDAS, from the Reference Stations database and, through the USSP API, from the U-Space Tracking and Monitoring service provided by the USSP. Once all the necessary data have been obtained, the service can provide GNSS signal monitoring, Position Velocity and Time (PVT) and Integrity calculation.

The **GI service** retrieves data from external data providers, in particular from commercial and / or free DSM data providers, from the GO database and from the orthophoto database. In addition, this service will interface with the USSP API to obtain data from the map API and mission planning API to calculate the altitude of the drone with respect to the surface and the ground obstacles, both in the strategic and tactical phase. This service is also closely coupled to GNSS Services and the Conversion and Information Service. The GNSS service provides the speed and timing position of the drone with its ID. Having obtained these data, the GI service allows mission planning, and the calculation of the altitude with respect to the surface (DSM) and ground obstacles, in both the strategic and tactical phases.

The data relating to the altitude of the drone are obtained from the connection with the Conversion Service, and provided in both strategic and tactical phases by the GI service.

The **Vertical Conversion Service** retrieves weather data from the service providers, from the USSP (Weather API) and from the Weather Reference Station database. In addition, this service interfaces with ATM through the ATM API-USSP API to obtain data relating to GA, in particular GNSS data and barometric data. Finally, through the link with the GNSS service, this micro-service is able to determine and share the geometric height the manned plane is flying at and the barometric height of the drone.

The **Vertical Alert and Information service** provides alerts to GA pilots who enter a GAMZ and also to drones/done pilots if there is a risk of collision with ground obstacles, through the use of the ATM API and USSP API respectively. To do this, it must be closely connected to the GI, GNSS, and Conversion services from which it obtains the position of the drone and of the manned aircraft, the GAMZ position and the barometric and geometric height.

2.3 Overall Detailed System/Service Architecture

As stated in the previous chapter, the approach proposed in ICARUS foresees the realisation of a service embedded in an Application Program Interface (API) that can be queried by the U-Space Service Provider to provide following main elements:

- GNSS-based altimetry as a common reference datum for vertical UAS separation in VLL airspace;
- information on the vertical distance to the ground (terrain, ground obstacles, buildings) and warnings to manned-aviation pilots near “Geometric Altitude Mandatory Zones”;
- conversion of reference systems enabling drone integration with GA users;
- acceptable information latency (near real time for the tactical phase);

- cartographic tool integration, 3D terrain model for flight planning;
- Digital terrain model (DTM) / Digital surface model (DSM) in the neighbourhood of the planned route with acceptable accuracy and resolution, including buildings in cities and ground obstacles in rural sites, for obstacle and terrain avoidance during the tactical phase;
- GNSS signal performance monitoring & GNSS integrity service reporting to UAS pilots or drones;

Moreover, the ICARUS services related to GA will be shared with ATM/ATC through the interface with the U-space service provider; in particular:

- warnings to manned-aviation pilots near and crossing a “Geometric Altitude Mandatory Zones”;
- conversion of altitude reference systems from barometric to geometric and vice-versa to align them with drone traffic;

The newly created system developed under the ICARUS project will operate in accordance with the Confidentiality, Integrity and Availability (CIA) model. To produce services and systems for the manned and unmanned aviation markets, it is necessary to create a single source of reliable information. Due to the obvious fact that it is not possible to aggregate all the necessary information needed to run the service in one system (database), a coherent, structured communication layer must be created, with the specification of appropriate protocols.

During the project the implementation of the ICARUS service will be evaluated in accordance with the System Wide Information Management (SWIM) concept and the service-orientated Collaborative U-space-ATM Interface concept. SWIM is a global ATM initiative for harmonising the exchange of aeronautical and weather information among all airspace users and stakeholders and is an integral part of the International Civil Aviation Organisation's (ICAO) Global Air Navigation Plan (GAMP). It is implemented through a number of active modules, including aircraft, either providing or using information.

The SWIM and Collaborative U-space-ATM Interface concepts are consistent with that of the ICARUS project. Their mutual relationship is dictated by the need to connect two different ecosystems that, until today, have been hermetic: the professional environment, almost entirely for certified manned aviation, on one hand, and the generally accessible, loosely connected environment of operators of UASs and the data and processes necessary to build their infrastructure on the other hand. Core ICARUS and SWIM services will enable systems to request and receive information when they need it, subscribe to automatic receipt, and publish information and services as needed. This will ensure the exchange of information between different systems. It will enable airspace users and air traffic controllers to have access to the most up-to-date information that could affect their responsibilities.

As mentioned above, the complete CAR system will be built up from multiple instances of smaller CAR systems serving dedicated areas. An example of the deployment architecture of such a single instance is shown in Figure 2-6.

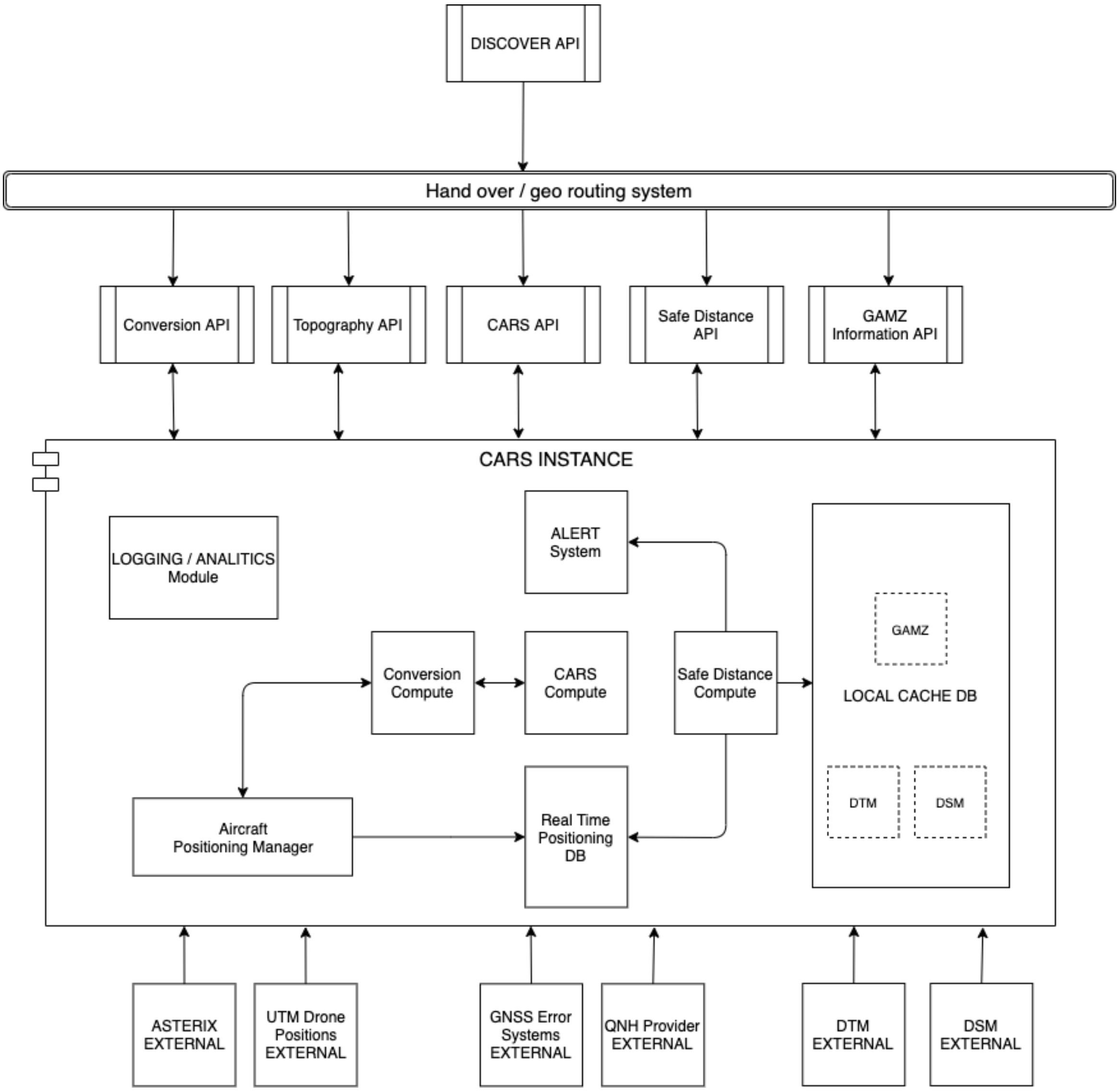

Figure 2-6 CARS instance

There are 3 main types of component in the CAR system:

- Handover / geo-routing system – the central, root CARS service responsible for providing the API discovery service (dispatching initial CARS service requests to appropriate instances of the CAR system e.g. based on geo-location of the request) and maintaining potential switch overs between CARS instances
- CARS instance – one of many copies of CARS, each of which implements all CARS services
- External systems modules that implement interfaces with external systems, such as QNH data providers or GNSS data providers

The handover / geo-routing system is a "root" CARS service, which is an initial access (entry) point for all new CARS service requests. It is responsible for redirection of the newly established session to a dedicated CARS instance (based on payload – geoJSON point). It acts also as an API gateway for all CARS API requests. When necessary it also supports switchover between different CARS instances.

A single CARS instance is responsible for serving aircraft in a designated area. It contains the following key modules:

- CARS Compute – responsible for CARS height calculations (used by VCS, VALS, GAW services to perform heights calculations);
- Conversion Compute – responsible for height conversion calculations (provided by VCS service);
- Aircraft Positioning Manager – responsible for acquiring aircraft positions from external systems (Asterix, UTM), normalising height data to the common reference system and storing theses normalised data into the Real-Time Positioning database;
- Real-Time Positioning Database (RTPD) – a fast, non-relational database with geographic filter functions that holds current trajectory data;
- Safe Distance Compute - uses data from RTPD to calculate the safe distance from the aircraft to the ground, to other aircraft, to the GAMZ (used by RGIS, GAW, VALS services); when safety buffers are exceeded an alert is published onto the inner data bus;
- Alert System - catches alerts form safe distance compute module and notifies affected subscribers (outside CARS) (used by VALS, RGIS and GAW services);
- Local Cache Database – persistent relational database, which keeps regional (CARS area of responsibility and some overlap) DSM, DTM and GAMZ area data; refreshed monthly from official U-Space CIS;
- Logging / Analytics Module – catches all or selected data from the data bus and saves it onto an internal Time-Series Database; enables traffic and events analytics.

General CARS APIs, which are implemented by a CARS instance, can be divided into the following API categories:

- Conversion API - converts any height to any other reference system;
- Topography API - returns 3D DTMs or DSMs; model range is limited to area of responsibility and alternatively some part of neighbouring instances; serves data directly from the DTM and DSM parts of the Local Cache Database;
- CARS API - returns CARS heights (height in defined unit, distance to obstacle, distance to terrain); the height unit/reference system is defined as a parameter in the request;
- Safe Distance API – an alert API that works on a publisher-subscriber pattern; alerts can be issued for aircraft with continuous height and position telemetry or radar-observed heights and position data when they approach too close to the ground or to another aircraft;
- GAMZ Information API – an alert API that works on a publisher-subscriber pattern; alerts can be issued for aircraft with continuous height and position telemetry or radar-observed heights and position data when they approach the GAMZ.

Each CARS instance must also support interfaces with external systems:

- Asterix – aircraft radar data provider;
- UTM – UAV telemetry data provider;
- GNSS system providers EMS;
- QNH provider;
- DTM/DSM providers.

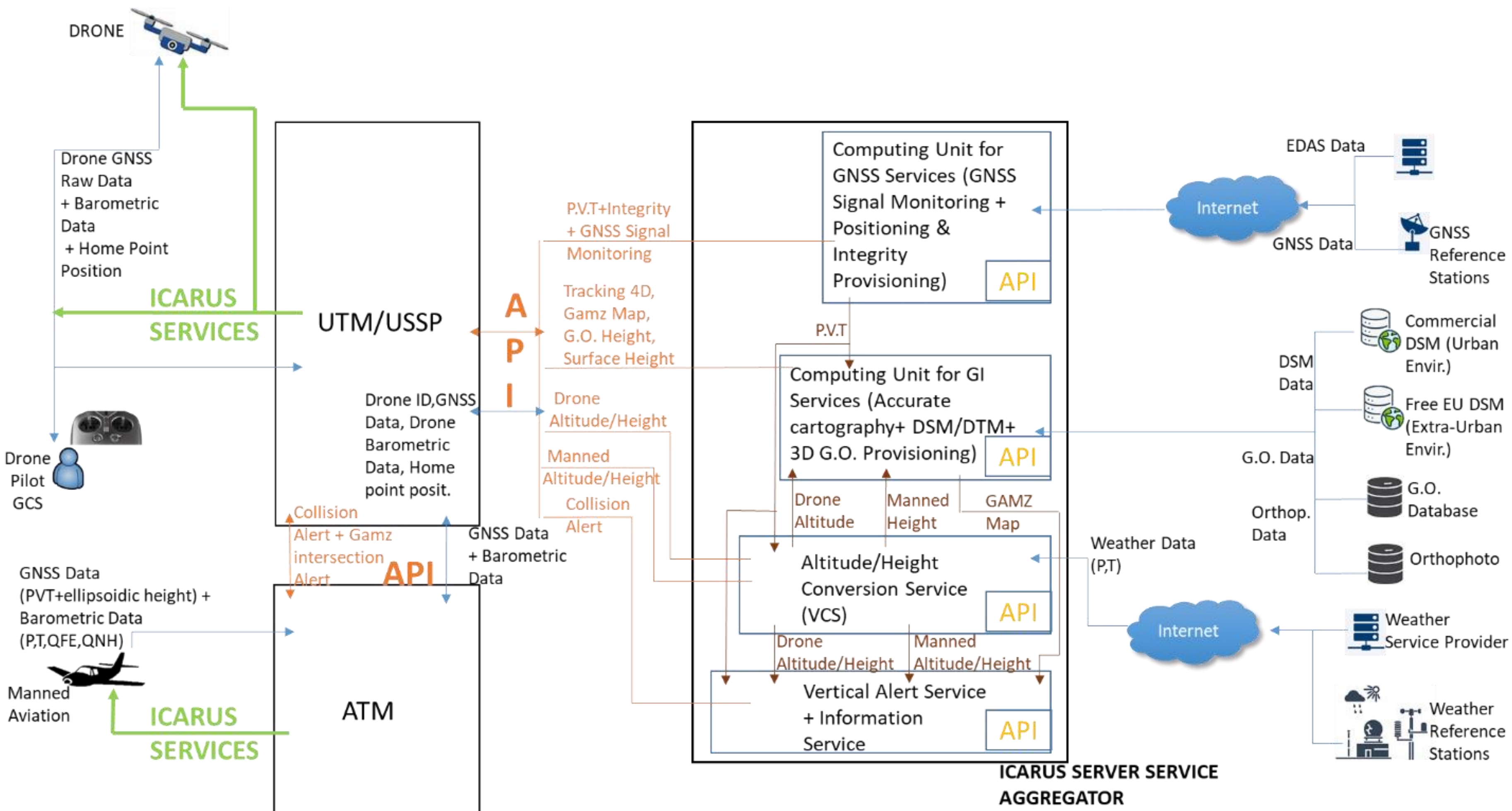

Figure 2-7: Overall ICARUS system architecture

The following diagram gives a description of the single micro-service network data infrastructure.

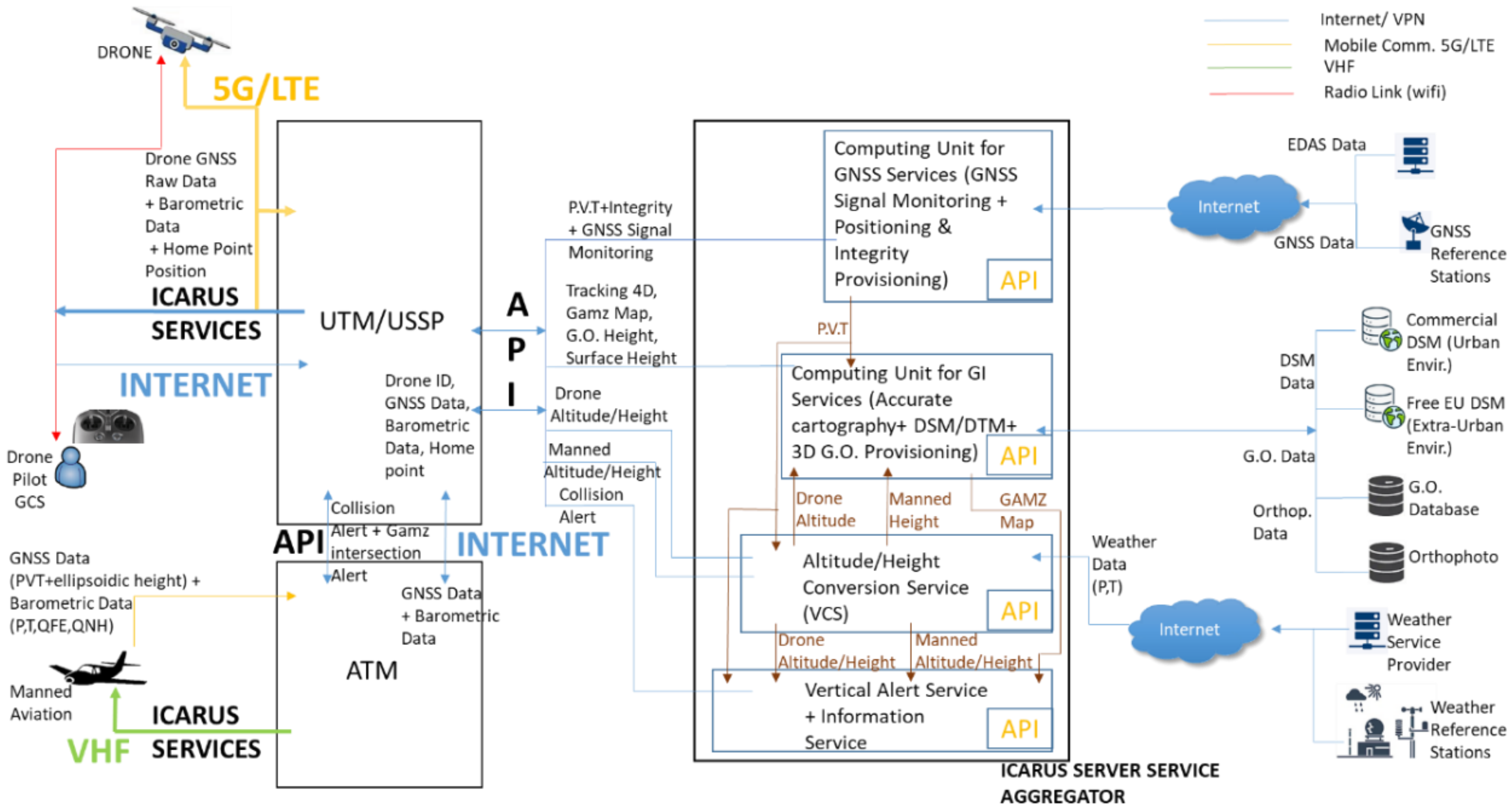

Figure 2-8: ICARUS network service architecture

2.3.1 GNSS service architecture and data network infrastructure

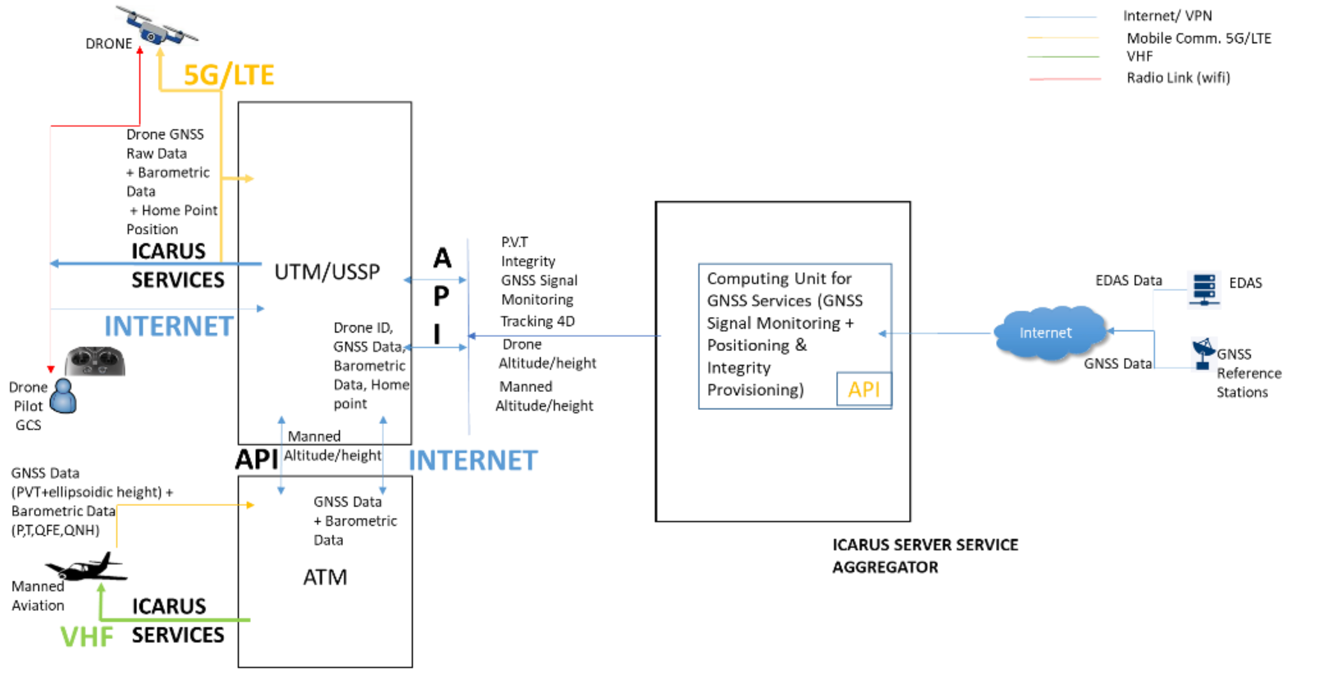

Figure 2-9: GNSS data network infrastructure

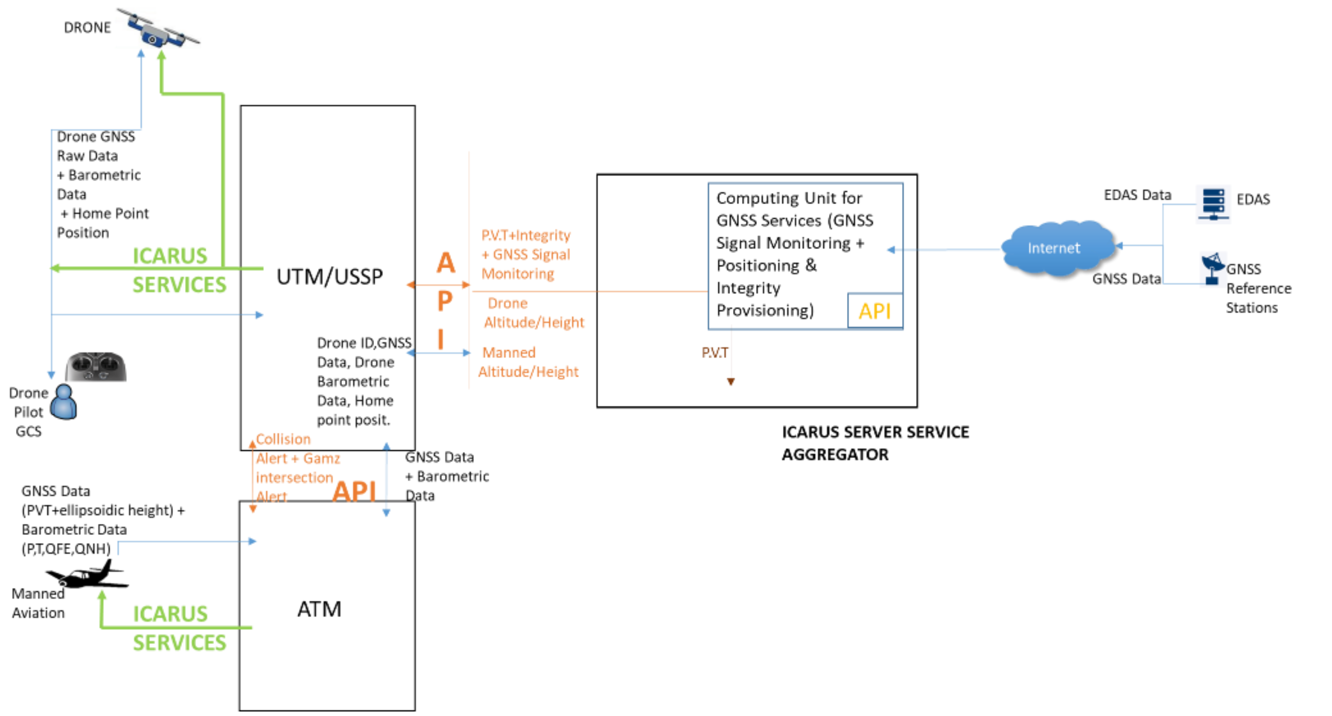

Figure 2-10: GNSS Service high level architecture

The raw drone GNSS data, barometric data and the GCS home-point position are provided to the USSP through a direct 5G/LTE link or through an internet connection with the GCS, and then shared with the ICARUS Server Service Aggregator through an API using the internet.

Similarly, the GNSS and barometric data coming from GAs are provided to the ATM through a 5G/LTE mobile communication channel or through a radio communication link. These data are then provided to the USSP using the "Collaborative Interface with ATC" U-space service via the internet.

Once all the data from the USSP (and from the ATM) have been received, the ICARUS micro-service related to GNSS services will compute the integrity, signal monitoring, and position. For this, the GNSS micro-service needs to receive the EDAS data and the GNSS reference station data through the internet.

Once the calculation has been performed, the drone position, altitude/height, the signal integrity and monitoring results will be shared with the USSP and ATM.

The end users, drone operators/pilots or the drones themselves, will receive the ICARUS services through the internet or 5G/LTE, while the GA pilots will get them through VHF channels

2.3.2 GI services architecture and data network infrastructure

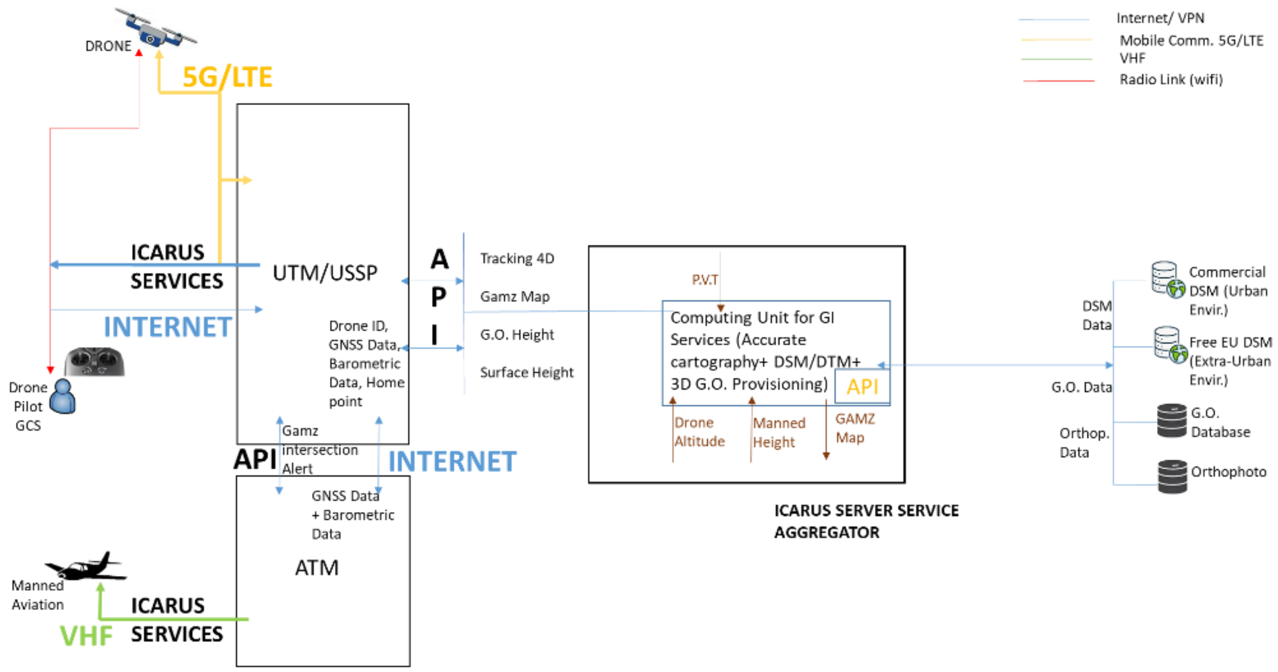

Figure 2-11: GI data network infrastructure

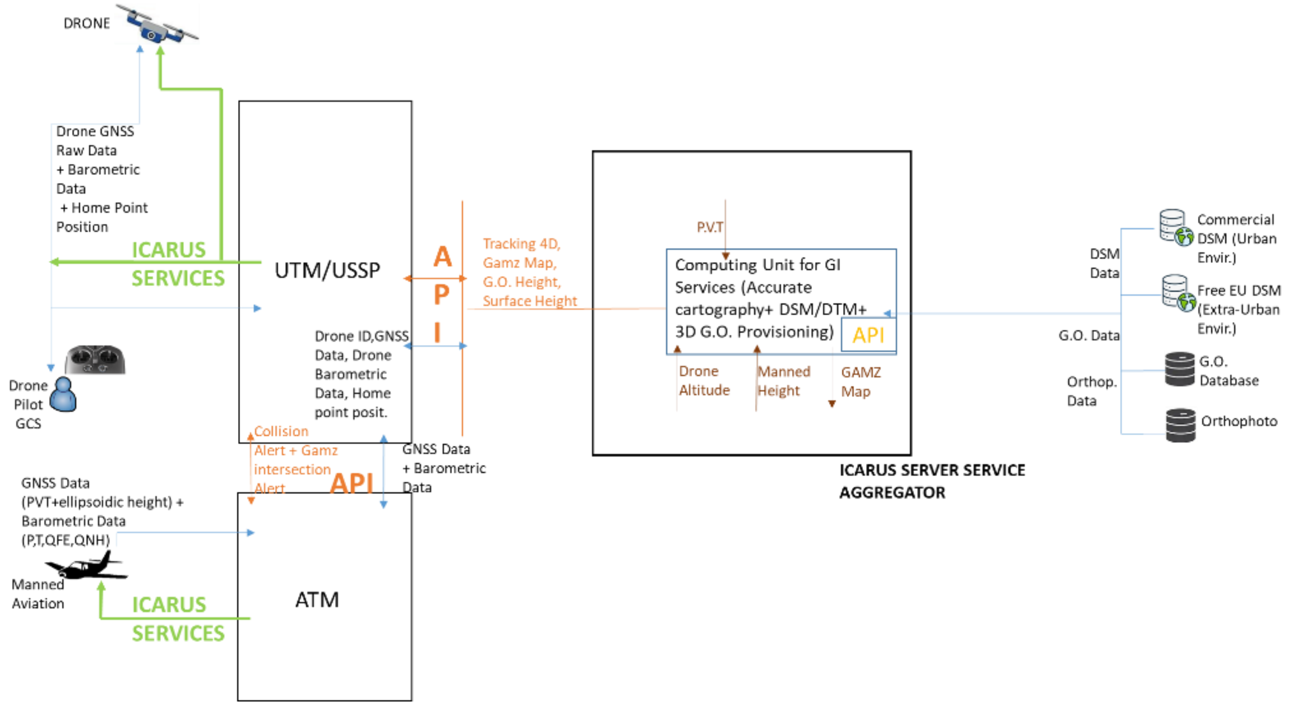

Figure 2-12: GI service high-level architecture

The GI micro-service will take the drone's position/height and the GA aircraft's position/height from the GNSS micro-service as input into the ICARUS service aggregator. The other inputs come from external sources, DSM, GO, and orthophoto, and will be shared through the internet to the computing unit for GI services where it will be possible to provide GAMZ position and extension, drone altitude and height with respect to buildings and ground obstacles, the GA position with respect to the GAMZ, and their current height and altitude. Moreover, the GI micro-service that allows the drone operations to be planned with the drone's altitude with respect to terrain, buildings, obstacles allows the avoidance of possible ground collisions at the strategic phase of the flight. For the tactical phase, the link with the GNSS module enables the drone to be tracked in 4D, showing its current altitude with respect to the surface and ground obstacles.

The services provided by the GI module will be shared with the USSP and then with ATM through the internet. The end users, drone operators/pilots or the drones themselves, will receive the ICARUS services through the internet or 5G/LTE, while GA pilots will get them through VHF channels.

2.3.3 Vertical Conversion & Information services architecture and data network infrastructure

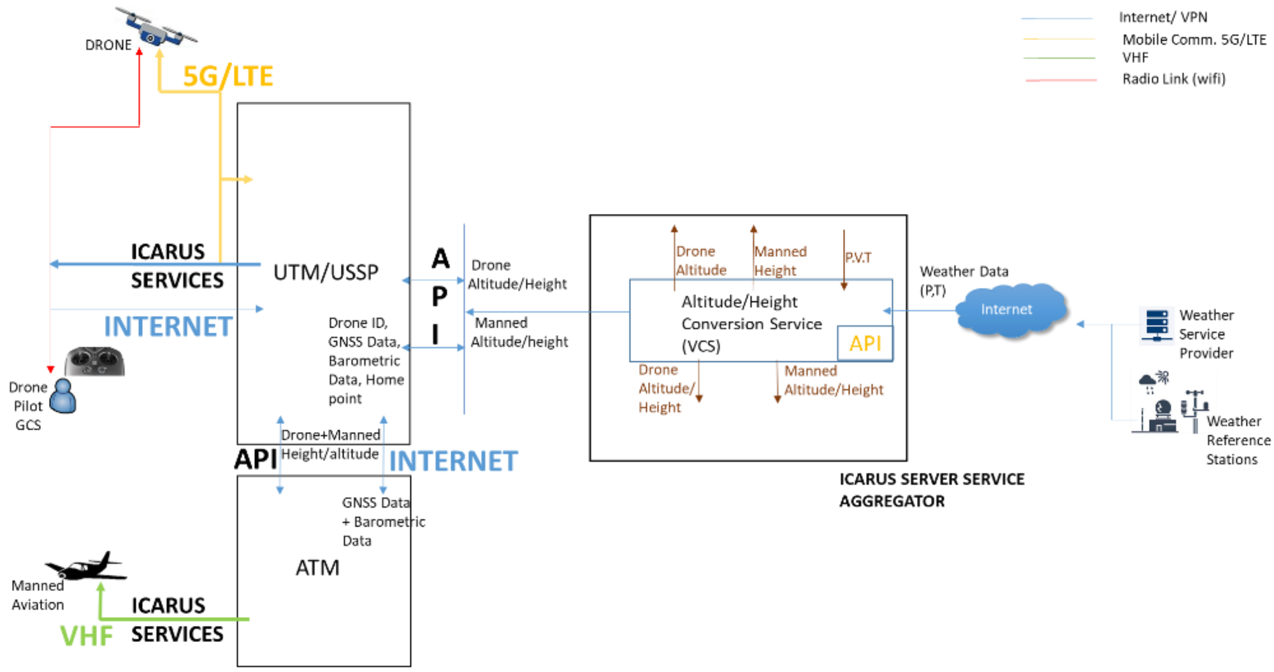

Figure 2-13: Vertical Conversion Service data network infrastructure

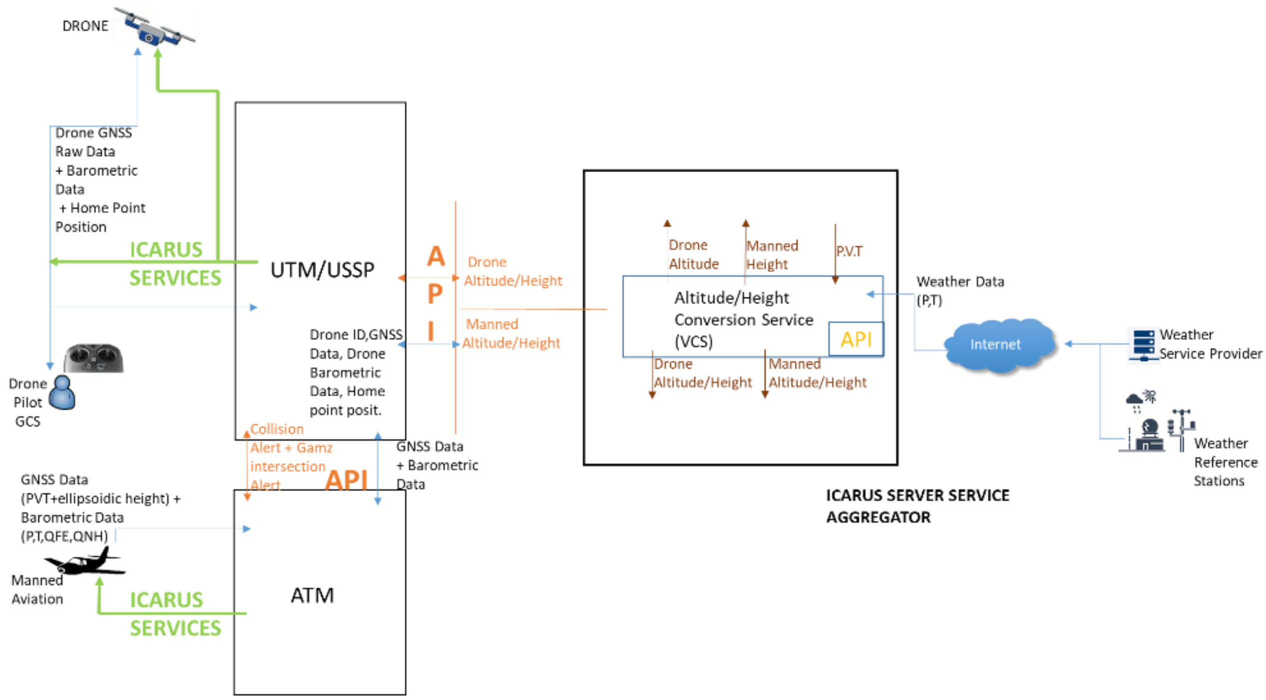

Figure 2-14: VCS high level architecture

The Vertical Conversion and Information micro-service will take the drone position/height from the GNSS micro-service and the GA aircraft position/altitude from ATM as input through the interface with the USSP. The other inputs come from external sources, in particular weather data will be shared from the computing unit from one certified weather service provider and from weather reference stations through the internet. The Vertical Conversion and Information service will compute a drone's altitude and height with respect buildings and ground obstacles, and a GA's current height and altitude.

The services provided by the Vertical Conversion and Information module will be shared with the USSP and then with ATM through the internet. The end users, drone operators/pilots or the drones themselves, will receive the ICARUS services through the internet or 5G/LTE, while GA pilots will get them through VHF channels.

2.3.4 Vertical Alert service architecture and data network infrastructure

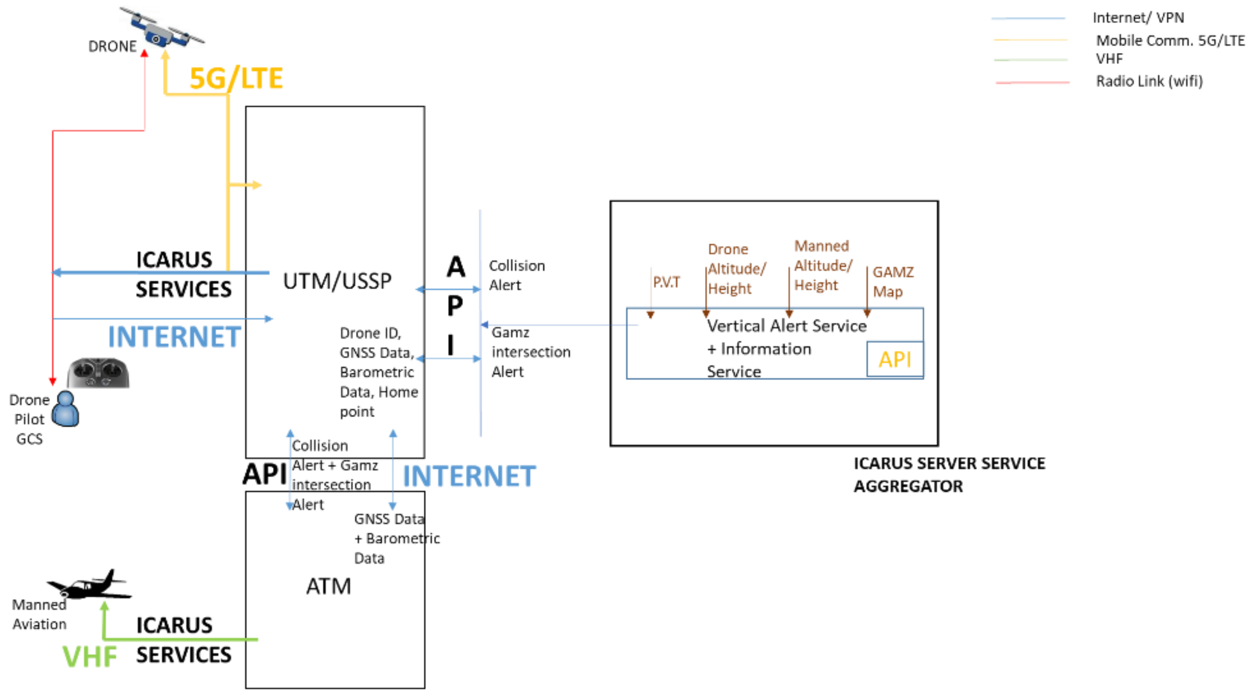

Figure 2-15: Vertical Alert & information service data network infrastructure

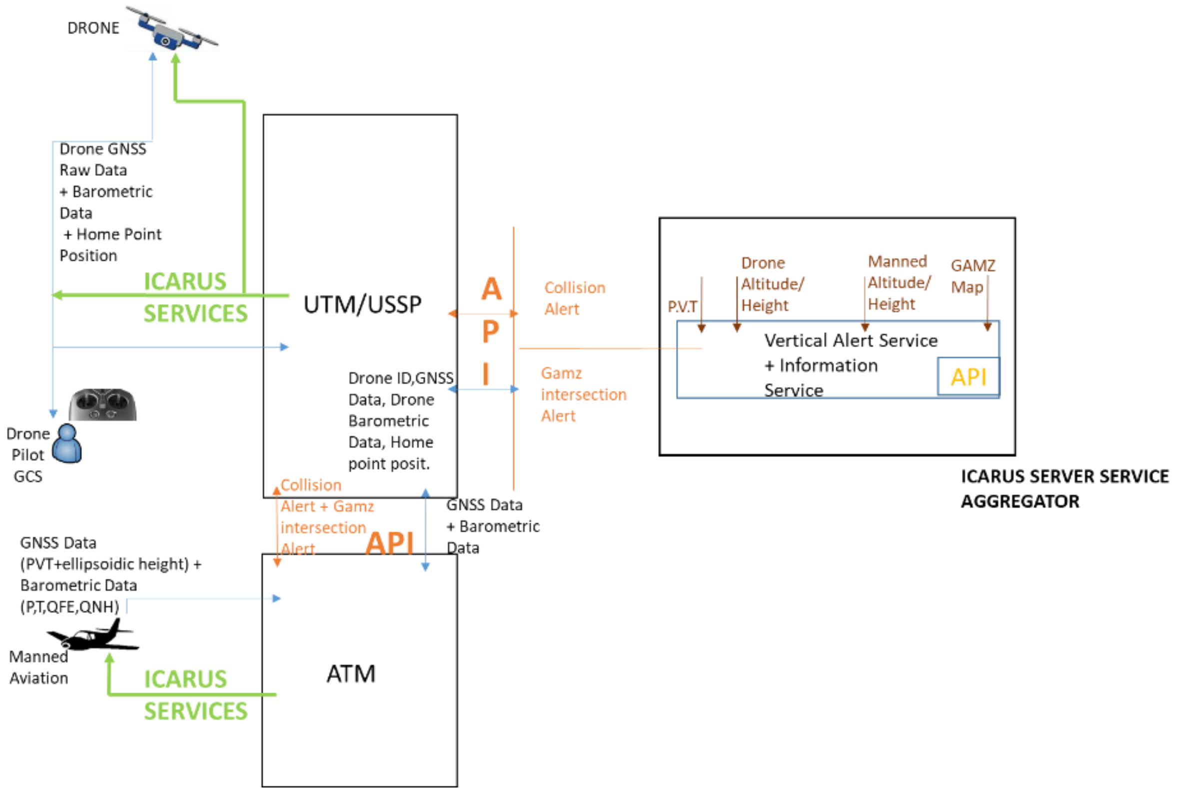

Figure 2-16: VAS high level architecture

The Vertical Alert and Information micro-service will take the drone position/height from the GNSS micro-service, the drone altitude from the conversion micro-service, and a GA aircraft position/altitude from ATM as input through the interface with the USSP, GA aircraft height from the conversion service and the GAMZ map from the GI micro service. The Vertical Alert and Information service will alert drones and drone pilots if there is a possible collision with obstacles and terrain in the strategic and tactical phases of the flight; moreover, it will also alert GA pilots if they are crossing a GAMZ.

The services provided by the Vertical Alert and Information module will be shared with the USSP and then with ATM through the internet. The end users, drone operators/pilots or the drones themselves, will receive the ICARUS services through the internet or 5G/LTE, while the GA pilots will get them through VHF channels.

3 Geo-Information service architecture and data flows

3.1 Requirements of GI services

The GI service subsystems provides a complete set of functions and data to support all the other subsystems in their interactions with geographical information.

All the data from external sources and generated by ICARUS subsystems that include a GI component will be treated with the appropriate procedures to obtain the appropriate level of robustness of the entire service and to keep the information provided updated and at the best level of accuracy possible.

The architecture design of the GI services starts from the analysis of the related requirements following what defined in [8]. The table below gives the requirements applicable to this component of the whole architecture.

ReqID	ReqTitle	ReqText	Type	Verification Method
ICARUS-D31-0020	Vertical separations	The main cases of investigation for vertical separation in the ICARUS study will be: - UAS / UAS common vertical reference; - UAS / ground obstacles vertical information provided by U-space services; - UAS / Manned aircraft vertical reference, provided through an altitude translation service;	General	RoD
ICARUS-D31-0030	Datum	WGS-84 shall be used as common datum for all airspace users in particular classes of airspaces at VLL (Zu, Y volumes) where a relevant number of drone operations is expected	functional	A
ICARUS-D31-0060	UAS-UAS Common vertical Reference at VLL	Each UAS shall be able to guarantee the Required Navigation Performance (Accuracy, Integrity, Continuity, Availability, Monitoring, …) for the common altitude reference and for a given airspace volume, route or procedure by means of airborne equipment and /or U-space services	functional	A
ICARUS-D31-0070	UAS-Ground Obstacles vertical Reference at VLL	Ground Obstacles represented in a given DSM shall be reported and referenced by U-space Geospatial Information Service in the same datum used by UAS for Common Altitude Reference System (WGS-84) Remark Geodetic->Geometric transformations of buildings and obstacles might be needed to ensure the same reference for all airspace users at VLL	functional	T
ICARUS-D31-0080	UAS-Manned Aircraft vertical Reference at VLL	UAS and Manned aircraft must use WGS-84 datum in Zu and Y volumes for vertical common reference.	functional	A
ICARUS-D31-0100	Altitude information in BVLOS	Geometric Altitude (above the WGS-84 ellipsoid) information shall be always visible on the pilot's Ground Control Station	operational	T

		during BVLOS operations for Common Altitude Reference with other UAS		
ICARUS-D31-0180	GAMZ	Geometric Altitude Mandatory Zones (GAMZ) shall be accessed only by drones or manned aircraft using WGS-84 datum as common reference for Altitude <u>Remark</u> The Geometric to barometric service can be queried by drone pilots, manned aircraft pilots or drones for datum translation in strategic and tactical phases	functional	A
ICARUS-D31-0190	Geo-Awareness service & GAMZ	The Geo-Awareness service shall present suitable logical interfaces through U-space for the following functionalities: - temporary (or periodic) GAMZ removal; - to force RTH for all drones involved in operations (i.e. presence of HEMS operations); - to warn all GAMZ airspace users about changes	functional	A
ICARUS-D31-0200	tracking service for CAR	The UAS shall provide position information (including integrity) with respect to WGS-84 datum for CAR at VLL. The altitude information must be expressed in metres	functional	A
ICARUS-D31-0290	ICARUS demonstrator	The ICARUS demonstrator shall be capable of showing the following functionalities during the strategic and tactical phases of the flight: - vertical profile of the planned trajectory with respect to the WGS-84 datum and to the ground (terrain, ground obstacles, buildings); - warnings to manned-aviation pilots and drones in proximity of "GAMZs"; - 3D model of buildings, ground obstacles and terrain profile in the defined area of simulation. - Display the conversion of reference datum (QNH/WGS-84) to airspace users through a dedicated service with a simulated communication mechanism	functional	T
ICARUS-D31-0300	Geometric-Barometric conversion service interface	The Geometric-Barometric altitude conversion service shall be interfaced with navigation (GNSS) performance monitoring stations (U-space service) and with barometric stations or service providers (ANSP or U-space service).	functional	RoD
ICARUS-D31-0310	Total System Error (Accuracy)	During BVLOS operations, for a straight trajectory (Waypoint 2 Waypoint), according to PBN ICAO definition, it shall possible for UAS to reach a navigation accuracy performance with TSE of about: - 10 metres for the horizontal accuracy for copters; - 3 to 9 metres for the vertical accuracy for copters; - 14 metres for the horizontal accuracy for planes; - 3 to 9 metres for the vertical accuracy for planes;	performance	A
ICARUS-D31-0360	Surface Model	The Terrain or surface model must provide the adequate level of information required by the specific operation, in terms of elements to be represented, resolution and accuracy. <u>Remark</u> The urban area may require a high level of detail for the presence of ground obstacles, while extra-urban or rural areas can opt for less detailed model.	functional	A

ICARUS-D31-0380	Detailed Surface Model Position Accuracy	Digital Surface Model accuracy must be: - for urban areas, in the range of [0.50-1.00] m; - for rural areas, in the range [5.00 – 10.00] m; - for suburban areas [0.50 – 2.00] m during inspection operations; - for suburban areas [5.00 – 10.00] m during transit;	performance	T

Table 3-1: Extract of ICARUS requirements used for GI subsystem design

NOTE: the verification methods listed are:

- A = Analysis: compliance with requirements is determined by interpreting results using established principles such as statistics, qualitative design analysis, modelling and computer simulation;
- RoD = Review of Design: compliance with requirements is validated by using existing records or evidence such as validated design documents, approved design reports, technical descriptions, engineering drawings;
- T = Test: compliance with requirements is validated by executing an item under controlled conditions, configurations, and inputs to observe the response. Results are quantified and analysed in dedicated test reports;
- I = Inspection: compliance with requirements is determined by visual determination of physical characteristics, which include constructional features, hardware conformance to document drawings or workmanship requirements, physical conditions, software source code conformance with coding standards.

3.2 Functional architecture

The general architecture of the ICARUS system, defined on the basis of the requirements stated here above, is shown in Figure 3-1.

The elements of the ICARUS system are represented in terms of modules (first level of decomposition).

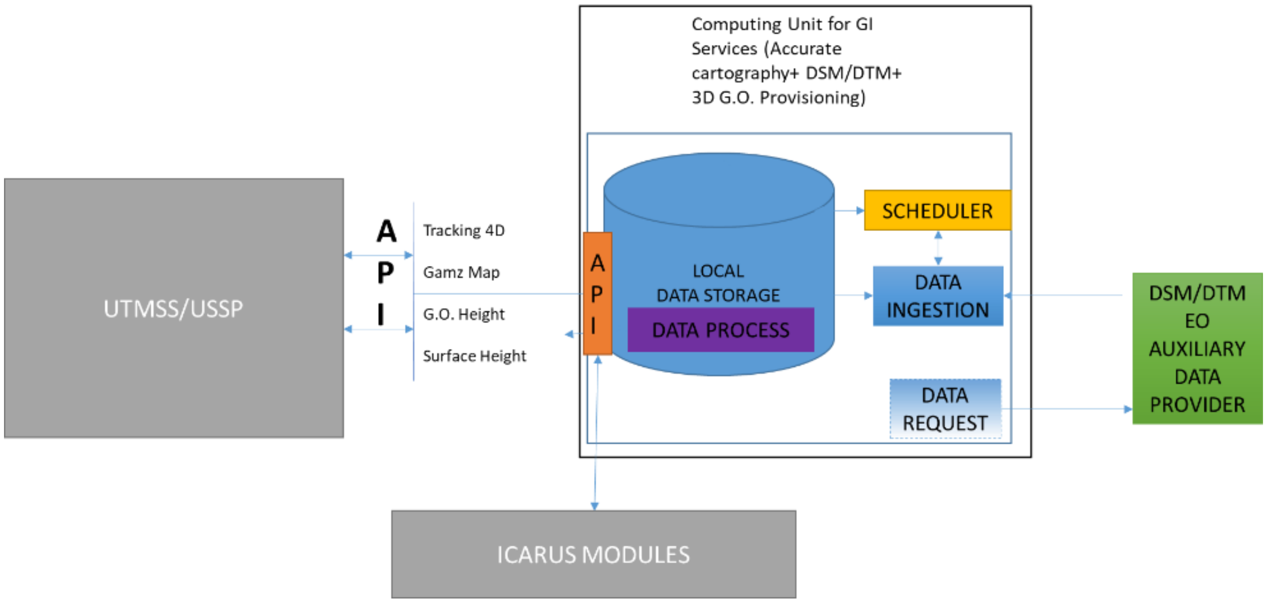

Figure 3-1 - ICARUS GI Services Architecture

A different view of the functional architecture, that provides a first refinement of the macro block in the previous figure is represented by the following components:

- GAMZ map management and provision
- DSM/DTM data management
- 3D GO computation and provision
- GIS computing unit for accurate cartography
- Geo-API provision

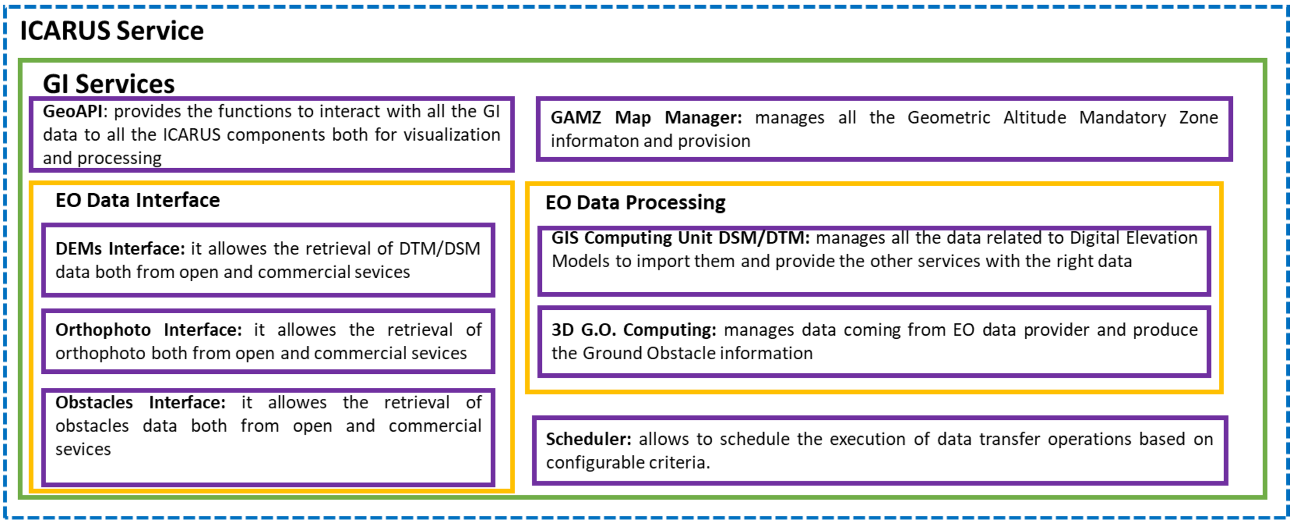

Figure 3-2 Functional architecture of GI service subsystem

3.2.1 GI service subsystem module descriptions

The following paragraphs will focus on each component of the ICARUS GI service architecture.

3.2.1.1 Data Ingestion

The ICARUS system receives the following input data:

- Satellite data;
- DSM/DTM data;
- Ground obstacle data

The types, origins and data access methods are very heterogeneous. For this reason, the Data Ingestion module must be able to handle this complexity.

The Data Ingestion module is responsible for collecting all the data necessary for the operation of the ICARUS system.

The preliminary scheme of the Data Ingestion module is shown in Figure 3-1.

In general, the Data Ingestion module must allow data to be recovered both automatically, where the data providers support this function, and through physical support. For online data transport it will support all possible transmission protocols, e.g. FTP, http, Web Service, point-to-point connection etc.

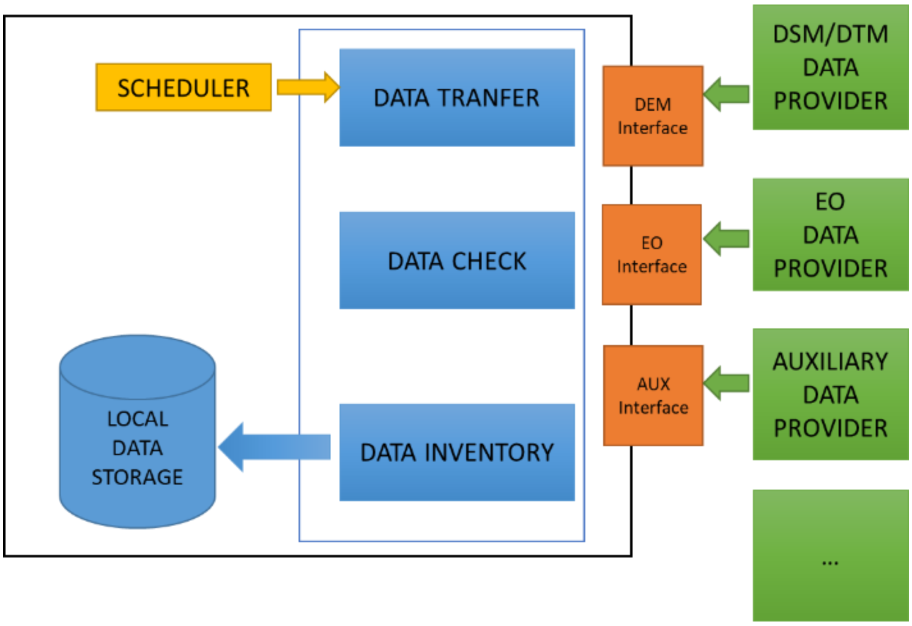

Figure 3-3 - DATA INGESTION

This design will make it possible to use a single module for the automatic retrieval of all the data necessary for ICARUS's operations, adapting to each case.

The Data Ingestion module, in addition to physically transferring the data made available online, performs the following operations:

- Quality control check;
- Metadata extraction;
- Storage in the central repository.

The quality control check consists of verifying that the data to be ingested into the system comply with the format and quality specifications required by the system in general.

Quality control is a fundamental aspect of the ICARUS system to assure the right level of service.

The metadata extraction process has the function of creating a catalogue inside the ICARUS system that can be interrogated by the various modules of the system to obtain the data necessary for a specific service.

The Data Ingestion module will be based on specific interfaces for managing the different data sources:

- DEM interface;
- EO interface;
- AUX interface.

3.2.1.2 Data Request

A fundamental module of the ICARUS system is represented by the Data Request. This module is represented with a dashed outline, as it is not yet defined the exact interaction process with external data provider in order to retrieve EO data for the ICARUS services

The Data Request module has the function of managing the procurement of the EO data necessary for the pre-operation of ICARUS. While the Data Ingestion physically performs the transfer and insertion of data into the system, the Data Request operates upstream and deals with communicating with the data providers in order to request the necessary data.

3.2.1.3 Data Repository

A central element of the ICARUS GI Services architecture is the Repository which consists of the following components:

- Physical storage;
- Metadata catalogue;
- API repository.

Physical storage is the area where data are physically stored so that they can be easily accessed and processed by the dedicated modules.

The Metadata catalogue contains the metadata extracted during the ingestion phase which will subsequently be used for the search, synchronisation and association of heterogeneous data and is a core function for all the ICARUS processes.

The API repository corresponds to a layer that exposes functions for accessing the GI data repository to the modules of the system, allowing an abstraction from the implementation model of the underlying system.

The Data Processing module contains all the algorithms common to most data processing, such as geo-coding, with precision ortho-rectification functions, and specialised for the various types of sensors, radiometric corrections, and atmospheric corrections. It should be remembered that a heterogeneous set of geographic information will be managed within ICARUS's data storage, so the processing chains and logics will be tailored on this basis.

Even if in many cases different products require different processing algorithms, the choice to enclose all the EO data processing modules in a single sub-module allows any synergies, where a single processor can contribute fully or partially to the generation of multiple products, to be exploited.

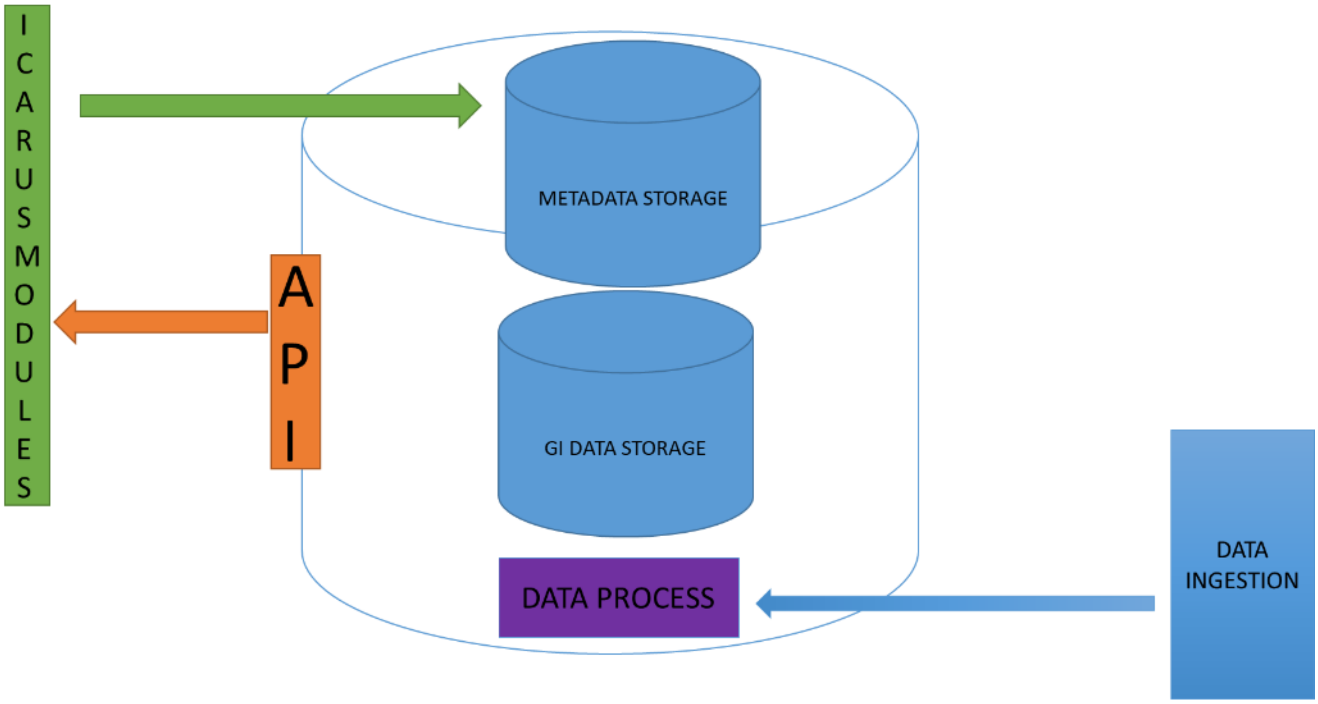

Figure 3-4 - Data Storage

4 GNSS service architecture and data flows

4.1 Requirements of GNSS services

The GNSS subsystem provides a centralised means of reliably computing the position of registered UASs, in real-time, and is a key enabler for all the ICARUS services.

Through appropriate processing of raw GNSS observables from drones, and support messages and data from external entities, it will provide the PVT solution for each monitored UAS, together with its integrity parameters and a validation mechanism based on the use of data coming from a network of trusted reference stations.

The architecture presented in this section answers the questions raised in [8]. In particular, the GNSS service subsystem will satisfy the subset of high-level requirements regarding position, and its accuracy, integrity, continuity, and availability, identified in §10 of the above-mentioned document, as summarised in Table 4-1.

Req ID	Req Title	Req Text	Type	Verification Method
ICARUS-D31-0030	Datum	WGS-84 shall be used as common datum for all airspace users in particular types of VLL airspace (Zu, Y volumes) where a relevant number of drone operations is expected	functional	A
ICARUS-D31-0050	Airspace Capacity	The ICARUS study shall provide information about precise vertical measurements with GNSS receivers considering the most important navigation figures (i.e. accuracy, integrity), to allow new UAS traffic organisation schemes for future feasible vertical alert strategies	General	A
ICARUS-D31-0060	UAS-UAS Common vertical Reference at VLL	Each UAS shall be able to guarantee the required navigation performance (accuracy, integrity, continuity, availability, monitoring) for the common altitude reference and for a given airspace volume, route or procedure by means of airborne equipment and /or U-space services	functional	A
ICARUS-D31-0170	Geometric-Barometric conversion service alert	The Geometric-barometric altitude service must warn users in case of malfunction in less than 6 seconds	functional	T
ICARUS-D31-0200	tracking service for CAR	The UAS shall provide position information (including integrity) with respect to WGS-84 datum for CAR in VLL. The altitude information must be expressed in metres	functional	A
ICARUS-D31-0210	Navigation for Tracking	The UAS shall provide estimated levels of accuracy and integrity for the navigation information. This information shall be provided within the position reporting packet payload	functional	A
ICARUS-D31-0220	Continuity requirement for tracking	The tracking service shall deliver information with a continuity (maximum tolerable probability of interruption of service per flight/hour) equal to 1E-05.	performance	A
ICARUS-D31-0230	GNSS signal availability	The availability of GNSS signal in rural, maritime and forestry environments shall be better than 99.9%	performance	A

ICARUS-D31-0240	GNSS Receiver Accuracy	The GNSS receiver accuracy in an urban environment shall be at least: - 1 m horizontal (1σ) - 1,5 m vertical (1σ)	performance	A
ICARUS-D31-0250	GNSS Integrity	GNSS signal integrity shall be monitored by UAS during BVLOS operations through: - Onboard: GNSS receiver autonomous techniques (RAIM / ARAIM); - Onboard: navigation data fusion using other sensors (barometer, vision system, D&A) - U-space service (navigation infrastructure monitoring)	functional	RoD
ICARUS-D31-0260	GNSS Receivers for altitude measurement	EGNOS-enabled DFDC (Dual Frequency Dual Constellations) GNSS receiver shall be used as minimum configuration to enable a reliable altitude measurement in an urban environment	functional	A
ICARUS-D31-0270	GNSS SiS Cybersecurity	EGNSS OS-NMA (or CS-NMA) shall be considered in the next generation GNSS receivers to enable urban UAS operations as a possible means to mitigate RF cybersecurity threats, before addressing mitigation procedures to address non-nominal situations	functional	RoD
ICARUS-D31-0310	Total System Error (Accuracy)	During BVLOS operations, for a straight trajectory (waypoint-to-waypoint), according to PBN ICAO definition, it shall possible for UAS to reach a navigation accuracy performance with TSE of about: - 10 metres for the horizontal accuracy for copters; - 3 to 9 metres for the vertical accuracy for multicopters; - 14 metres for the horizontal accuracy for fixed-wing planes; - 3 to 9 metres for the vertical accuracy for fixed-wing planes;	performance	A

Table 4-1: Extract of ICARUS Requirements used for GNSS subsystem design

NOTE: the verification methods listed in Table 4-1 are given in section 3.1.

4.2 Functional architecture

The functional architecture of the GNSS subsystem aims to (see also [8], §3):

- compute the position of a registered UAS;
- compute the integrity parameters (i.e. protection levels) of the position solution;
- monitor the expected GNSS signal performances by selecting one or more reference stations as near as possible to the flying UAS.

The possible system statuses are:

Status no.	PVT + integrity solution status (drone)	Monitored parameter status (regional)	GNSS solution status (overall)
1	OK	OK	OK

			Normal condition
2	OK	Not OK • integrity estimation raises alert and/or • SiS problems in area	WARNING Working without guarantees (should never happen)
3	Not OK • no PVT provided or • integrity alert raised	OK	LOCAL ALERT Local problem: • Obstacles blocking signal • Multipath • Interference • Spoofing • Meaconing • Receiver failure
4	Not OK • no PVT provided or • integrity alert raised	Not OK • integrity estimation raises alert and/or • SiS problems in area	GLOBAL ALERT Not working as expected

Table 4-2: Possible status of the solution

The overall functional architecture of the GNSS service subsystem is shown in Figure 4-1.

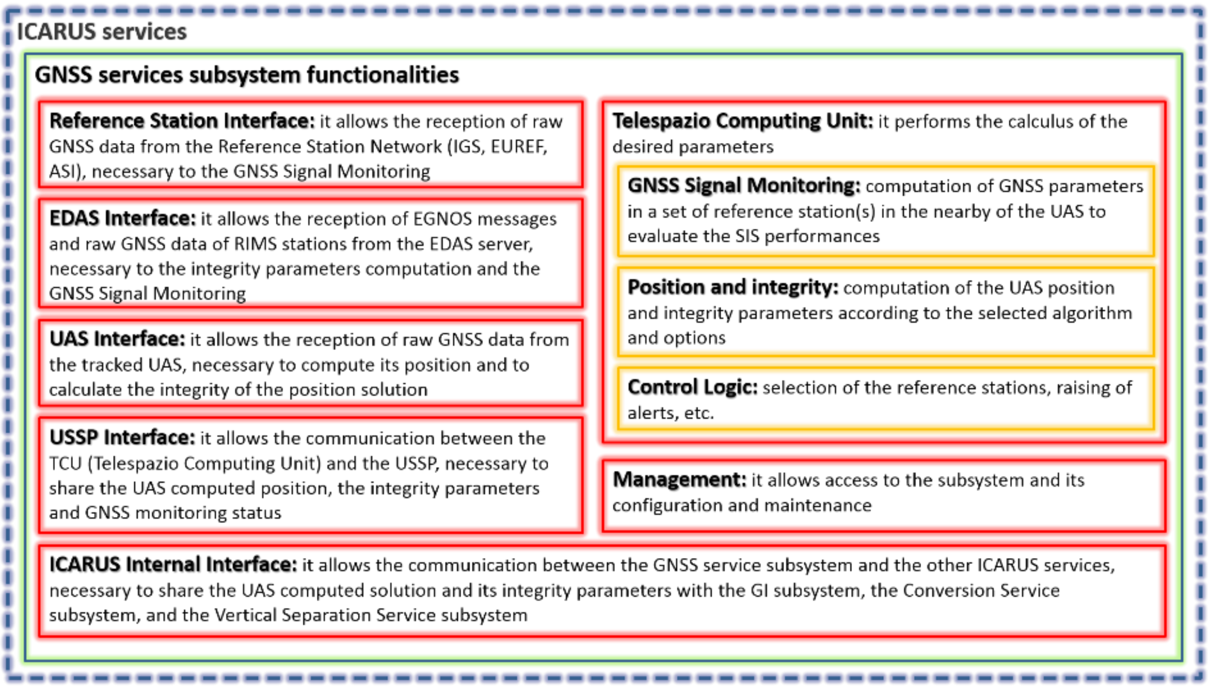

Figure 4-1: functional architecture of GNSS services subsystem

4.2.1 GNSS services subsystem modules description

The modules listed above are described briefly below.

- **Reference Station Interface:** this interface allows the selected GNSS raw data (GNSS observations, navigation message) to be collected from one or more reference stations belonging to public or trusted networks (IGS and/or EUREF and/or ASI), in real-time through the NTRIP protocol. These data are used for GNSS monitoring and the "geographic validation" of the solution. It will mainly consist of a Common Off The Shelf (COTS) Networked Transport of RTCM via Internet Protocol (NTRIP) client (such as BNC).
- **EGNOS Data Access Service (EDAS) Interface:** this interface allows European Geostationary Navigation Overlay Service (EGNOS) messages to be collected from the EDAS server for integrity calculation and accuracy improvement. At the same time, the EDAS protocol allows the raw GNSS data (observations, navigation message) to be collected from the Ranging Integrity Monitoring Stations (RIMS) stations, geographically improving the number of sources that can be used for GNSS monitoring and the "geographic validation" of the solution. It incorporates the following functionalities:
  - EDAS client: COTS component, provided by the European GNSS Agency (GSA) to connect and register to the EDAS server
  - EDAS multi-caster: module that transparently allows the concurrent use of EDAS data by multiple units
  - EDAS filter: extracts GNSS and SBAS navigation messages
  - EDAS decoder: decodes the EDAS-certified navigation messages for the processors in the Telespazio Computing Unit (TCU) – see below
- **UAS Interface:** this interface allows the raw GNSS data to be collected from a registered UAS. These data are used to compute the position and its related protection levels (integrity). The protocol used will be a customised version of Radio Technical Commission for Maritime services (RTCM), transmitted over a data link.
- **USSP Interface:** this interface is used to communicate the results calculated by the TCU to the USSP for UAS tracking. The communication will be implemented through a Message Broker mechanism (the GNSS service subsystem being the "publisher" and the USSP the "subscriber")
- **ICARUS Internal Interface:** this is used to communicate the results calculated by the TCU to the ICARUS subsystems providing the other services:
  - Geo Information subsystem (see chapter 3)
  - Conversion Service subsystem (see chapter 5)
  - Vertical Alert service subsystem (see chapter 6)

  The communication will be implemented through a Message Broker mechanism (the GNSS services subsystem being the "publisher" and the other ICARUS services the "subscribers")
- **Telespazio Computing Unit (TCU):** this will be the core of the GNSS subsystem, and will consist of:
  - A component dedicated to GNSS signal monitoring, that uses data coming from the reference station and EDAS interfaces

- A component dedicated to the position and integrity calculation for the tracked UAS, using data coming from the UAS interface and possibly the EDAS interface
- A control logic to manage the two modules above

* **Management:** a set of APIs and configuration mechanisms to access, configure and manage all the modules listed above.

4.3 Architecture context diagram of GNSS services subsystem

The high-level perspective of the system, related to the GNSS part, taken from [1], is repeated in Figure 4-2, with the derived context diagram associated with the subsystem given in Figure 4-3.

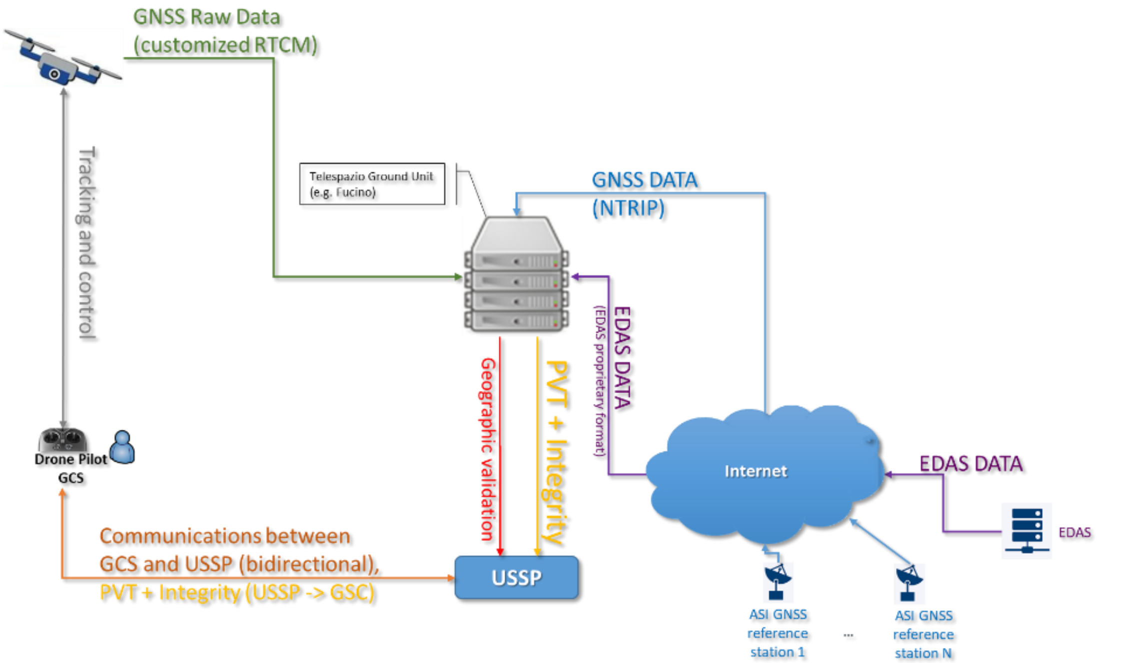

Figure 4-2: high-level perspective of the GNSS subsystem

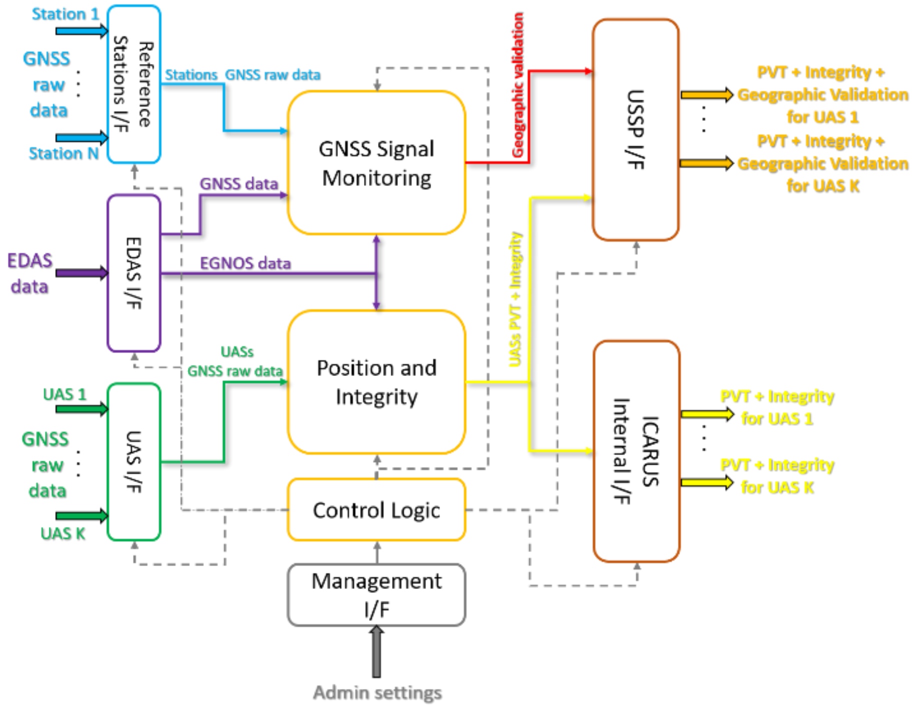

Figure 4-3: GNSS subsystem context diagram

4.3.1 High-level description of the external interfaces of the subsystem

The following table lists the external interfaces of the GNSS subsystem, with a short description of the protocols and standards used, and of the types of data passing through them.

Interface ID	Source	Destination	Protocol	Data
EDAS.TCU.01	EDAS	TCU	EDAS proprietary[1]	SBAS EGNOS messages, RIMS GNSS raw data
REF.TCU.01	IGS EUREF ASI trusted network	TCU	NTRIP	GNSS raw data
UAS.TCU.01	UAS	TCU	Receiver proprietary format	GNSS raw data
ADM.MAN.01	Administrator (authorised user)	Management unit	ssh access	Configuration files & settings
TCU.USSP.01	TCU	USSP	JSON on MQTT	Positioning, Integrity, Geographic Validation

[1] (encapsulating RTCM)

TCU.GI.01	TCU	Geo Information ICARUS subsystem	JSON on MQTT	Positioning, Integrity
TCU.CS.01	TCU	Conversion Service ICARUS subsystem	JSON on MQTT	Positioning, Integrity
TCU.VA.01	TCU	Vertical Alert ICARUS subsystem	JSON on MQTT	Positioning, Integrity

Table 4-3: external interfaces of GNSS services subsystem

4.4 Use cases

The representative use cases will be presented below to show the functioning of the ICARUS GNSS service subsystem and its data flows.

The use cases described cover:

1. The GNSS signal performance monitoring based on the EGNOS algorithm
2. The GNSS signal performance monitoring based on the ARAIM algorithm
3. The provision of GNSS position and integrity to the USSP and to the other ICARUS subsystems, based on the EGNOS algorithm (including the use case described in point 1)
4. The provision of GNSS position and integrity to the USSP and the other ICARUS subsystems, based on the ARAIM algorithm (including the use case described in point 2)
5. The configuration of the processing chain by an administrator

4.4.1 Use case 1: GNSS signal monitoring based on EGNOS

This use case demonstrates the ability of the GNSS subsystem to correctly treat EGNOS messages and GNSS raw data to evaluate the GNSS signal performance. The sequence diagram is given in Figure 4-4. The steps are as follows:

1. Reception and decoding of raw GNSS data from the reference station network;
2. At the same time, reception and decoding of the EDAS data stream, retrieving the EGNOS SBAS messages and the RIMS GNSS raw data;
3. Processing of the retrieved data to identify and discard possible faulty satellites and to compute the integrity parameters (i.e. Horizontal/Vertical Protection Levels) over a regional grid;
4. Estimation of the integrity parameters corresponding to a given coordinate pair (according to a distance criterion from the nearest grid point computed), with a result according to Table 4-2.

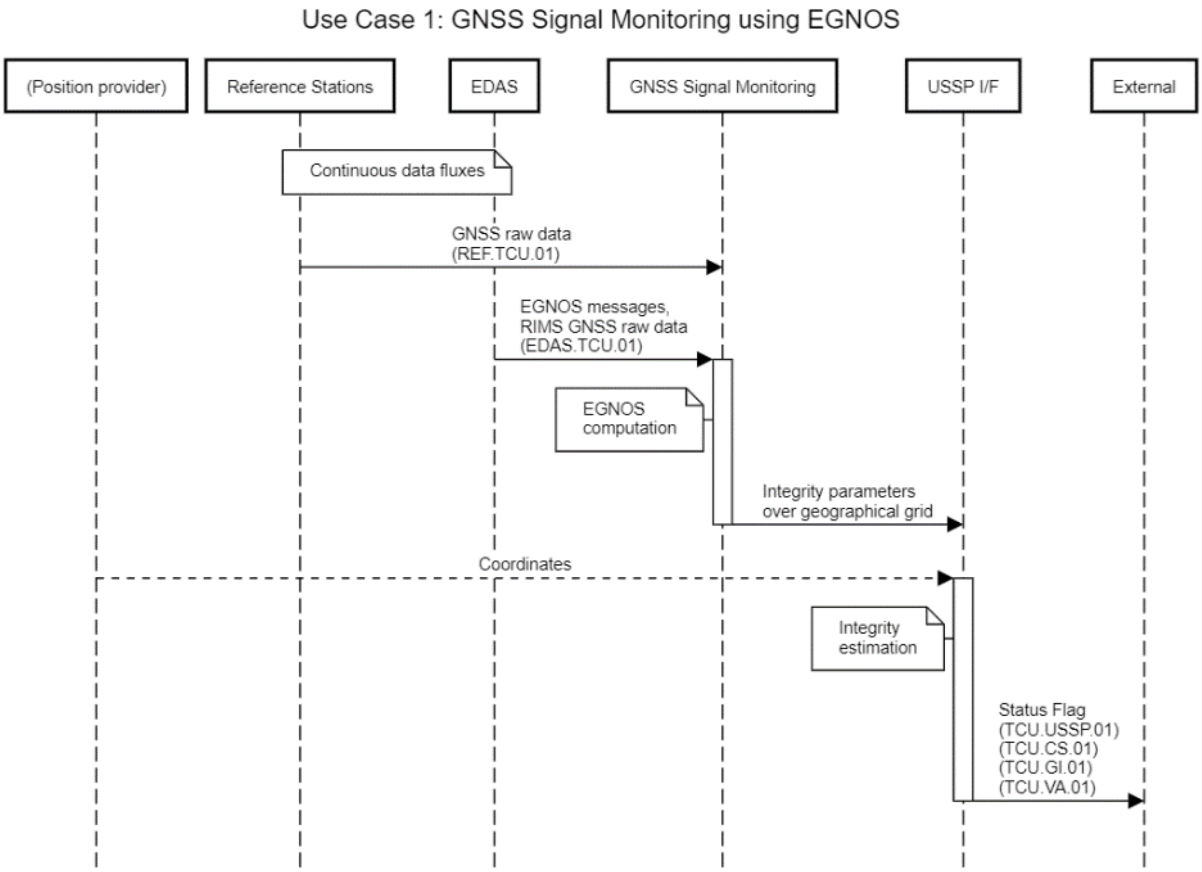

Figure 4-4: Use case 1 sequence diagram

4.4.2 Use case 2: GNSS signal monitoring based on ARAIM

This use case demonstrates the ability of the GNSS subsystem to correctly treat stored ARAIM-related data (ISM message) and GNSS raw data to evaluate the GNSS signal performance. The sequence diagram is given in Figure 4-5. The steps are as follows:

1. Reception and decoding of raw GNSS data from the reference station network;
2. Processing of the retrieved data to identify and discard possible faulty satellites and to compute the integrity parameters (i.e. Horizontal/Vertical Protection Levels) over a regional grid;
3. Estimation of the integrity parameters corresponding to a given coordinate pair (according to a distance criterion from the nearest grid point computed), with a result according to Table 4-2.

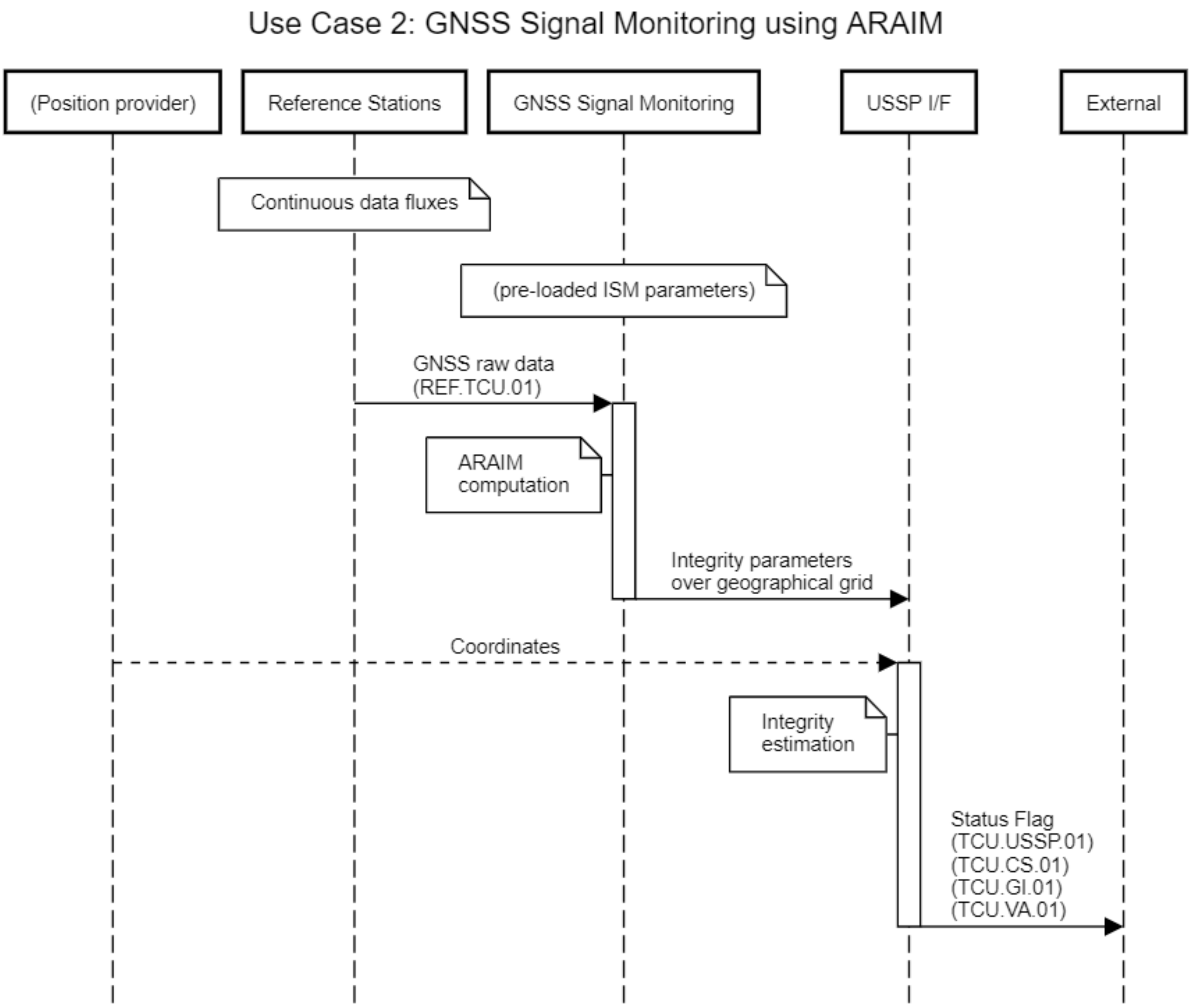

Figure 4-5: Use case 2 sequence diagram

4.4.3 Use case 3: GNSS positioning and integrity based on EGNOS

This use case demonstrates the ability of the GNSS subsystem to correctly treat EGNOS messages and GNSS raw data from a UAS to compute its position and its integrity parameters. This use case incorporates the one described in paragraph 4.4.1 The sequence diagram is given in Figure 4-6. The steps in addition and in parallel to what is described in 4.4.1 are as follows:

1. Reception and decoding of the EDAS data stream, retrieving the EGNOS SBAS messages;
2. Reception and decoding of raw GNSS data from the tracked UAS;
3. Processing of the retrieved data to compute the UAS PVT and related integrity parameters (i.e. Horizontal/Vertical Protection Levels).

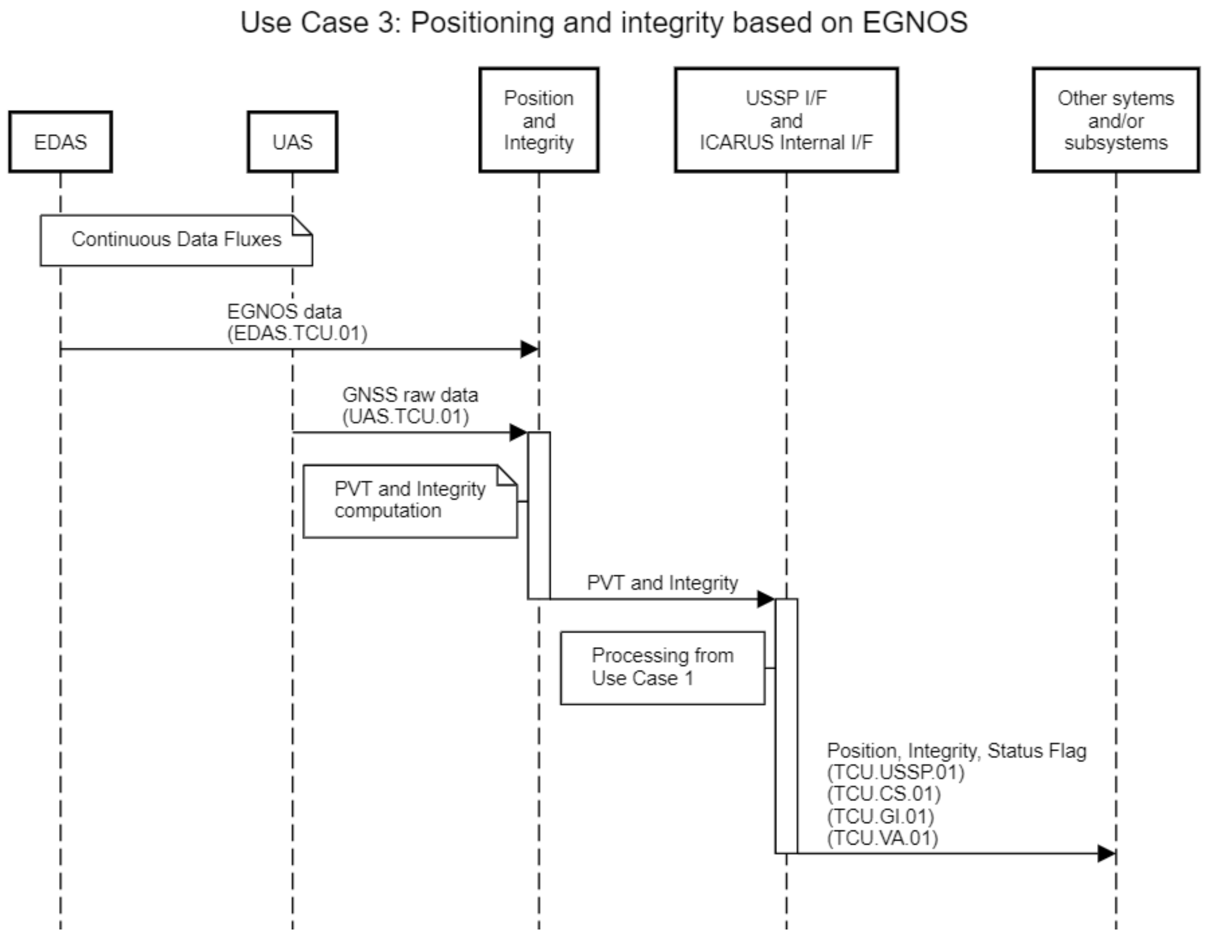

Figure 4-6: Use case 3 sequence diagram

4.4.4 Use case 4: GNSS positioning and integrity based on ARAIM

This use case demonstrates the ability of the GNSS subsystem to correctly treat GNSS raw data from a UAS to compute its position and its integrity parameters using the ARAIM algorithm. This use case incorporates the one described in paragraph 4.4.2 The sequence diagram is given in Figure 4-6. The steps in addition and in parallel to what is described in 4.4.2 are as follows:

1. Reception and decoding of raw GNSS data from the tracked UAS;
2. Processing of the retrieved data to compute the UAS PVT and related integrity parameters (i.e. Horizontal/Vertical Protection Levels).

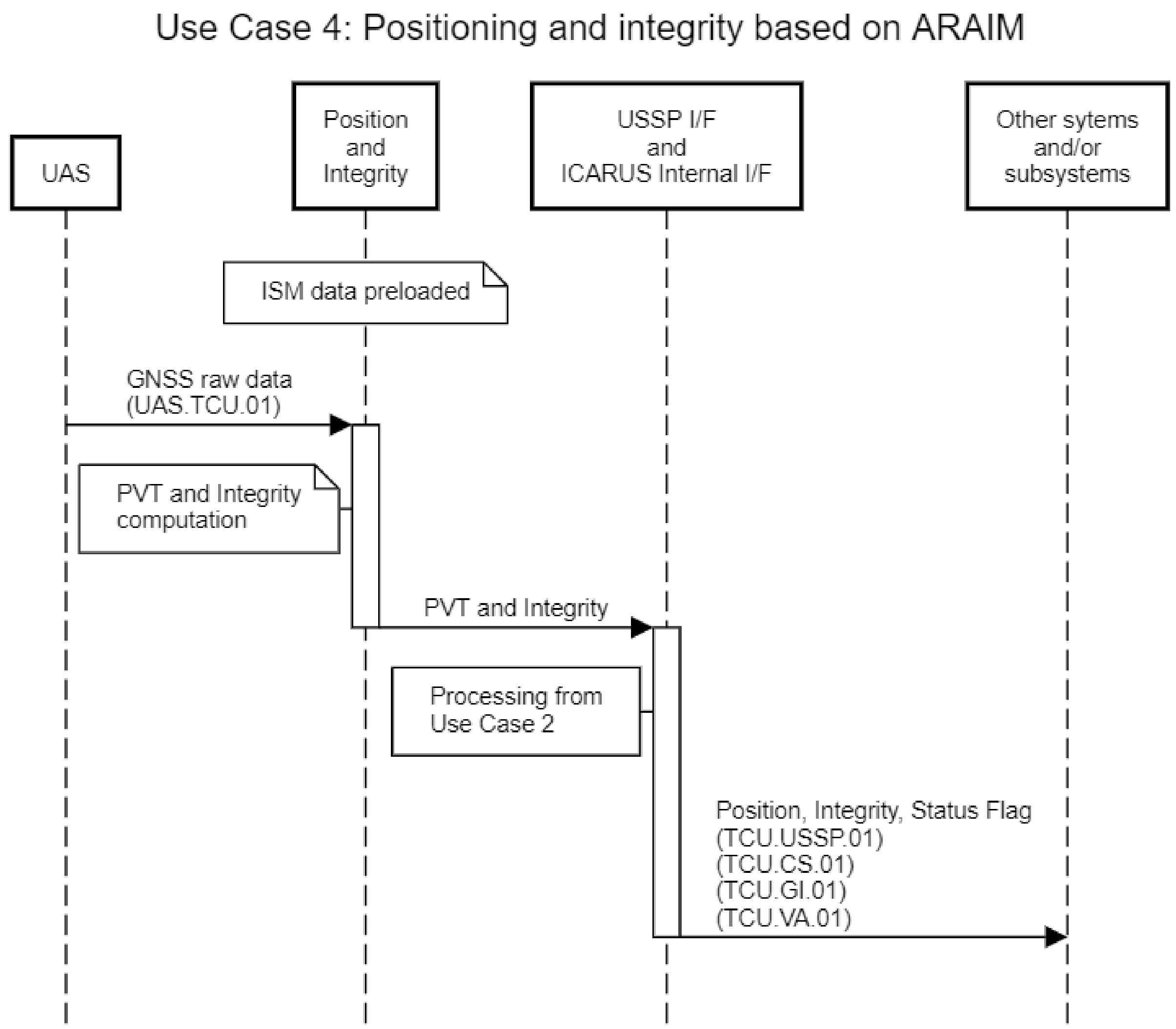

Figure 4-7: Use case 4 sequence diagram

4.4.5 Use case 5: configuration of the processing chain by an administrator

This use case represents the possibility for an administrator to set some specific processing options or configurations:

1. The administrator logs on to the maintenance interface through an ssh connection (ADM.MAN.01).
2. The administrator configures one of the following subsystem components by properly editing the configuration files:
    a. Reference station interface: NTRIP client configuration (selection of stations and connection parameters).
    b. EDAS interface: connection parameters (URL and port used).
    c. GNSS signal monitoring: algorithm implemented (ARAIM or EGNOS), observables used.

d. Position and integrity: algorithm implemented (ARAIM or EGNOS), observables used.
e. Output interfaces: MQTT broker features (address, port, topics).

After the maintenance/reconfiguration activity is completed, the administrator disconnects from the module of interest and from the control logic interface.

5 Vertical Conversion Service architecture and data flows

5.1 Requirements of the VCS

The VCS has the job of:

- providing drone altitude and height with respect to the surface, so that the drone operator can see the current distance from the surface in both barometric and geometric reference systems;
- converting drone altitude into barometric altitude to be sent to manned aviation;
- converting manned barometric altitude to geometric to be supplied when they enter a GAMZ

The essential part of the solution being developed is the definition and test implementation of the services identified by ICARUS as being necessary for ensuringe the functionality of the Common Altitude Reference System (CARS). For this reason, an important role is played by the APIs, which are methods of connecting to the system (online, pub-sub, offline), as well as the specifications of the protocols themselves, that contain basic information about the data exchanged. It is also particularly important at the system definition stage to focus on data models first, and then design them so that there is some flexibility in their implementation, assuming that U-space regulation in EU will be performance-based (i.e. technology-agnostic).

The Vertical Conversion Service will satisfy the subset of high-level requirements identified in §10 of the document [8], as summarised in the table below:

ReqID	ReqTitle	ReqText	Type	Verification Method
ICARUS-D31-0010	CARS options	According to the following options for a Common Altitude Reference System for Manned aircraft and drones at VLL: - Option 1: barometric measurements for all operations at VLL, no U-space services; - Option 2: GNSS measurements for all operations at VLL, no U-space services; - Option 3: Mixed approach; each airspace user will use their approved altimetry system, U-space services will be used for translation; ICARUS will provide option 3 (mixed approach)	General	RoD
ICARUS-D31-0020	Vertical separations	The main cases of investigation for vertical separation in the ICARUS study will be: - UAS / UAS common vertical reference; - vertical UAS / ground obstacle information provided by U-space services; - vertical UAS / Manned aircraft reference, provided through an altitude translation service;	General	RoD

ICARUS-D31-0070	UAS-Ground Obstacles vertical Reference at VLL	Ground obstacles represented in a given DSM shall be reported and referenced by U-space Geospatial Information Service in the same datum used by UAS for Common Altitude Reference System (WGS-84) Remark Geodetic->Geometric transformations of buildings and obstacles might be needed to ensure the same reference for all airspace users at VLL	Functional	T
ICARUS-D31-0080	UAS-Manned Aircraft vertical Reference at VLL	UAS and manned aircraft must use the WGS-84 datum in Zu and Y volumes for common vertical reference.	Functional	A
ICARUS-D31-0090	AGL Height information in BVLOS	Above Ground Level (AGL) height information shall always be visible on a UAS pilot's Ground Control Station during BVLOS operations in the tactical phase Remark during planning, at least each waypoint shall report its AGL height	Operational	T
ICARUS-D31-0100	Altitude information in BVLOS	Geometric Altitude (above the WGS-84 ellipsoid) information shall be always visible on a pilot's Ground Control Station during BVLOS operations for Common Altitude Reference with other UAS	Operational	T
ICARUS-D31-0110	Geometric-Barometric conversion service	The U-space service for geometric altitude to barometric height conversion (and vice versa) shall be available in the strategic and tactical phases for airspace users of GAMZ	Functional	A
ICARUS-D31-0120	Geometric-Barometric conversion service measure units	The geometric altitude (Z axis according to the ECEF coordinate system) must be expressed in metres [m], while the QNH pressure value must be expressed in hectoPascals [hPa]. The offset between WGS-84 datum and QNH datum must be expressed in metres and hectoPascals	Functional	A
ICARUS-D31-0140	Geometric-Barometric conversion service to GA users	The translation service shall be able to provide GA pilots with the height of UAS (using their given WGS-84 datum) expressed in feet with respect to the current QNH datum in use	Functional	A
ICARUS-D31-0150	Geometric-Barometric conversion service update	The Geometric-barometric conversion service must calculate the dynamic offset among WGS-84 and local QNH datum at least every 30'	Functional	T
ICARUS-D31-0160	Geometric-Barometric conversion information	Pilots must be informed every time an altitude-height calculation by the geometric-barometric service is performed. The communication shall be made by means of effective communication on target devices (different colours, sounds, etc.)	Functional	A

ICARUS-D31-0300	Geometric-Barometric conversion service interface	The Geometric-Barometric altitude conversion service shall be interfaced with navigation (GNSS) performance monitoring stations (U-space service) and with barometric stations or service providers (ANSP or U-space service).	Functional	RoD

Table 5-1: Extract of ICARUS Requirements used for VCS subsystem design

NOTE: the verification methods listed are defined in section 3.1.

The following is a high-level list of interfaces taking data characteristics into account.

Data feeds (flows):

- QNH
    - QNH regions (basic, and contingency) – geography (geoJSON)
    - Local QNH (airports including CTR geometry)
    - Broadcast information about requests for switching between contingency and normal QNH
    - QNH and converted QNH value
- GNSS
    - Information about areas of GNSS degradation and their nature and duration
    - GNSS Integrity
- DTM/DSM
    - Ad-hoc queries for point elevation
    - Ad-hoc queries for aerial (polygon) geometry (MIN/MAX)
    - eTOD
- Online Tactical interface
    - For drones and manned aviation for height/altitude conversion
    - For drones and manned aviation concerning local obstacles
    - Telemetry / e-Identification / Asterix
    - ATM systems
- Confidentiality, Integrity, Availability (CIA)
    - Information about SLA degradation (understood as an entire service)

5.2 Functional architecture

The typical flow of information during the ICARUS height conversion service request is presented in Figure 5-1

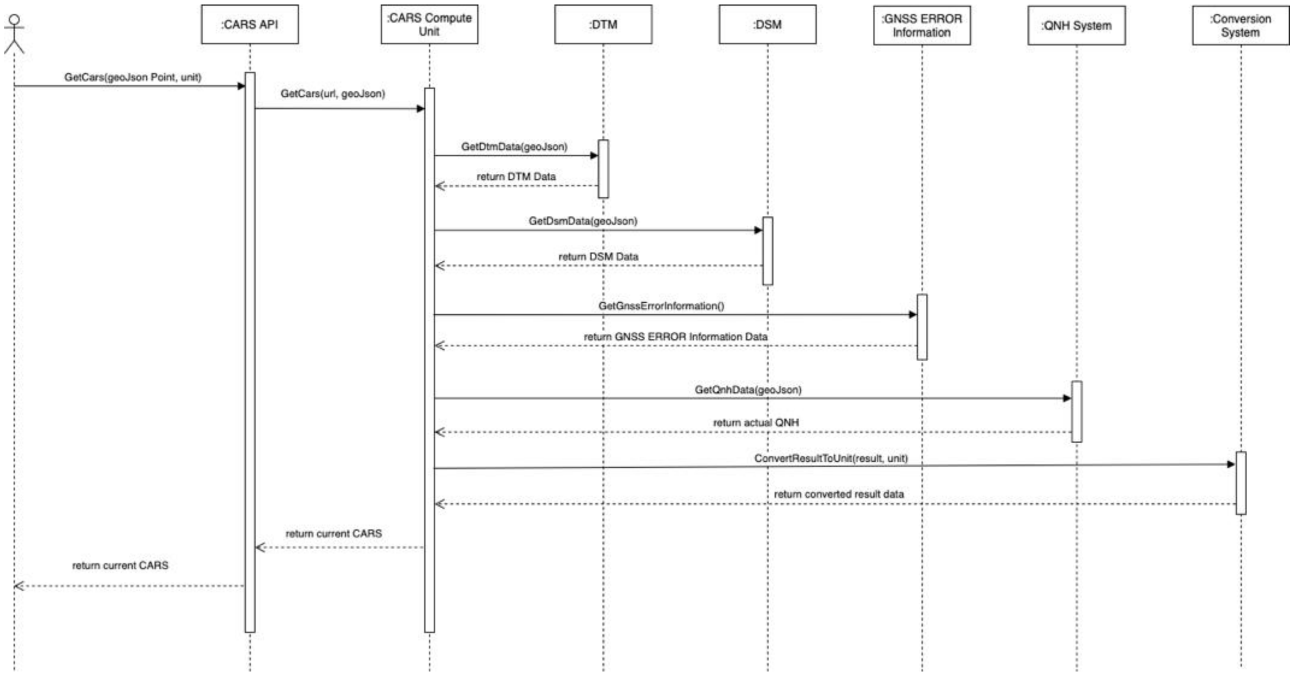

Figure 5-1 CARS VCS request flow

The request allows a given position/height measurement to be converted/adjusted to any other height measurement reference system. As an input, the geoJSON point, which contains input measurements in the given format, is provided with additional information (reference system, version of the GNSS module, etc.). Another parameter defines the target reference system of the converted result. Additional data such as information about the terrain/surface model, the system correction to be applied to GNSS results calculations, or the value of QNH might be required for the conversion calculation.

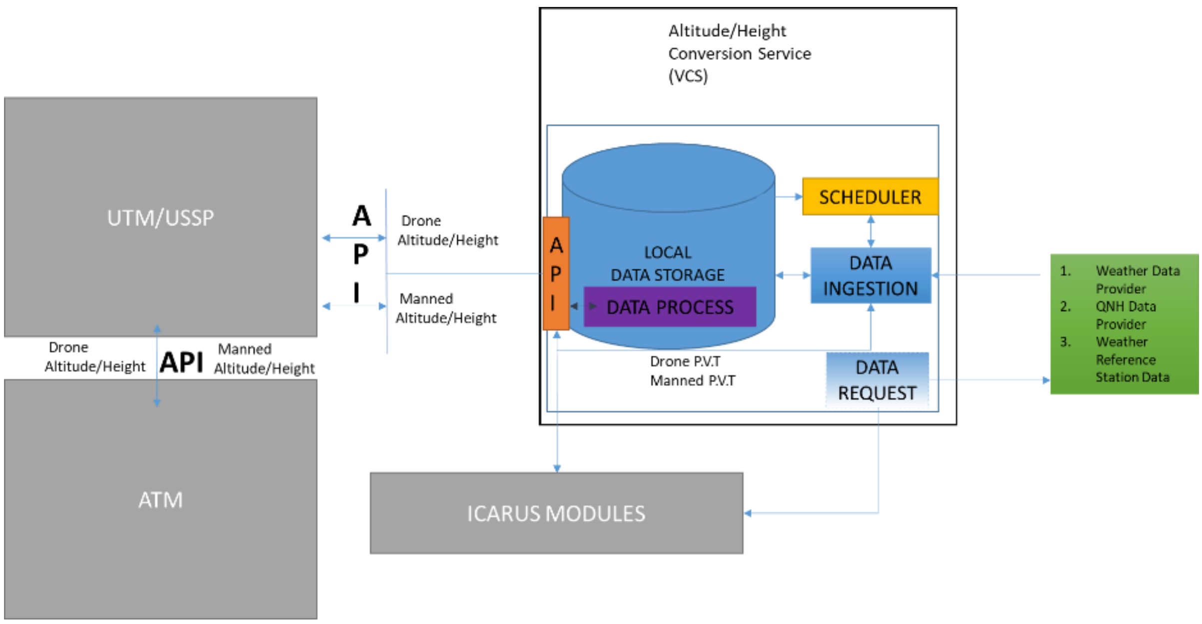

Figure 5-2: VCS Architecture

The VCS retrieves the drone position from the GNSS computing unit, which is connected to the other modules that compose ICARUS.

Once the drone position has been retrieved, the VCS needs the manned aircraft position given as input to the system by the USSP/ATM interface to fully provide its services.

All of these data are stored in the Real-Time Positioning database. In particular:

- Aircraft Positioning Manager – is responsible for acquiring aircrafts positions from external systems (Asterix, UTM), normalising height data to the common reference system and storing these normalised data in Real-Time Positioning database;
- Real-Time Positioning database (RTPD) – is a fast, non-relational database with geographic filter functions to hold actual trajectory data.

The algorithm needs weather data, in particular the QNH data, to complete the conversion. These types of data are requested from external providers by the Data Request module and provided as input to the computing unit (Data Process) that implements the conversion algorithm. The position data is then stored in the Real-Time Positioning database.

Once the altitude/height of both drone and manned aviation have been calculated, they are sent to the VALS to be distributed to the pilots/drone operators.

It must be underlined that each ICARUS instance must also support interfaces with external systems:

- Asterix – aircraft radar data provider
- UTM – UAV telemetry data provider
- GNSS systems providers
- QNH provider
- DTM/DSM providers
- Weather data provider

5.3 ATM Interface and ICARUS Service Provisioning

Obtaining data related to manned aircraft position and altitude requires integration with external systems. Nowadays there many options, because there are several third party providers of aircraft surveillance services available. Selecting the appropriate provider requires careful analysis beforehand. One of the key factors to be considered is data reliability. From this perspective, aircraft surveillance data service providers should be considered in the context of two main types:

1. Official (certified)
2. Unofficial (uncertified)

5.3.1 Official, certified data sources

From an historical point of view, traffic data collected by ANSPs mainly relate to manned traffic. They are based on official, certified standards and devices, such as Mode A, C, S, and ADS-B aviation transponders. It should be noted that official traffic information aggregation systems, both primary and secondary radars, although consistent and highly reliable, relate by definition to manned traffic (most often commercial and GA), so that the data collection is focused on the vicinity of controlled airports (CTR), TMA and controlled airspace above the transition layer. The Flight Information Service (FIS) also has access to radars, focused at slightly lower altitudes, but unfortunately, in most cases these radars do not provide information about traffic in the VLL space (below 150m).

From a technical perspective, ASTERIX [26] is the most common interface used by ANSPs. It must be noted that this standard is used internally by the ANSPs, and access to its endpoints is rarely shared with third parties.

Another example of air traffic information awareness is Aireon – a satellite-based system. It is a commercial network of ADS-B satellite-based transponders, which can provide real time, worldwide air traffic information for surveillance, tracking and situational awareness purposes. ASTERIX is also used as its integration interface.

Some official data, e.g. data using Mode-S transponders, may contain altitude referenced to the STD pressure, calibrated altitude, and GPS altitude.

5.3.2 Unofficial data sources (uncertified)

There is much more unofficial data about air traffic in the airspace. Usually cheap terrestrial receivers (DVB-T, ADS-B IN, OGN, FLARM, etc.) are used to collect and aggregate data, which makes them relatively easy to replicate and install. The tests carried out with an ADS-B OUT 1W transmitter indicate that it is enough to install about 10 receivers on the tallest buildings to ensure sufficient coverage "from the ground" in a city the size of Warsaw.

It should be remembered, however, that while official protocols such as manned transponders or ADS-B operate on legally protected frequencies, other popular standards operate on public frequencies. It should also be noted that broadcast items are relatively easy to counterfeit (spoofing).

However, the biggest problem in the context of the ICARUS project is the reference height system problem. Most transponders are calibrated in relation to the STANDARD pressure and show their altitude in relation to this pressure. ANSP radar systems with the awareness of regional and local QNH data can convert these values online to “Above Mean Sea Level” (AMSL). Although the aircraft continuously broadcasts its altitude, it may appear in the radar display as the corrected AMSL altitude, while another user does not know the current and official QNH pressure, may only read the altitude relative to the Standard pressure. Such a situation may result in a potential hazard and a collision.
In ICARUS, we need to consider an aggregation from each type of source with information about:

- the altitude reference system used. If the reference system is to be the take-off point, then knowledge of this point along with its known reference system should be used;
- resolution of height measurements and measurement error used or determined by the applied standard (calculations should consider the greatest potential error introduced by the measuring method applied)

From a technical point of view, we also need to consider the case where we receive information about the position of the aircraft in space from multiple sources with various altitude reference models. Worse yet, different data can arrive at different times and give different values. We can also receive information from reflected signals, so we should also create an algorithm for rejecting unreliable data as shown on Figure 5-3. This figure illustrates the case where no filtering algorithm was applied: some data arrived out of order, causing incorrect graphical interpretation.

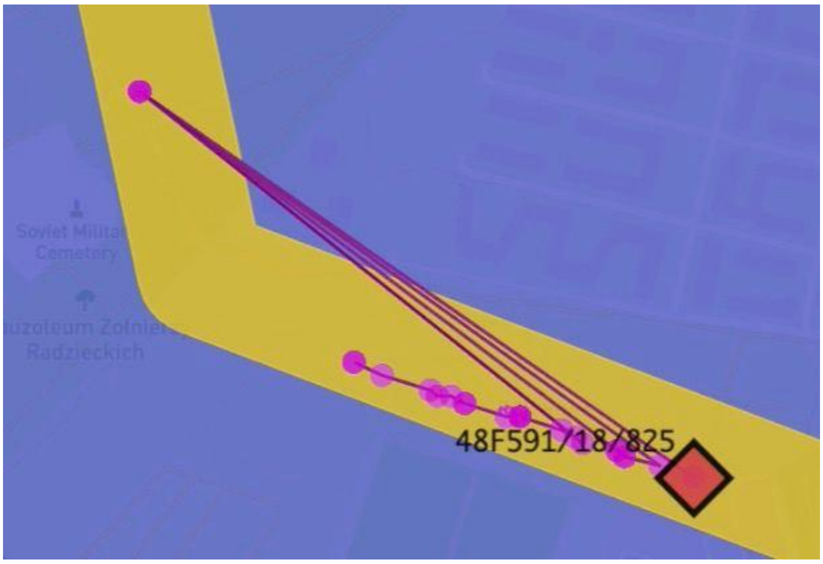

Figure 5-3 Aggregation problem of various data sources

Hence, it is necessary to standardise the method of aggregating information from various data sources and ensure that it is of sufficient efficiency.

The integration of unmanned traffic into the existing structures and systems used in manned aviation must be multidimensional, considering extreme cases. The entire process from the first step, must be performed in the way not to lower high level of safety. The ICARUS project therefore will try to address every aspect of linking to an existing system. However, it should be clearly emphasised that this process will be multi-stage and based on the tests and analyses carried out.

While today we can allow ourselves some freedom in creating standards and guidelines for unmanned aviation, changes to the systems used in manned aviation will require re-certification, and technical and procedural changes, as well as changes in operating procedures. This process, although not impossible, will take a long time, and decisions made about which direction to go in must be supported by reliable calculations, research and tests. With this in mind, we analysed the integration of manned and unmanned aviation in terms of systems that inform about mutual positions, warning about potential conflicts, and resolving conflicts. However, it should be clearly emphasised that the height parameter is one of many that should be taken into account. It is inseparable from situational awareness and should not be taken in isolation.

In-depth interdisciplinary analyses and recommendations are available in Annex I: "UAV and ACAS/TCAS inter-relation".

5.4 Conversion Service - Safety and Regulation

A summary of the ICARUS APIs, of the related U-Space services identified in previous chapters of this document, and their safety criticality is presented in the following table:

ICARUS API	U-Space service	Covered by			Safety Criticality	Notes
		CORUS	EASA Opinion 01/2020	ISO 23629-12		

GNSS	EMS	YES	NO	YES	Safety-related	Not covered by the EASA Opinion since safety-related and hence not subject to certification by the authority (i.e. risk-based regulation)
GI	GIS	YES	NO	YES	Safety-related	As above
	RGIS	**NO**	**NO**	**NO**	Safety-critical	**NEW service**
	GAW	YES	YES	YES	Safety-critical	Subject to certification by aviation authority according to EASA Opinion 01/2020
VCS	VCS	**NO**	**NO**	**NO**	Safety-related or critical	**NEW service**
VALS	VALS	**NO**	**NO**	**NO**	Safety-critical	**NEW service**

EMS, GIS and GAW are services already known by EASA, by the aviation authorities and by Standard Development Organisations (SDOs). Since they do not present peculiar aspects related to the proposed ICARUS architecture, their safety and regulatory compliance does not need to be analysed.

Paragraph 2.5.2 of vol. II of the CORUS CONOPS, having stated the need for a Common Altitude Reference System (CARS), envisaged that U-space might offer services to convert between different altitude systems (i.e. geodetic to barometric and vice-versa). This Vertical Conversion Service (VCS) is however not described in the CORUS CONOPS.

In the ICARUS architecture, VCS is complemented by RGIS (Real -time information on geometric vertical distance from obstacles) and VALS (Vertical Alert).

Furthermore, ICARUS D3.1 proposes the concept of “Geometric Altitude Mandatory Zones” (GAMZ), for which a few “gaps” to be filled are identified, since a common technical solutions are necessary for manned and unmanned aviation to ensure mutual Vertical Alert at VLL. At least in certain scenarios a simple ATM/UTM interface, invoking the barometric – geodetic Vertical Conversion Service (VCS) can be defined for reporting manned traffic position and height information to remote UAS pilots. Conversely, it is necessary to provide VCS to manned aircraft in a GAMZ in airspace type Zu (over urban areas) with information on their geodetic altitude.

6 Vertical Alert & Information service architecture and data flows

6.1 Requirements of the VALS

The Vertical Alert micro-service has specific functions:

1) alerting drones about their current vertical distance from the ground;
2) warning pilots of manned aircraft flying in VLL airspace about the presence of new "Geometric Altitude Mandatory Zones" (GAMZ) where it will be mandatory to set the altimeter in accordance with a geometric reference system (WGS 84-Ellipsoid Datum);
3) informing pilots of manned aircraft when entering a GAMZ

The Vertical Conversion Service will satisfy the subset of high-level requirements, identified in §10 of the document [8], as summarised in the table below:

ReqID	ReqTitle	ReqText	Type	Verification Method
ICARUS-D31-0010	CARS options	According to the following options for a Common Altitude Reference System for Manned aircraft and drones at VLL: - Option 1: barometric measurements for all operations at VLL, no U-space services; - Option 2: GNSS measurements for all operations at VLL, no U-space services; - Option 3: Mixed approach; each airspace user will use their approved altimetry system, U-space services will be used for translation; ICARUS will provide option 3 (mixed approach)	General	RoD
ICARUS-D31-0020	Vertical separations	The main cases of investigation for vertical separation in the ICARUS study will be: - UAS / UAS common vertical reference; - vertical UAS / ground obstacle information provided by U-space services; - vertical UAS / Manned aircraft reference, provided through an altitude translation service;	General	RoD
ICARUS-D31-0160	Geometric-Barometric conversion information	Pilots must be informed every time an altitude-height calculation by the geometric-barometric service is performed. The communication shall be made by means of effective communication on target devices (different colours, sounds, etc.)	Functional	A
ICARUS-D31-0170	Geometric-Barometric conversion service alert	The Geometric-barometric altitude service must warn users in less than 6 seconds in case of malfunction	Functional	T

Table 6-1: Extract of ICARUS Requirements used for VALS subsystem design

NOTE: the verification methods listed are defined in section 3.1.

6.2 Functional Architecture

Different service scenarios can be implemented with the Vertical Alert & Information service architecture. A few representative examples are described below.

The most common, basic service is the ground approach alert service. The main purpose of this service is to recognise aircraft whose height above the terrain surface or an obstacle is below a given safety margin. The service is executed in continuous loop in which the dedicated module (Safe Distance Compute) detects whether any of observed aircraft heights fall below the defined threshold value or whether their course may result in terrain or obstacle collision. In this case the respective alert is raised and sent to Alert system which notifies and publishes the appropriate alerts. The flow for this scenario is presented in Figure 6-1.

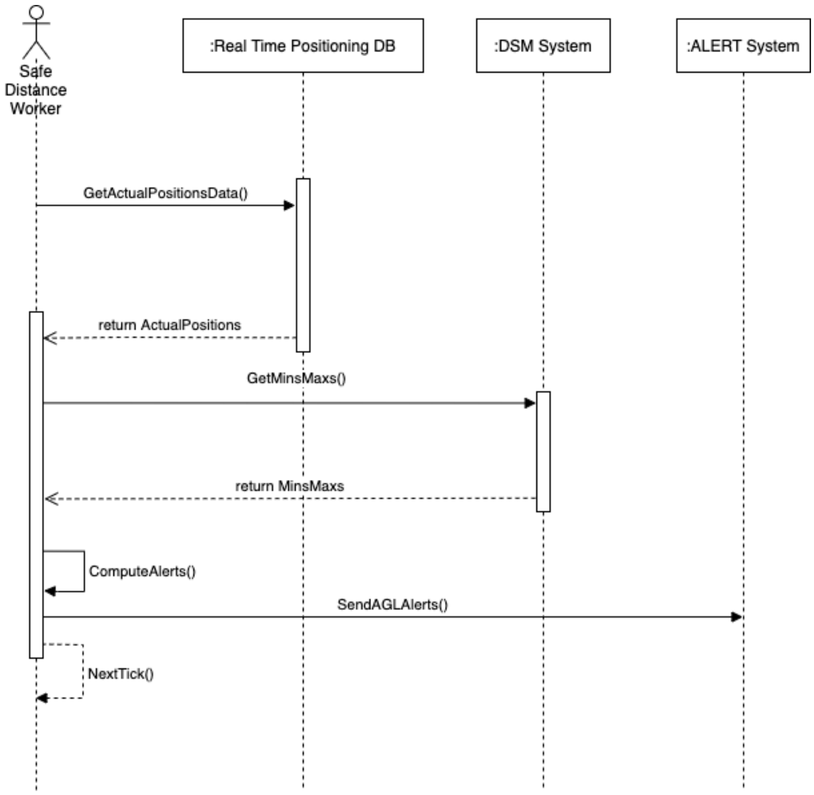

Figure 6-1 VALS service alert

Another example of a distance alert might be the service for low-distance alert between different aircraft. In this service, all the aircraft monitored in the Real-Time Positioning database are verified to ensure that the safety distance between them is preserved. If such a defined safe distance is breached, the appropriate alert is raised (SendDistanceAlert). An example flow for such a service is presented in Figure 6-2

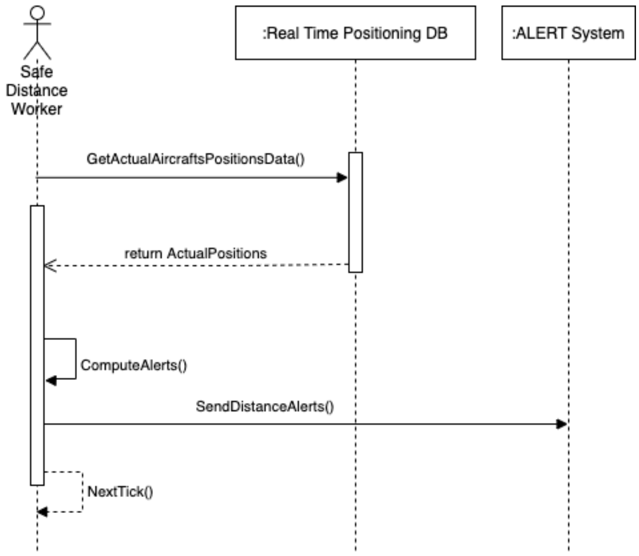

Figure 6-2 Safe distance alert service information flow

A very similar service to that described above is one that raises an alert when an aircraft approaches the boundary of GAMZ (GAW warning service). The flow for this service is presented in Figure 6-3.

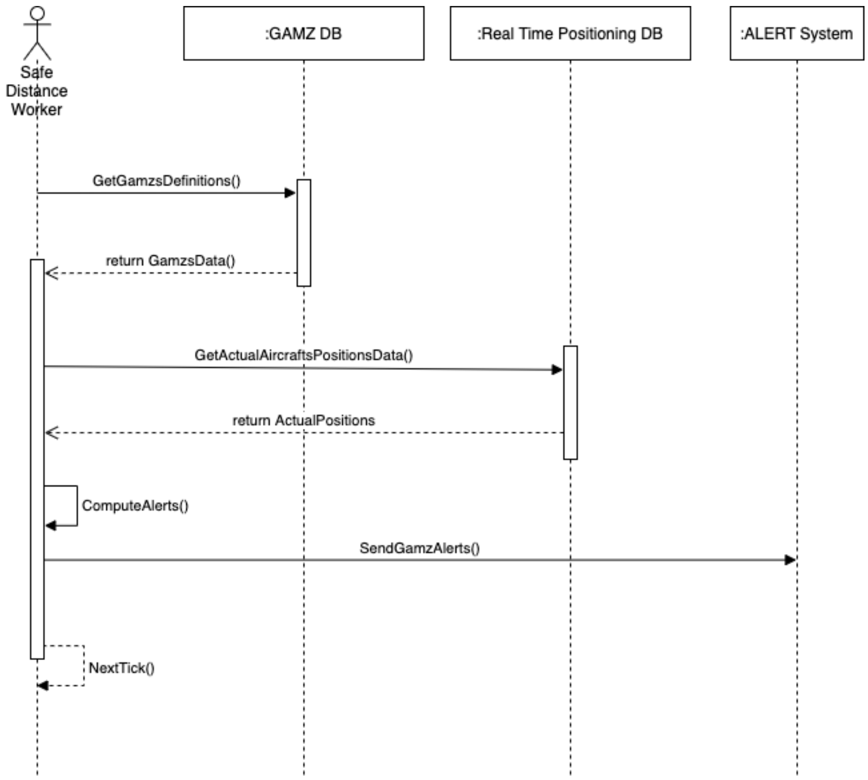

Figure 6-3 GAW service alert information flow

In this case alert is raised when any of the aircraft approaches the predefined GAMZ (defined in the GAMZ database).

So generally, the Vertical Alert and Information module will use the drone position calculated by the GNSS computing unit, the drone height/altitude calculated by the VCS, the GA aircraft position/altitude from ATM (through the interface with the USSP), and the manned aircraft height calculated by the VCS.

Moreover, the GAMZ map will be retrieved from the GI micro service.

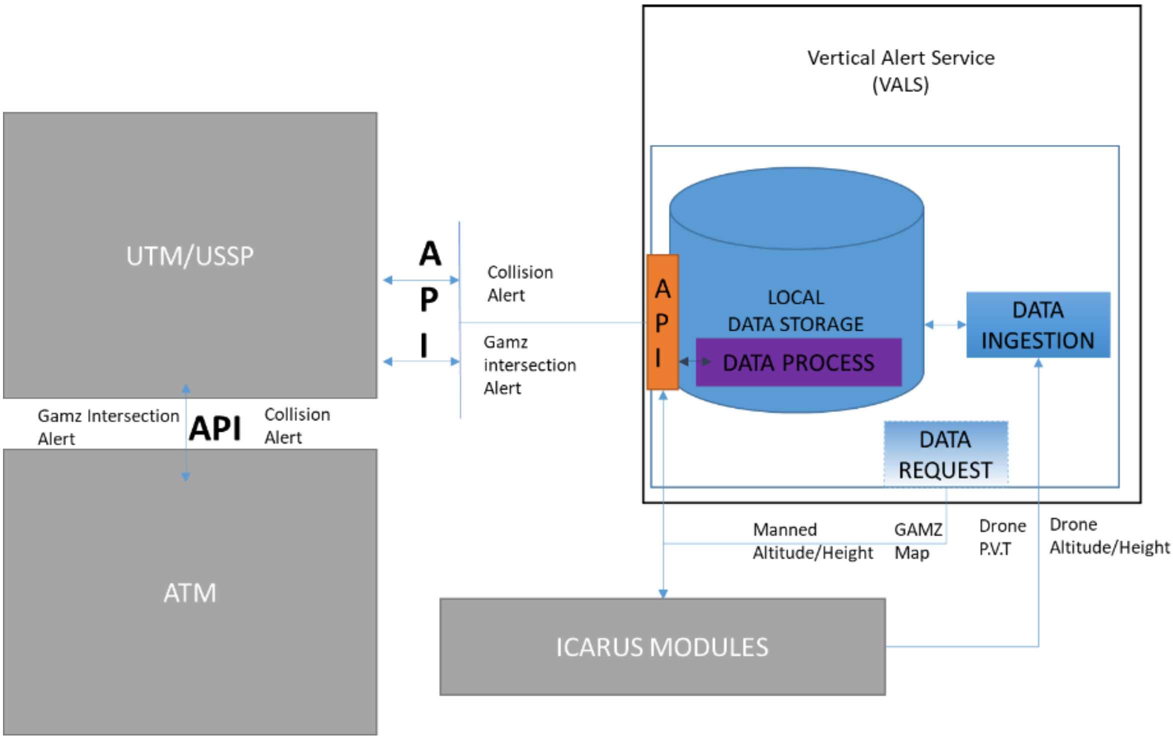

Figure 6-4: VALS Architecture

All of these data are retrieved from the Real-Time Positioning database by the Data Request Module and then sent to the VALS computing unit for the computation.

In particular:

- Safe Distance Compute - is the component for safe distance calculations using data from RTPD for aircraft distance to the ground, other aircraft, GAMZ (used by RGIS, GAW, VALS services); when safety buffers are exceeded an alert is published onto the inner data bus;
- Alert System – is the component that catches alerts from the Safe Distance Compute module and notifies affected subscribers (outside CARS) (used by VALS, RGIS and GAW services);
- Local Cache database – is a persistent relational database that keeps regional (CARS area of responsibility and some overlap) DSM, DTM and GAMZ data; refreshed monthly from official U-Space CIS.

All of this information is collected to generate the alert/warning to be provided to drone operators and manned aviation.

Drones positions and altitudes in a specific sector can be shared with GA pilots after being defined by ICARUS micro-services.

The proposed communication mechanism for receiving the information provided by the service is VHF. On the airborne side, a simple and cheap electronic device (similar to FLARM) can be used forquick information retrieval by the pilot (i.e. Vertical Alert service).

7 Applicable and reference documents

[1] Article 3(30) of EU Regulation 2018/1139 defines 'unmanned aircraft' any aircraft operating or designed to operate autonomously or to be piloted remotely without a pilot on board. Therefore, if the pilot is on-board, the aircraft becomes "manned". The manned or unmanned nature of the aircraft is not affected by the possible presence of passengers on board.

[2] Commission Implementing Regulation (EU) No 923/2012 of 26 September 2012 laying down the common rules of the air and operational provisions regarding services and procedures in air navigation and amending Implementing Regulation (EU) No 1035/2011 and Regulations (EC) No 1265/2007, (EC) No 1794/2006, (EC) No 730/2006, (EC) No 1033/2006 and (EU) No 255/2010, as lastly amended by Regulation (EU) 2017/835.

[3] According to Article 2(26) of Regulation (EC) No 549/2004 of the European Parliament and of the Council of 10 March 2004 laying down the framework for the creation of the single European sky (the framework Regulation), as lastly amended by Regulation (EU) 1070/2009, 'general air traffic' means all movements of civil aircraft, as well as all movements of State aircraft (including military, customs and police aircraft) when these movements are carried out inconformity with the procedures of the ICAO.

[4] Article 2(26) of Commission Implementing Regulation 2019/947, as lastly amended by Regulation 2020/746, states that: 'Command Unit' ('CU') means the equipment or system of equipment to control unmanned aircraft remotely as defined in point 32 of Article 3 of Regulation (EU) 2018/1139 which supports the control or the monitoring of the unmanned aircraft during any phase of flight, with the exception of any infrastructure supporting the command and control (C2) link service.

[5] ISO TC/20 SC/16 Committee Draft CD 23629-12

[6] CORUS Concept of Operations (CONOPS) Enhanced Overview, Edition 01.01.03 of 04 Sept 2019.

[7] EASA Opinion 01/2020

[8] ICARUS D3.1, " ICARUS Concept Definition: State-Of-The-Art, Requirements, Gap Analysis"

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[20] Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft, as lastly amended by Commission Implementing Regulation (EU) 2020/746 of 4 June 2020.

[21] EASA, EUROCONTROL, Discussion Document on UAS ATM Flight Rules. Edition: 1.1 of 27 November 2018.

[22] Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems, as lastly amended by Commission Delegated Regulation (EU) 2020/1058 of 27 April 2020.

[23] http://geonumerics.es/index.php/projects/88-reality-rpas-egnos-adoption-and-liaison-with-navigation-integrity

[24] EASA Terms of Reference for Rulemaking Task RMT.0230, Regulatory framework to accommodate unmanned aircraft systems in the European aviation system, issue 2 of 04 June 2018.

[25] EASA, Concept Paper RMT.0230, Concept for regulation of UAS ‘certified’ category operations of Unmanned Aircraft Systems (UAS), the certification of UAS to be operated in the ‘specific’ category and for the Urban Air Mobility operations, Issue 2.2 FINAL of June 2020.