"5G for Drone-based Vertical Applications"

D3.2 – Report on vertical service-level enablers of 5G!Drones

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Executive summary

5G!Drones derives from the need to support and validate Unmanned Aerial Vehicles (UAV) use cases by running trials on top of 5G systems, leveraging ICT-17 5G facilities, and modern test methodologies and advancements. 5G!Drones project is driven by the four selected UAV vertical use cases, which cover the three 5G service classes (i.e., eMBB, uRLLC, mMTC). These use cases are:

- UAV Traffic Management that will demonstrate a common functionality for all UAV applications, namely UTM (UAS Traffic Management), which is expected to manage drone traffic in the lower altitudes of the airspace, providing a complete and comprehensive end-to-end service to accumulate real-time information of airspace traffic, drone registration, weather, and credentials of drone operators, among others. It includes two scenarios: UAV command and control application; 3D mapping and supporting visualisation/analysis software for UTM.
- Public safety/saving lives with it two scenarios: Monitoring a wildfire; Disaster recovery, will demonstrate the usage of UAVs to take high-resolution images and perform 3D mapping in large-scale disasters such as earthquakes, flooding and wildfires to identify hotspot areas that have sustained the most damage and upload the data in real-time to coordinate relief efforts.
- Situation awareness shows the role of UAVs in providing or supporting IoT services from the high ground. Drones equipped with IoT devices allow for offering new types of services that can be delivered only from the high ground. UAVs equipped with IoT, and other monitoring devices can enhance situation awareness in various ways. For example, power distribution companies are required to regularly inspect their networks (powerlines), and these inspections are currently being carried out using helicopters hovering closely over the powerlines. This use case includes three scenarios: Infrastructure inspection, UAV-enhanced IoT data collection, Location of UE in non-GPS environments.
- Connectivity during crowded events with its main scenario: connectivity extension and offloading, will show the usage of a swarm of UAVs equipped with 5G small cells to extend connectivity and provide a better coverage resulting in fewer dropped calls and better Internet connectivity to people attending the events.

To achieve and support the objectives aimed behind these use cases, Task 3.4 of the 5G!Drones project aims to enhance the existing UAV software or develop new software, called UAV enablers. This pertains both to onboard units and to software to be run remotely (e.g., virtual instances on edge or remote clouds) and includes both control functionality and application-level one. Also, in another line of activities, the necessary software and hardware components for the integration of 5G technology on UAVs will be provided (e.g., installation and integration of UE onboard equipment).

This deliverable provides a detailed description of the UAV enablers developed by the consortium to support and implement the considered scenarios and use cases of the 5G!Drones project. It first recalls the description and details of the four use cases and their corresponding scenarios. Then, for each use case, the list of supporting UAV enablers developed by the consortium.

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List of abbreviations

4G	4^{th} Generation cellular technology
5G	5^{th} Generation cellular technology
ACE	Autonomous Control End node
ADS-B	Automatic Dependant Surveillance - Broadcast
AI	Artificial Intelligence
AIM	Aeronautical Information Management
AIP	Aeronautical Information Publication
AMQP	Advanced Message Queuing Protocol
API	Application Programming Interface
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
BVLOS	Beyond Visual Line Of Sight
C2	Command and Control
CAAC	Civil Aviation Administration of China
CNN	Convolutional Neural Networks
CQI	Channel Quality Indicator
C-UAS	Counter-Unmanned Aircraft Systems
CUP	CAFA Tech UgCS-based Platform
D2D	Device-to-Device
DDPG	Deep Deterministic Policy Gradient
dFPL	drone Flight Plan
DJI	Da-Jiang Innovations
DLN	Drone Logistics Network
eMBB	enhanced Mobile Broadband
FAA	Federal Aviation Administration
FLARM	Electronic system used to selectively alert pilots to potential collisions
F-MEC	Flying Multi-access Edge Computing
FPV	First Person View
GCS	Ground Control Station
GIS	Geographic Information System
gNB	Next Generation Node B
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPU	Graphics Processing Unit
HAT	Hardware Attached on Top
HD	High Definition
HTTP	Hypertext Transfer Protocol
I2C	Inter-Integrated Circuit
ICAO	International Civil Aviation Organization
ICT	Information and Communications Technology
IMU	Inertial Measurement Unit
IoT	Internet of Things

IoTaaS	Internet of Things as a Service
IP	Internet Protocol
IR	InfraRed
KPI	Key Performance Indicator
LAS	LASer
LED	Light Emitting Diode
LiDAR	Light Detection and Ranging
LiPo	Lithium Polymer
LTE	Long Term Evolution
MEC	Multi-access Edge Computing
MLAT	Multilateration
mMTC	massive Machine-Type Communication
Mode-A/C	Transponder messages augmented with altitude information
Mode-S	Selective radar operation – interrogations and replies
MQTT	Message Queuing Telemetry Transport
MTOW	Maximum Take-Off Weight
NFZ	No-Fly Zone
NOTAM	NOtice To AirMen
OBC	On-Board Computer
P2P	Peer-to-Peer
PANSA	Polish Air Navigation Services Agency
PC	Personal Computer
PCD	Point Cloud Data
PDAL	Point Data Abstraction Library
PHR	Power Headroom
PiD	Person in Distress
PoC	Proof of Concept
QoS	Quality of Service
RC	Radio Command
REST	Representational State Transfer
RGB	Red-Green-Blue
RNIS	Radio Network Information Service
ROS	Robot Operating System
RSRP	Reference Signal Receive Power
RSRQ	Reference Signal Receive Quality
RTH	Return To Home flight mode
RTMP	Real-Time Messaging Protocol
RTSP	Real-Time Streaming Protocol
RTT	Round-Trip Time
SAR	Search And Rescue
SESAR-JU	Single European Sky ATM Research Joint Undertaking
SIM	Subscriber Identity Module
SoC	System on Chip
SORA	Specific Operations Risk Assessment

SPI	Special Peripheral Interface
TDoA	Time Difference of Arrival
ToA	Time of Arrival
TWR	Two Way Ranging
UART	Universal Asynchronous Receiver Transmitter
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UDP	User Datagram Protocol
UE	User Equipment
UgCS	Universal ground Control Station
UI	User Interface
UL-ACE	Unmanned Life--Autonomous Control End Node
UL-CCP	Unmanned Life-Central Command Platform
UL-VA	Unmanned Life-Video Analytics
UL-WEB	Unmanned Life-Web
uRLLC	Ultra-Reliable and Low-Latency Communication
USB	Universal Serial Bus
USSP	Operation Plan Processing System
UTM	UAS Traffic management
UWB	Ultra-wideband
VIP	Very Important Person
VLOS	Visual Line Of Sight
VNF	Virtual Network Function
WMS	Warehouse Management System
WUI	Web User Interface
YOLO	You Only Look Once

1. INTRODUCTION

1.1. Objective of the document

The 5G!Drones project objectives are to trial and test UAV use cases using 5G infrastructure. The 5G!Drones project identified four main UAV use cases to trial and test: (1) UAV Traffic Management; (2) Public safety/saving lives; (3) Situation awareness; (4) Connectivity during crowded events. To run these use cases, software and hardware adaptations are needed at the UAV side. This adaptation and add-on functions constitute a set of enablers named UAV enablers.

This deliverable aims to give a detailed description of UAV enablers developed in Task 3.4 of the 5G!Drones project. Notably, a set of UAV enablers have been specified and developed to support the four use cases of the project. For each use case, the deliverable recalls its description and considered scenarios and provides a detailed description and functions provided by the UAV enablers supporting it.

1.2. Structure of the document

The deliverable is organised per use case. Section 2 is dedicated to the UAV Traffic Management use case, where a description of the use case and its related scenario is provided first. Then, the list of UAV enablers supporting the use case is presented. For each enabler, a description, as well as features and functions, are provided. Section 3, Section 4, Section 5 are dedicated to public safety/saving lives, Situation awareness, and Connectivity during crowded events, respectively. These sections follow the same structure as Section 2. Finally, a conclusion is provided in Section 6.

1.3. Target audience

This project consortium deliverable is mainly addressed to the general public for obtaining a better understanding of the framework and scope of the 5G!Drones project, and particularly the role of the UAV enablers to support the project's use cases. It shows the list of UAV enablers developed by the project to run the trials. Furthermore, this deliverable targets the two communities in the scope of the project, namely 5G (5G PPP and beyond) and UAV.

2. USE CASE 1: UAV TRAFFIC MANAGEMENT

2.1. Description and list of scenarios

UC1 is focused on ensuring the near real-time (under 1 second latency) Command and Control (C2) and telemetry communication for the drone – to control it with high level of accuracy and precision in space and time. The UAV control is performed by a Ground Control Station (GCS) and supervising pilot, but some of the information must be passed further to the U-space for monitoring and allowing a global picture of the airspace. U-space also can send at any time new warnings or requests based on the actual situation in the airspace where the UAV flight is happening. This is valid today for the existing Radio Command (RC) systems, but only in the area limited by the range of the RC controller. We aim at continuous and reliable connectivity of the drone to the GCS through the cellular network. Thanks to the omnipresence of the cellular network and new features brought by 5G, it will be possible to perform BVLOS operations with the required level of confidence and safety in a much broader, virtually unlimited area.
Scenarios in UC1 include a demonstration of working Command and Control (C2) link over 5G and the small package delivery to end customer, i.e., medicines saving the life.

2.1.1. UC1:SC1 UTM Command & Control application

The main focus of UC1:SC1 tests is the services provided by U-space, Trial Controller, and Facility to the GCS deployed by UAV Operator in the EDGE server. The intent is to ensure that everything is under control before and during a mission. The plan is to simulate the problems which can occur, such as the unanticipated addition of a No-Fly Zone (NFZ), an incoming lousy weather alert or a connectivity problem. In case of such an event, the mission can continue, or be terminated, according to the defined rules. An essential requirement is that everything is happening in a controlled manner. It is planned to add the INVOLI LEMAN tracker, which will report independently of the onboard drone system its position, direction, altitude, and speed. This data stream is the additional safety backup, which is considered to be required in the real BVLOS operations in medical delivery missions. The INVOLI's K-1090 receiver connected either through 5G test network or 4G commercial network will deliver the actual airspace traffic to the U-Space service in the test area.
CAFA Tech conducts automatic drone flights using the UAV enablers below.

2.1.2. UC1:SC2 UAV logistics

The purpose of this scenario is to demonstrate how UAVs can provide logistics solutions, thanks to 5G network capabilities. The scenario is the delivery of a drug (paracetamol) to a sick person with a drone. A sick person who cannot go to a pharmacy can receive his/her medicine through a personal delivery by subscribing to a Drone Logistics Network (DLN). DLN bases on the CAFA Tech Field GIS system. The delivery is conducted by CAFA Tech drone, the drone built by CAFA Tech based on the Holybro PX4 Vision Kit. Video transmission and remote drone control take place over a 5G network. When the drone reaches its destination, there are inaccuracies with the Global Navigation Satellite System (GNSS) signals. Therefore, the drone logistics company (actually the CAFA Tech operator) takes over the drone's control. The operator uses the video stream from the drone camera and uses the gamepad to conduct drone's landing to the Delivery Box and releasing paracetamol using electrical hook mechanism. During the flight, the virtual Air Traffic Control (ATC) operator monitors the UTM system and CAFA Tech drone flight thanks to U-space integration via the CAFA Tech UgCS C2 system..

2.2. UAV enabler 1: UgCS C2 cloud native application enhanced by CAFA Tech

2.2.1. Description

This enabler is common for all scenarios where CAFA Tech participates as drone operator (UC1:SC1, UC1:SC3, UC2:SC1, UC2:SC3, UC3:SC1:sub-SC1, UC4:SC1).

CAFA Tech has developed the Docker image (Cloud-native application) of UgCS C2 system, which also contains Frequentis plugin to send real-time telemetry data to the Frequentis SmartSIS.

More details about UgCS are available in [1].

2.2.2. Features and functions

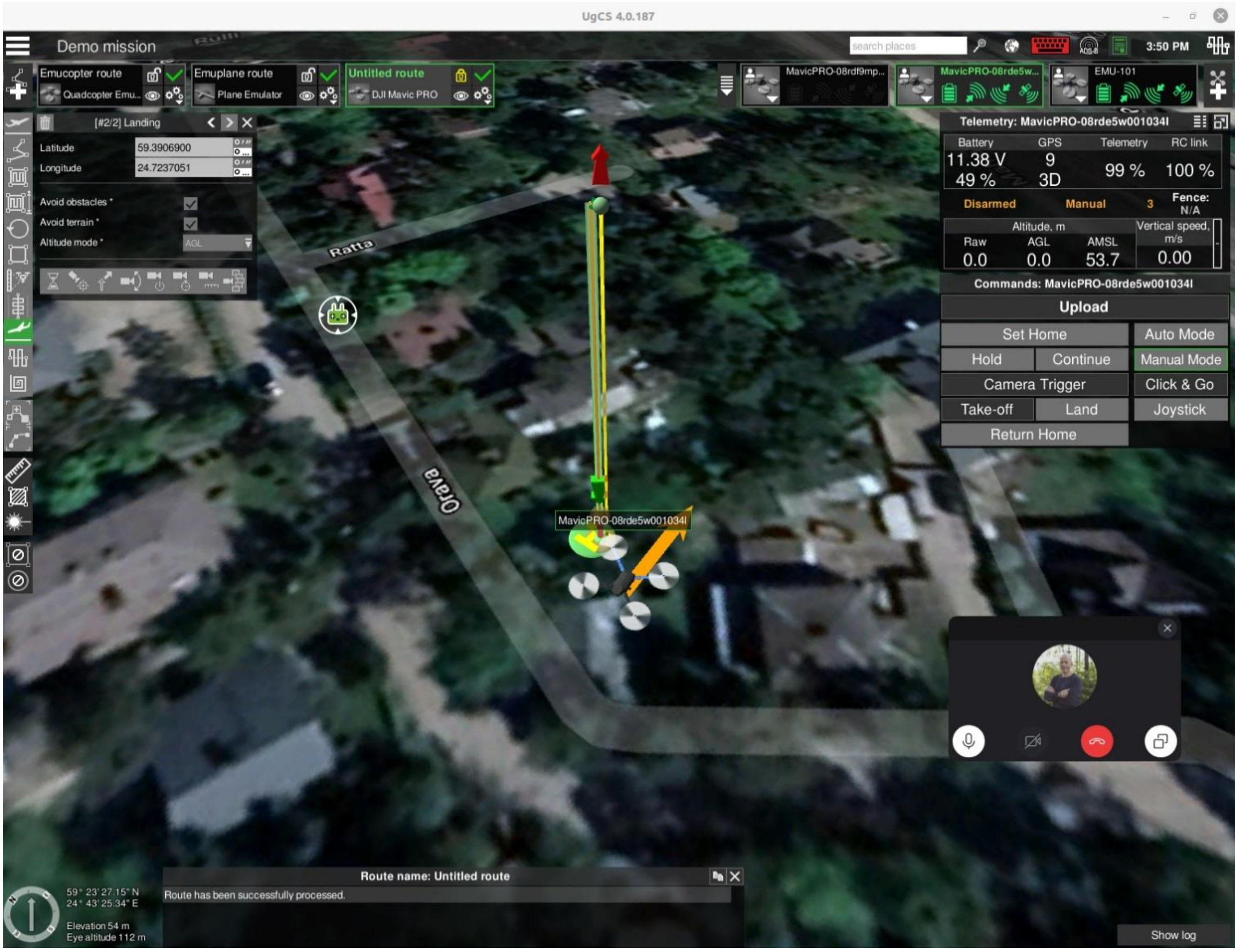

Figure 1. Screenshot of the graphical user interface of CAFA Tech UgCS C2 container

UgCS supports the most popular UAV platforms: DJI M600, M300, M200, Inspire, Phantom 4, Mavic and series, Parrot and MAVLink-compatible Pixhawk/APM drones. The telemetry data window in UgCS displays telemetry data, including the charge level of the battery, radio link and GPS signal quality, current course and heading, speed, altitude and more. UgCS enables multiple flight modes. The manual flight mode allows controlling the drone with the remote control. Once a flight plan is created and uploaded to the autopilot, the Automatic flight mode can be used. For many drones, UgCS also supports Click & Go and Joystick control flight modes.

UgCS features a mission planner with a 3D interface for UAV mission planning, enabling it to navigate the environment more easily. Moreover, a 3D mission planning environment gives more control, allowing for viewing the created flight plan from all angles, taking into account any obstacles such as terrain or buildings (details from [1]).

CAFA Tech UgCS-based drone flights C2 platform cloud-native application contains Frequentis plugin to send telemetry data in near-real-time to the Frequentis SmartSIS from which the data is sent to DroneRadar Pansa UTM. In this way, it is possible to transmit the location of the drone to other drone operators in near real-time via the UTM system.

A screenshot of the graphical user interface of UgCS is shown in Figure 1.

2.3. UAV enabler 2: CAFA Tech Field GIS C2 system for Police operations and Drone Logistics

2.3.1. Description

This enabler is common for UC1:SC3 and UC2:SC3 scenarios.

CAFA Tech Field is a geoinformation system that can be used on Personal Computers (PCs) as well as Android smartphones. The Oracle database is used as the system database.

The location of the drone can be displayed on the map in near real time. The screenshot below in Figure 2 describes the map view of the CAFA Tech Field C2 system.

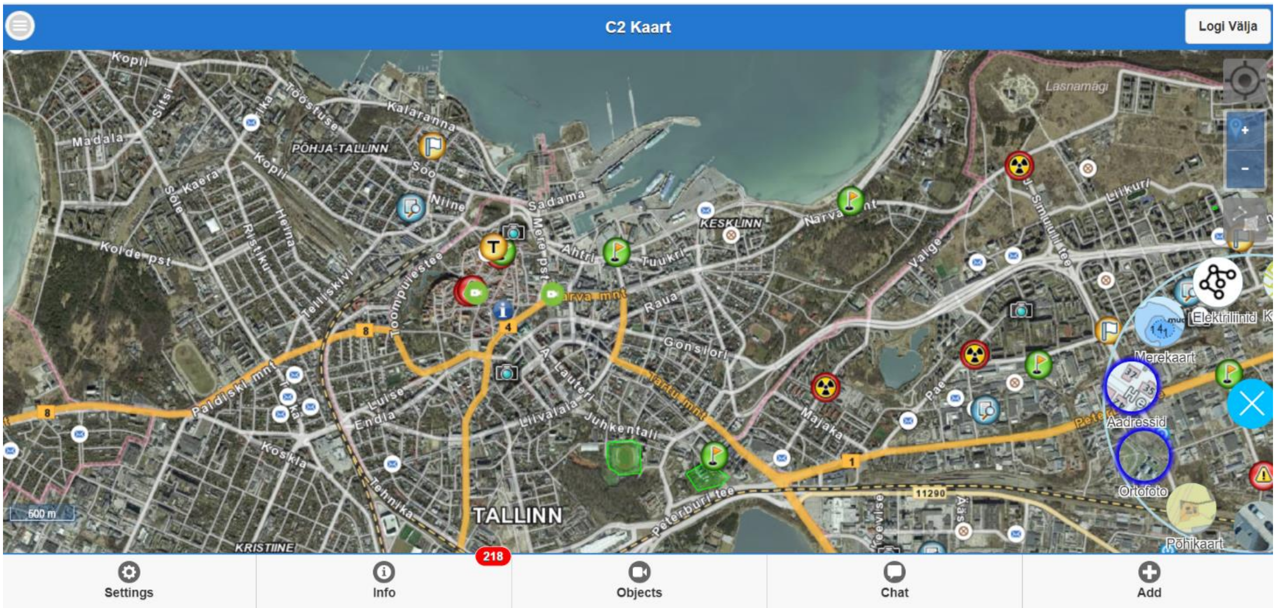

Figure 2. Screenshot of the CAFA Tech Field C2 system

2.3.2. Features and functions

The CAFA Tech Field system can be used to manage various field activities: Police, Rescue, Inspection, Logistics, etc. In a Police scenario, a police officer can create operations and mark tasks and information on the map and share it with the parties.

The location of drones and other vehicles can be displayed on the map. It supports a function to add video cameras to different locations on the map, which helps to better understand the situation, as the location of the camera and the video stream can be understood spatially.

In drone logistics, Drone Logistics Company can assign access rights for a customer. Then, the customer can mark the location of the delivery box and order the package. Once the drone has delivered the package, the corresponding information will also appear on the CAFA Tech Field map.

2.4. UAV enabler 3: CAFA Tech cellular drone (PX4 platform-based) supporting onboard 5G commands

2.4.1. Description

This enabler is common for all scenarios where CAFA Tech participates as a drone operator (UC1:SC1, UC1:SC3, UC2:SC1, UC2:SC3, UC3:SC1:sub-SC1, UC4:SC1).

CAFA Tech uses a rebuilt cellular drone based on Holybro PX4 Vision Autonomy Development Kit (details can be found on [2]). The depth camera is removed and replaced with 4K RGB camera.

For 5G communication, a Quectel RM500Q-GL 5G Modem [3] is also attached.

- The drone MTOW is 1.95 kg.
- The flight time of the drone is max. 20 minutes.
- The maximum speed of the drone is 15 m/s.
- The maximum delivery payload is 100 g.

Flight Controller is Pixhawk 4® which is an advanced autopilot designed and made in collaboration with Holybro® and the PX4 team. More details are available in [4].

The Mavlink protocol is used for Command & Control Protocol, the details of which are described in [5].

2.4.2. Features and functions

CAFA Tech cellular drone uses 5G communication:

- for Command and Control (C2) of the drone, i.e. to send flight plans from the GCS working in 5G MEC/edge server;
- to send telemetry data (drone position, speed, direction, battery information, etc.) from the drone to the GCS working in 5G MEC/edge server;
- to stream 4K video from the drone to the video server working in 5G MEC/edge server;
- to control the electrical hook mechanism to release the delivery item (small package).

2.5. UAV enabler 4: 4K Video streaming system from drone to MEC/Edge server

2.5.1. Description

This enabler is common for all scenarios where CAFA Tech participates as drone operator (UC1:SC1, UC1:SC3, UC2:SC1, UC2:SC3, UC3:SC1:sub-SC1, UC4:SC1).

The CAFA Tech Video Streaming system consists of an onboard CAFA Tech cellular drone 4K camera that streams video over a 5G network to a predefined video server application running on the MEC/edge server. Video server application is a Docker image based on Nimble Streamer (freeware). Technical details of Nimble Streamer are described in [6].

The video streaming system works as follows: Docker image is installed on the 5G!Drones partner's MEC/Edge server. The drone's 4K camera captures video, transcodes it and forwards it to onboard computer, which sends the Real Time Streaming Protocol (RTSP) video stream over 5G to a specific IP of the video server. Video is usually in Full HD or 4K quality, which requires a bandwidth of up to 30 Mbit/s. From the video server, the video stream is forwarded to the drone operators as well as other parties involved. For 5G!Drones trials, the most important are the in/out RTSP flows and the H.264 and H.265 protocols.

2.5.2. Features and functions

The CAFA Tech 4K Video streaming system gives the drone pilot and other stakeholders (media companies, customers etc.) the opportunity to see Full HD or 4K video in near real-time, allowing the drone to be controlled in teleoperation mode. This is especially necessary and useful in cases where the drone pilot has to interrupt the drone's automatic mode and take over the control of the drone (for example: if the GNSS signal quality is poor; the situation is dangerous, or the drone needs to be grounded quickly).

Full HD and 4K quality videos enable the use of highly accurate video analytics (Computer Vision) solutions. The CAFA Tech Video Streaming system is a Docker image based on Nimble Streamer (freeware) and Warehouse Management System (WMS) Panel using the adaptations required for the 5G!Drones project.

2.6. UAV enabler 5: INVOLI K-1090 receiver

2.6.1. Description

INVOLI proposes a professional system of plug-and-play receivers, trackers, servers, and software components, which have the task of gathering cooperative air traffic information on a unique and intuitive interface: the INVOLI.live platform.

The system is composed of some hardware parts for the detection of traffic, hardware, and software parts for the processing of the raw data gathered on an INVOLI central server, and a software part for visualization and data analytics. One significant advantage of the whole INVOLI system comes from the seamless integration of all those components.

2.6.2. Features and functions

K-1090 receiver (Figure 3) is able to detect aerial traffic up to 20-400 km around the unit. The range depends on the position of the receiver and the aircraft avionics emitting power.

It detects the signals emitted by different transponder types: ADS-B, Mode-S, Mode A/C and FLARM (in option). It needs to be connected to the Internet, and it has been built to be rugged and resist any kind of weather. The K-1090 receiver natively supports the INVOLI MLAT algorithm to use the transponders signals, not including the aircraft position (Mode A/C, Mode S) for calculating this location, based on the Time of Arrival (ToA) difference between different receivers detecting the same transmitted signal.

At the moment, the system is deployed and operational in Switzerland.

Figure 3. K-1090 receiver

2.7. UAV enabler 6: LEMAN

2.7.1. Description

The new legislation entering soon to the power is requiring that flying UAV can be identified by people being around with the help of hand-held devices, like a mobile phone. This is a kind of “licence plate”, equivalent to a car’s identification plate. Two kinds of remote ID are possible – networked and broadcast. INVOLI has the networked tracker in his offer, and soon the broadcast feature will be available as well. It is planned to use the broadcast remote ID version for the tests in September 2021.

2.7.2. Features and functions

LEMAN (a networked remote ID version), shown in Figure 4, is a fully independent Drone Tracker equipped with its own GPS and its own battery. Once configured and equipped with a SIM Card, it will start transmitting its position to the INVOLI Server. Once on a drone, it is possible to use it to monitor the drone position on the INVOLI.live display platform or to integrate its data stream in a third-party software – like a UTM or a drone GCS – using the INVOLI API & Stream. The LEMAN Drone Tracker complies with the American Society for Testing and Materials (ASTM) standard for Remote ID.

The new function, allowing the local detection of the UAV by handheld device close to the flying drone, is still under development and should be available soon.

Figure 4. LEMAN tracker

2.8. UAV enabler 7: INVOLI.live data stream to U-space

2.8.1. Description

INVOLI.live platform is concentrating manned and unmanned air traffic information in a unique and intuitive interface. It is the XXI century version of the air traffic controller screen. External systems can also use the aggregated data stream with API provided by INVOLI. In SORA, INVOLI.live platform is successfully used in Switzerland and abroad to lower the risk of BVLOS drone flight.

2.8.2. Features and functions

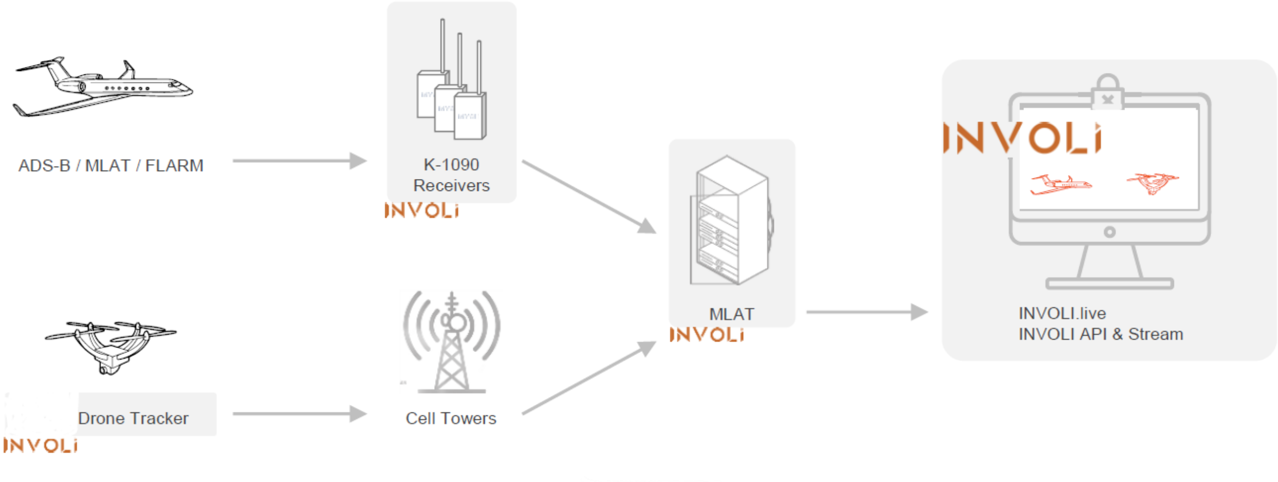

Figure 5. INVOLI.live platform overview

INVOLI is providing traffic data information for manned aviation (different transponder types) and cooperative drones with INVOLI's trackers. The system overview is shown in Figure 5.

Table 1. Data types of availability for different transponder types

	ADS-B	Mode S	Mode A/C	Flarm	LEMAN tracker
ICAO Address	Y	Y	N	Y/N	N
SQUAWK	Y	Y	Y	N	N
Call Sign	Y	N	N	N	N
Position message	Y	N	N	Y	Y
Position MLAT	Y	Y	Y	N	N
Altitude	Barometric, GNSS-based	Barometric	Barometric	GNSS-based	GNSS-based
Speed	Y	N	N	Y	Y
Heading	Y	N	N	Y	Y
Climb speed	Y	N	N	Y	N
Signal strength	Y	Y	Y	N	Y

For manned aviation, we collect and present data from different transponders: ADS-B, Mode S, Mode A/C and FLARM. Table 1 below shows which information is received from different data sources. Each type of transponder has its own set of data – i.e., for Mode A/C, the aircraft position is not included, but INVOLI is able to calculate it, based on ToA of the radio signal to several of our receivers spread on the ground. Using the same method, INVOLI is also capable of validating the position of aircraft sent by transponders, which are including their position (ADS-B).

ADS-B system is very vast and carries much more information than specified in the table above, but INVOLI selected the set of data, which is the most important for traffic awareness and makes it available for its output stream.

2.9. UAV enabler 8: Trajectory planning for a fleet of 5G drones

2.9.1. Description

This enabler aims to provide a global solution for trajectory planning. Indeed, the objective is to be able to define trajectories for a set of drones, and each drone is supposed to go from a point A to a point B: drones' flights can be correlated, acting as a real fleet which means they have the same initial and final coordinates, or not, each drone has an independent mission.

This enabler shall take into consideration an optimisation issue. The trajectories are calculated to be optimized in terms of distance, network quality (avoid areas with a weak 5G coverage) and energy (especially eliminate trajectories for which the drone has not to have enough energy resources).

Moreover, this enabler has a maximum of ten minutes for pre-flight calculations and must be able to make trajectories updates – the update process will be described next – in real-time.

The working process, depicted in Figure 6, is organised as follows:

1. Network quality map: from the given coordinates, we model the flying environment according to network quality features (such as Received Signal Strength Indicator values) we have been collecting during previous experiments or from online available data sets (openmobiledata_public especially).
2. Initial path planning: we train a model based on the Deep Deterministic Policy Gradient (DDPG) to output the optimized trajectories with fast convergence. Designed for continuous control, the DDPG combines the actor-critic approach and Deep Q-Networks.
3. On-flight updates: during the flight, trajectories are updated in real-time from on-flight received data, especially from the Radio Network Information Service (RNIS). RNIS exposes four radio measurements:

- Reference Signal Received Power (RSRP) provides cell signal strength, and it is used by the base station to select a stronger cell for each UE;
- Reference Signal Received Quality (RSRQ) provides cell signal quality. While RSRP indicates only the signal strength, RSRQ enables the combined effect of signal strength and interference;
- Power Headroom (PHR) provides how much transmission power is left for a UE to use at a given time;
- Channel Quality Indicator (CQI) indicates the channel quality between the UE and the base station.

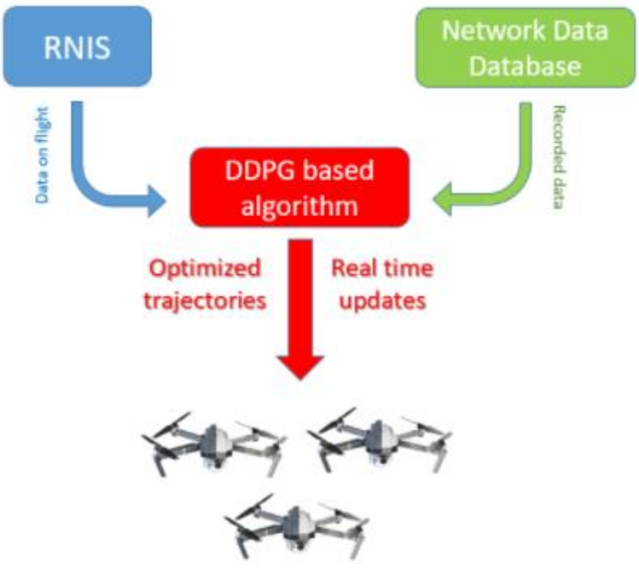

Figure 6. Working process scheme.

Specification of the manipulated features: in addition to the features collected during the flight by the RNIS, those used for pre-flight trajectories definition is worth mentioning. First developments were made with the openmobiledata_public dataset, using measurements such as:

- Received Signal Strength Indicator (RSSI);
- Packets_sent/Packets_loss;
- Mean/max./min. Round-trip time (RTT);
- Ping_interval_sec;

2.9.2. Features and functions

Our enabler is fitted to serve the purpose of Flying Multi-access Edge Computing (F-MEC), i.e., manage the traffic of UAVs in mobile edge computing development. UAVs' resources are used to perform tasks off-loaded by UEs, and, as a consequence, their trajectories are managed to optimize tasks off-loading, especially the realization delays.

Furthermore, military missions, weather prediction, network performances analysis are examples of data collection application fields where drones are taking a considerable place nowadays and stand as an illustration of UAVs' involvement in data collection. Therefore, UTM finds into this scenario a reliable testing context and a concrete, practical application. Collected data can be as diversified as we want, first idea is to collect data about 5G network coverage and performances in order to map and describe its reliability geographically and across time.

This enabler aims to provide the following main functionalities:

- Flights planning in less than ten minutes;
- Working through all Europe;
- Process live received data;
- Update trajectories from it in real-time.

2.10. UAV enabler 9: Drone flight plan enabler

2.10.1. Description

This enabler is a common and obligatory component for all the use case scenarios. Thus, this description applies to all use cases.
The Drone flight plan enabler (implemented as U-space interface for dFPL, drone flight plan, support) addresses one of the essential requirements for safe operations in shared airspace. All major regulatory and advisory bodies in the scope of airspace regulation (EUROCONTROL, SESAR-JU, FAA, CAAC, Etc.) recognize the need for standard services to harmonize and coordinate flights of all airspace users. One of the fundamental functions must be collecting and processing information about all flight intents like the drone operator, place, and date/time of flying to achieve this goal. All of this must be done in a formalized legal commitment of the applicant (e.g., drone operator).

2.10.2. Features and functions

In principle, the Drone flight plan enabler allows to submit the operational flight plan and receive its validation. It follows a common and basic process:

- Drone operator submits the operational flight plan;
- U-space checks the operational flight plan;
- Drone operator receives the response regarding the operational flight plan validation;
- If valid, the operational flight plan is registered as the current flight plan;
- The valid operational flight plan can be deployed (e.g., corresponding mission/flight plan can be loaded into the drone) and executed;

- If invalid, the drone operator should adjust the operational flight plan according to the feedback/remarks received from the U-space;
- At any time, U-space can change the validation status of any operational flight plan (which would lead to it becoming an invalid one).

In the 5G!Drones project the first step (definition and submission of the operational flight plan) is performed by the operator using the Web Portal 1 (more information on Web Portal 1 functions can be found in, e.g., deliverable D2.4). The operator fills all the necessary information into dedicated forms. The required data comprises the following information:

- the unique serial number of the unmanned aircraft or, if the unmanned aircraft is privately built, the unique serial number of the add-on;
- mode of operation;
- type of flight (special operations);
- category of UAS operation (“open,” “specific,” “certified”) and UAS aircraft class or UAS type certificate if applicable;
- 4D trajectory (described by 3D space volume and time of the mission);
- identification technology;
- expected connectivity methods;
- endurance;
- applicable emergency procedure in case of a loss of command and control link;
- registration number of the UAS operator and, when applicable, of the unmanned aircraft

It is passed through Trial Validator to the U-space via the U-space Adapter module when completed. The U-space Adapter module implements the interface to the Drone flight plan enabler.
On the U-space side following “checks” are performed with each submitted operation flight plan:

- Some parts of the pre-tactical (during the flight planning phase) Geofencing;
- Strategic Conflict Resolution;
- Dynamic Capacity Management, Etc.

In more detail, the validation process performed on the U-space side is shown in Figure 7. Depending on the complexity of the operational plan flight request definition, some steps might be performed manually, even if the goal is to make this process as automatic as possible to allow most of the missions to be accepted immediately. Due to that fact, the processing time would vary because manual processing, when required and depending on its nature, would last longer than automatic. From the operation planning flow, it can be noted that the central processing component, namely the Operation Plan Processing System (USSP1), would call other modules (internal and external to the system) for required services (like ConflictResolutionSystem) as well other peer Operation Plan Processing Systems (USSP2). In 5G!Drones environment, there will be two USSPs: one provided by Frequentis and the second by DroneRadar.

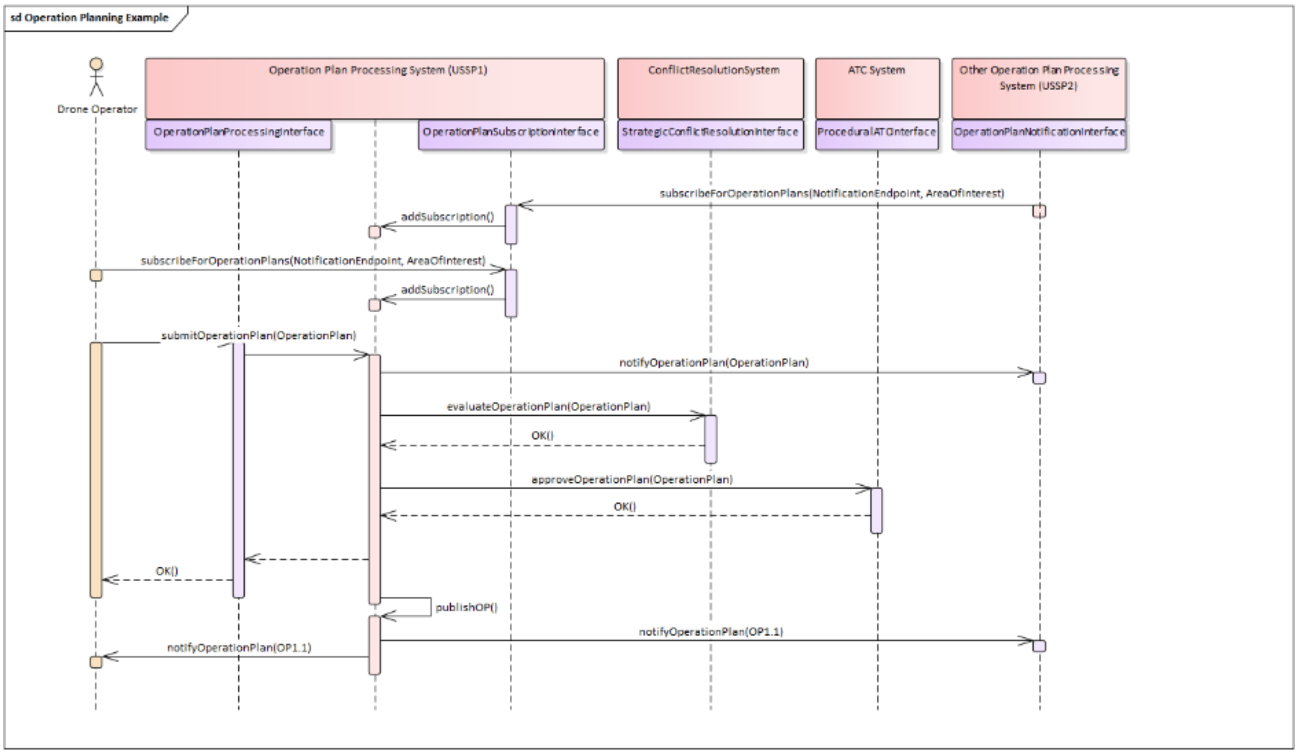

Figure 7. The operational flight plan evaluation by U-space

Based on these checks, the appropriate validation response is sent (valid/not valid) to the initiator (in our case, U-space Adapter).
The Drone flight plan enabler is an interface/API type of the enabler. It exposes the interface to predefined U-space services related to operation plan management.
The U-space services used in the project are provided by DroneRadar and Frequentis service platforms. Those implementations are fully aligned with SESAR JU/GOF 2.0 recommendations and requirements.

2.11. UAV enabler 10: Geo-zones/AIM enabler

2.11.1. Description

Geo-zones/AIM is another enabler provided on the U-space side, common and obligatory for all use case scenarios.
The primary purpose of this enabler is to provide exchange and management (Drone AIM, Aeronautical Information Management) services of necessary situational awareness information to all operational nodes of U-space.
The drone operator's perspective would allow knowing the defined, using so-called Geo-Fencing mechanism, different types of flight restricted zones.The information about current Geo-Fenced areas should be used during flight planning (pre-tactical) and in-flight (tactical) phases. The Geo-zones/AIM enabler allows access to this most up-to-date and reliable type of information (current and planned airspace Geo-zones definitions).

2.11.2. Features and functions

The Geo-zones are defined based on the aeronautical sources (Aeronautical Information Publication - AIP, NOTAM) and non-AIP sources.
Special purposes have Geo-Fences with immediate or near-immediate effect. They will play a very important role in handling emergency situations like immediate airspace allocation to the air ambulance, firefighters, or police drones.
To better classify different categories of possible Geo-zones, different types of Geo-zones were defined. The proposed types of zones are presented in Figure 8.

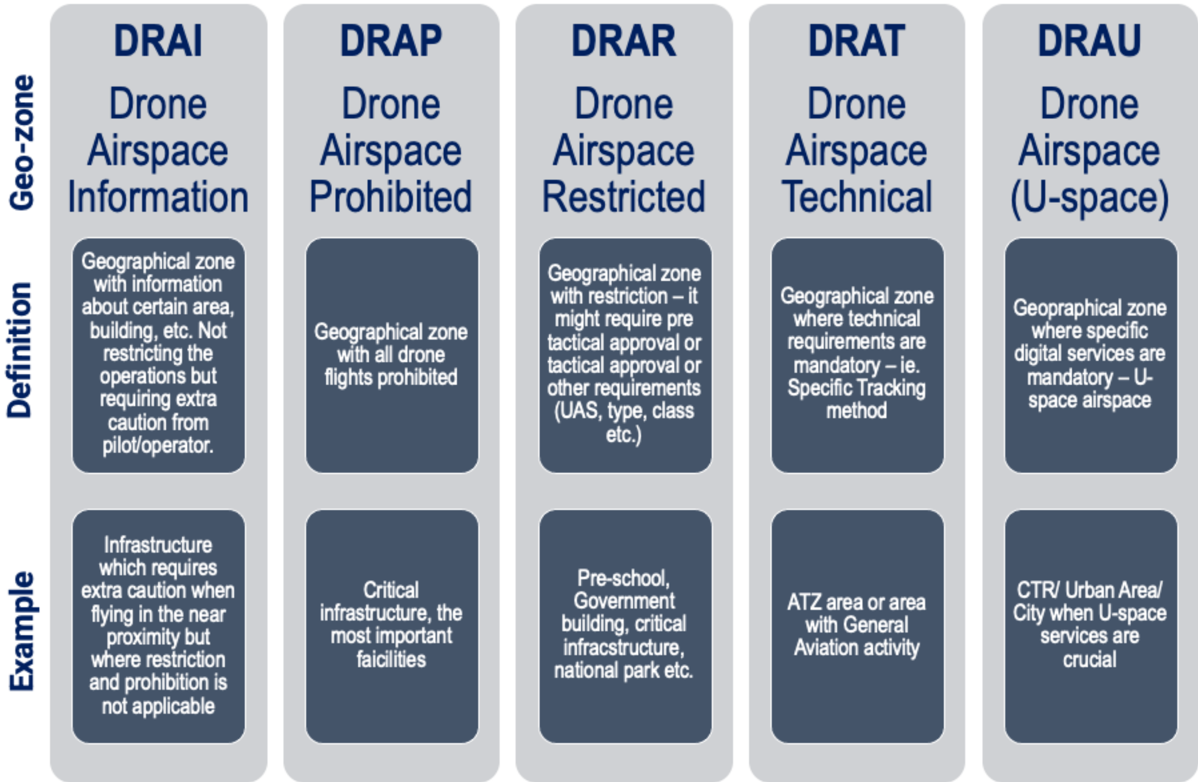

Figure 8. Proposed types of Geo-zones (based on PANSA UTM)

The Geo-zones/AIM enabler is an interface/API type of the enabler. It exposes the interface to a predefined U-space Geo-zone exchange service (GeozoneExchangeService).

2.12. UAV enabler 11: Telemetry enabler

2.12.1. Description

Telemetry is another enabler provided on the U-space side, which is common and obligatory for all use case scenarios.
The Telemetry enabler is an accessible entry point to U-space Traffic/Telemetry service, and the primary purpose is to generate and provide a common situational picture in terms of current and up-to-date locations of all UAVs. For fetching UAVs location, the Telemetry enabler receives surveillance data (position reports) from data sources (e.g., radars, drone onboard position telemetry services, tracking services, Etc.) and passes them to the Tracking service, which, in turn, can provide

the information about the current overall situation. This type of information can be consumed by different applications, like tracking and monitoring services, operators' displays, dashboards, Etc.

2.12.2. Features and functions

The proposed data schema of the position report is presented in Figure 9. As can be seen, this report, which should be usually provided more than once per second, is a complex data structure. It should contain the position and altitude and velocity, heading, and many other parameters.

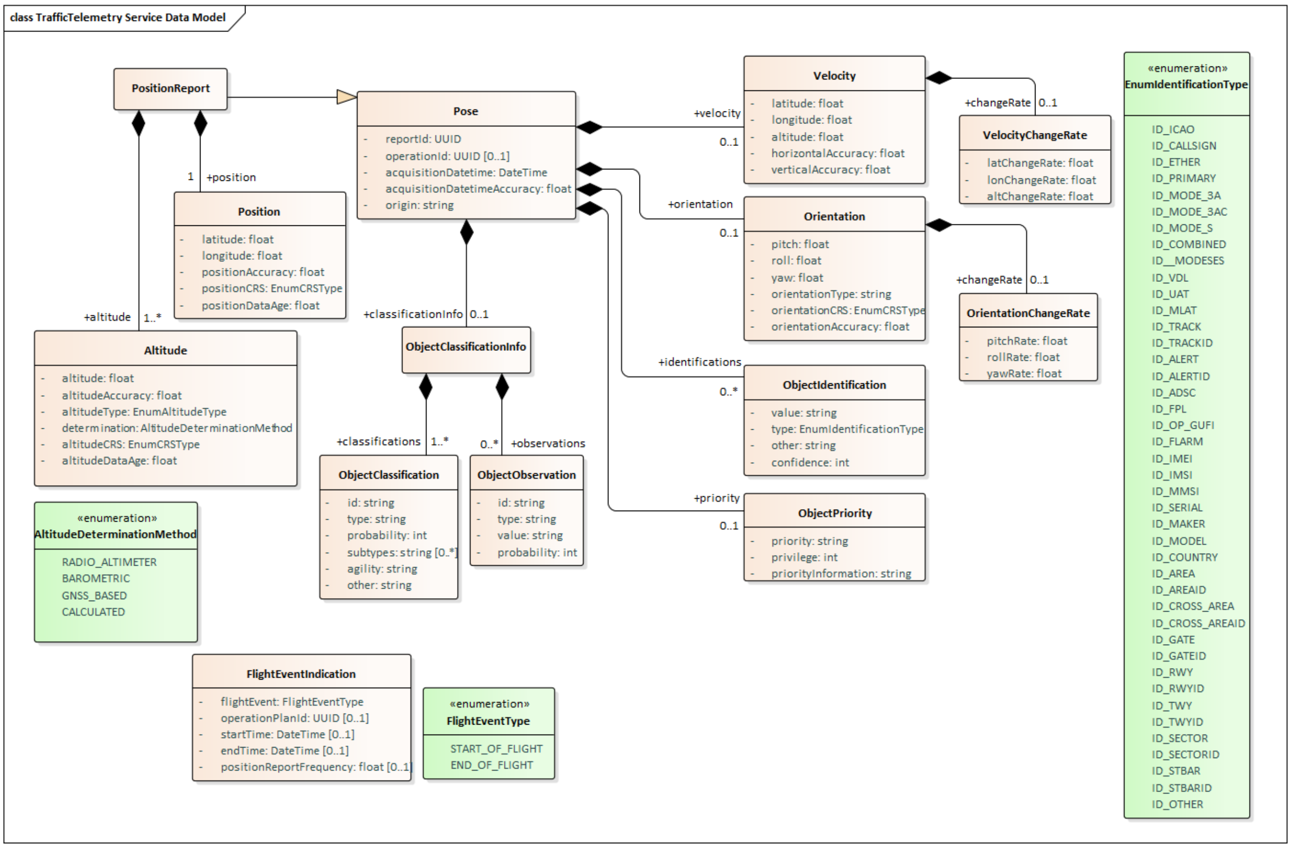

Figure 9. Data model schema of the Traffic/Telemetry Service

A typical process flow for the Traffic/Telemetry service component of the U-space is shown in Figure 10.

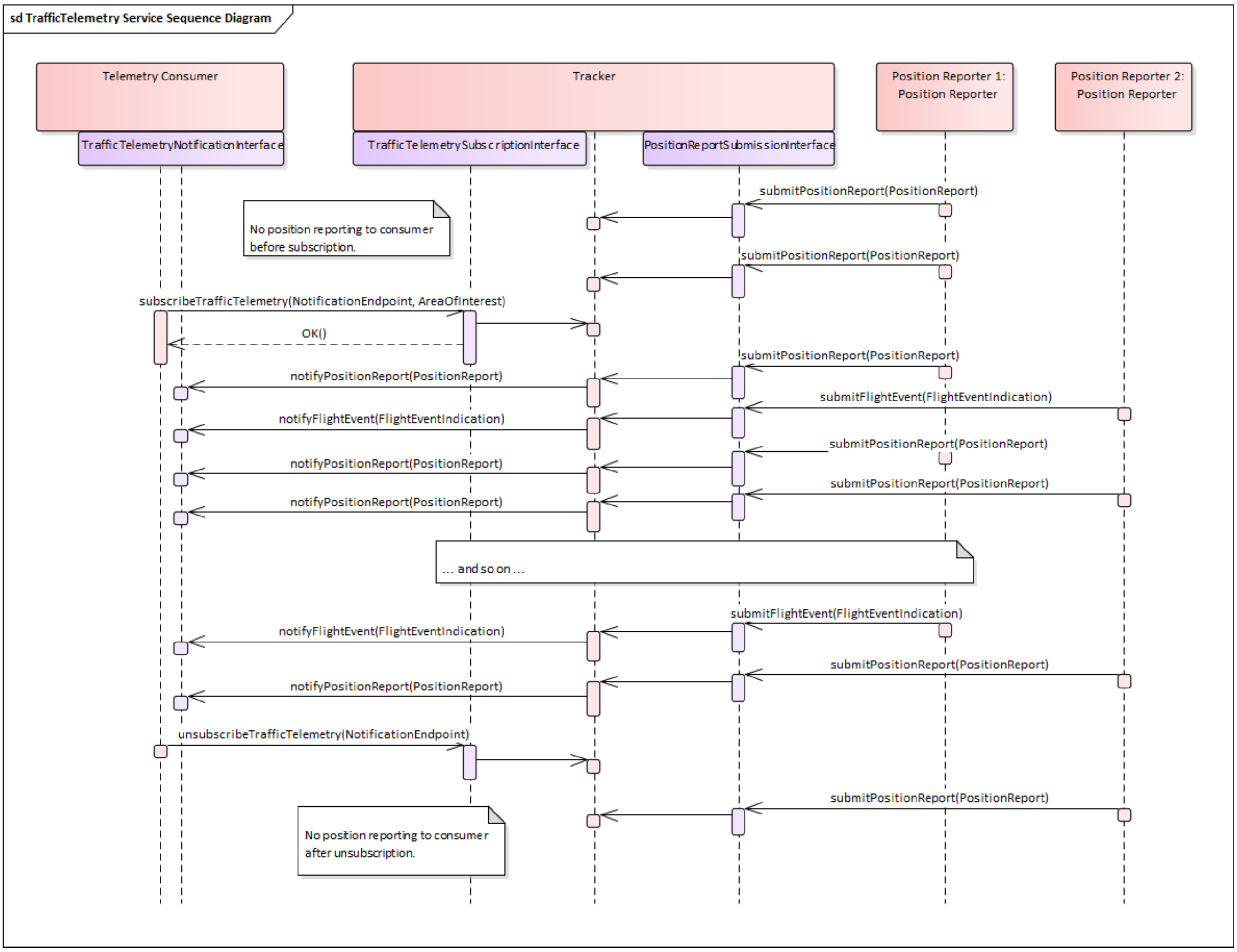

Figure 10. Traffic/Telemetry service operation

As can be seen, on one side, different Position Reporters entities are supplying the Tracker with position reports. Those reports are sent through the PositionReportSubmissionInterface. In 5G!Drones this interface will be accessed directly by UAVs (mostly GCSs) to provide the telemetry data (position reports). The U-space Adapter will not be involved in this part of the flow.
The U-space Adapter will be used to fetch the telemetry data through the TrafficTelemetrySubscriptionInterface (it will act as a Telemetry Consumer).
The Telemetry enabler is an interface/API type of the enabler. It exposes the interface to predefined U-space Traffic/Telemetry service.

2.13. UAV enabler 12: Cable drone enabler

2.13.1. Description

This enabler provides the possibility to realize repetitive and controlled measures using various sensor configurations, which is common and obligatory for all use case scenarios to provide reliable measurements.

2.13.2. Features and functions

The body is made of aluminium, and it weighs 3,85 kg alone. Its dimensions are 1000 x 220 x 230 presented as L x W x H in mm. The surface is anodized to enhance corrosion resistance. The maximum payload of the cable drone is 15 kg. Cable's maximum slope should not exceed 9 °. Cables are 200 meters long. The system's speed can be set from a minimum of 3 km/h to a maximum of 45 km/h. We have made some changes to the original cable drone-like; for example, we replaced the original batteries with two larger 22.2V 16 Ah LiPo batteries. Schematic view of the cable drone with portable sensor system is shown in Figure 11.

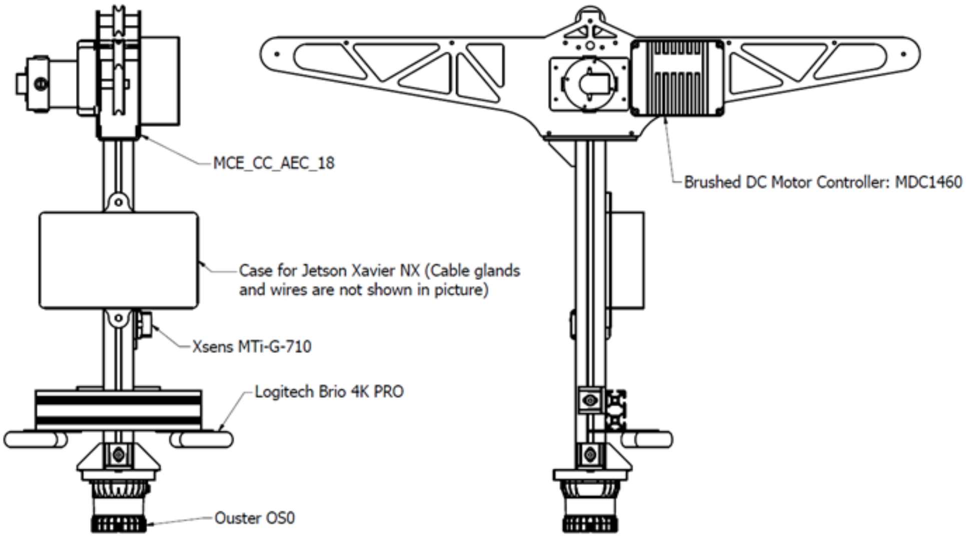

Figure 11. Schematic view of the cable drone with portable sensor system

A cable drone is equipped with a portable sensor system where different sensors and cameras can be attached. The diagram of the portable sensor system is shown in Figure 12. The portable sensor system is powered by the same battery which is used to power the cable drone. Jetson Xavier NX collects data and powers sensors and cameras via USB. Data is saved to Jetson's memory, but it can also be transferred to another laptop so that live visualization would be possible in the future.

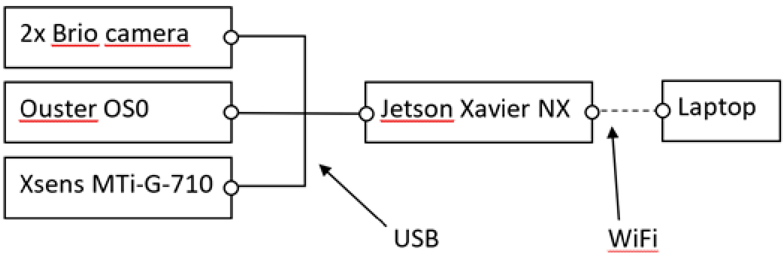

Figure 12. Diagram of portable sensor system

We are trying to establish a secure way to find the position of the cable drone by using the Intel RealSense tracking camera T265. Tests are being made, and the cable drone is currently operated with T10J Radio remote controller. The cable drone is equipped with an optical encoder which was the first option for positioning. However, the wheel odometry is a relative positioning method, and it does not consider if the wheel spins without moving the cable drone linearly as intended. This causes inaccuracy and drifting on the estimated position; thus, it is not an appropriate solution for this application. Another briefly tested solution for positioning was RTK GPS positioning, but it was abandoned when setting up the base station receiver with sufficient accuracy took too much time, and it was decided to try first the tracking camera. The control diagram of the cable drone is shown in Figure 13.

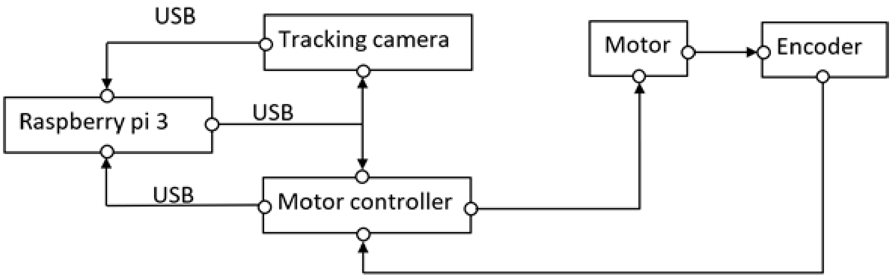

Figure 13. Control diagram

A cable drone can be used in tests that aim to determine how changing environmental conditions and the movement speed of the observing sensor or camera effects acquired data. There are three main issues that can be measured. There are three main issues that can be measured.
The first one is the accurate position of the drone. When the real location is known, we can compare it to the data collected from the sensors attached to the drone. By comparing the data collected from the same location while moving with the data collected while in place, we will hope to receive numerical data of the error and uncertainty in the future.
The second thing to measure is drone's perception. Objects and materials which are known to be recognizable can be placed near the cable drone's track. This means that we will accelerate the cable drone to the desired speed and measure the exact distance from the drone to the specific object when the drone recognizes this object.
The third issue is related to drone's communication. This includes inspection on the radio quality, while using different kinds of antennas. Different technologies that are to be tested can be Bluetooth, UWB (Ultra-wideband) and Wi-Fi. The cable drone can be mounted with a transmitter, and the receiver can be placed, for example, to the charging place of the cable drone or further away. Points of interest are factors that affect data transfer rates such as bandwidth, speed, and network latency.

3. USE CASE 2: PUBLIC SAFETY/SAVING LIVES

3.1. Description and list of scenarios

3.1.1. UC2:SC1 Monitoring a wildfire

A team of firefighters, equipped with their mission-critical communication system, performs a coordinated operation in a forest fire scene with the aid of a drone. A drone supports Rescue operations in limited time. The best solution is combining drones with firefighters. Firefighters can provide an area where they need aerial live video feed to get an overview from a larger area. CAFA Tech cellular drone provides a video feed from an operational area. The main requirement of the scenario is that all team members know exactly what to do for the safety and efficiency of the firefighting operations. This needs timely and relevant operational decisions and proper communications as well as data and video feed sharing through mission-critical channels.

3.1.2. UC2:SC2 Disaster recovery

This use case scenario is a “disaster recovery” simulation in which UAVs are used to provide on-demand network connectivity and video footage of the affected area simultaneously and autonomously. UAVs can interconnect and communicate with ground stations over direct D2D links, thus allowing for the rapid deployment of a wireless backhaul in situations where capacity is needed on an expedited basis. These UAVs can then bridge the signal for backhaul interconnect to provide ultra-reliable, low-latency wireless connectivity to end-users in need. These networks allow both victims and emergency workers to communicate when is of prime importance.

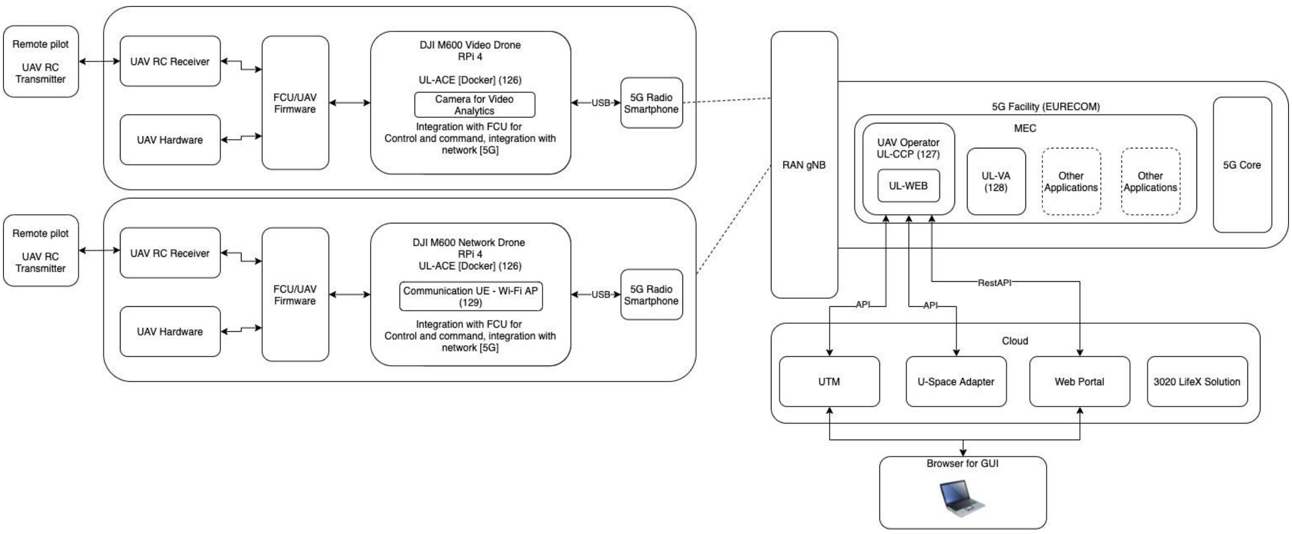

Figure 14. the architectural schematic of the UC2:SC2 setup

This scenario will make use of two UAVs (hereafter referred to as the network UAV and the video UAV). Both UAVs will be augmented by a small onboard computer (Unmanned Life – Autonomous Control Endpoint) and managed by a software pilot (Unmanned Life – Central Command Platform) hosted at the Multi-access Edge Computing (MEC). Initially, the video UAV will patrol the affected area, streaming video to services hosted at the MEC. These services will analyse the video stream for potential humans on-site. Once a human is detected in the video stream, the network UAV will be autonomously dispatched to the detection coordinates in order to provide ad-hoc network connectivity to the end-user in the disaster area. The network connectivity will be provided via a Wi-Fi access point, although this can optionally be substituted for a 4G small cell (if available).

This service will require two Docker containers deployed on the MEC infrastructure. The first container provides the C2 link service (UL-CCP) for controlling and coordinating between the UAVs in use. The second VNF container provides video stream reception and analysis. Both VNFs require two connections – one to the Internet and one to the UEs (i.e., the video and network UAVs). The external network connection is required to communicate with externally hosted services such as UTM and the 3020 LifeX Solution.

Figure 14 provides the architectural schematic of the UC2:SC2 setup.

The trial components are:

1. UAV Components: DJI 600, Video Streaming Camera, Wi-Fi Access Point, 5G Smartphones (w/ USB tethering). Providers: Hepta, Unmanned Systems, Eurecom;
2. UAV Operator Components: UL-ACE, UL-CCP, UL-VA. Providers: Unmanned Systems;
3. UTM Components: Support for dFPL (drone Flight Plan), Situational awareness (airspace perspective) service to submit dFPL. Provider, U-space telemetry endpoint. Providers: Frequentis, DroneRadar;
4. 5G Components: 5G Network, MEC Infrastructure. Provider: Eurecom;
5. Other Components: 3020 LifeX Solution. Provider: Frequentis.

3.1.3. UC2:SC3 Police including counter-UAS

This use case will demonstrate how remotely piloted UAV and video analytics can be used for police tasks, including C-UAS activities using 5G communication. The police are preparing for a VIP visit. The police also use a drone that automatically flies and streams video to the video analyser software and the command centre. The video analysing software, CAFA Tech VideoLyzer, installed on the MEC, uses videos and photos provided by the drone. As a part of the VIP visit, a temporary NFZ and restricted ground area are established.

During the visit, the police drone flies on autonomous mode. The police drone streams video feed continuously to the MEC server, where at the same time, computer vision software CAFA Tech VideoLyzer works. CAFA Tech VideoLyzer detects a suspicious activity (person or drone in the restricted area). The police operator then changes drone control from automated mode to teleoperation mode and flies near the suspicious person, and affects the pilot to stop the illegal activity.

3.2. UAV enabler 1: UL-ACE

3.2.1. Description

The UL- Autonomous Control End Node (UL-ACE) is a computing unit installed on a drone in addition to a flight controller. This computing unit provides higher processing power than the flight controller and enables higher-level autonomous control by sending C2 commands to the flight controller. The autonomous control endpoint also communicates with a central command platform (UL-CCP) that orchestrates the individual actions of a group of autonomous vehicles hosted on a local server, on the network edge, or in the cloud. This communication can take place over Wi-Fi, 4G, or 5G.

3.2.2. Features and functions

This module is mainly used for command-and-control functionality. Some significant features are provided below:

- Integration of hardware and installation of companion computer software to enable them for autonomous control operations;

- Waypoint navigation;
- Mission functionalities (play, pause, RTH, emergency stop);
- Integration with Drone from Hepta and installation of necessary payloads.

3.3. UAV enabler 2: UL-CCP

3.3.1. Description

The UL-Central Command Platform (CCP) is a containerized application that is comprised of software modules and acts as the “central brain” for an Unmanned Systems deployment, gathering data from connected UL- Autonomous Control End node (ACEs) to create a single context for devices in the fleet. UL-CCP integrates and orchestrates all the systems involved in the solution, processed via the Edge and/or cloud-enabling the cloud-based Autonomy-as-a-Service operation.

3.3.2. Features and functions

This module is mainly used for orchestration and fleet management. Some significant features are provided below:

- Creation of behaviour tree nodes;
- Creation of a behaviour tree for swarm orchestration;
- Integrating the output of the object recognition tool with the behaviour tree, integration with 5G edge infrastructure, integration with UTM;
- Development of UAV interfaces API to interact with Trial controller, UL-ACE;
- APIs to integrate with U-space Adapter;
- Software tools to measure KPIs;
- Development of APIs for KPI measurement and monitoring;
- Development of software front-end and end-user interface (UL-WEB).

3.4. UAV enabler 3: Unmanned Systems Video Analysis

3.4.1. Description

The UL-Video Analytics (VA) module collects and processes the sensor data streamed from the drone for tasks that are related to computer vision. Typically, this module is located on edge with the UL-CCP. The focus is on the sensor type and methods of analysis that can be applied for different system inspections. E.g., a visual inspection will be camera-based and will use AI techniques to analyse the camera data to perform object detection. Depending on the training data used during the learning process, the algorithm will detect different types of objects. The modules can be custom-made or a third-party plug-in to the UL-CCP.

3.4.2. Features and functions

This module is mainly used for image processing and analysis. Some significant features are provided below:

- Streaming video from the drone to the UL-VA for object recognition;
- Interacts with UL-CCP for behaviour tree reactions;

- Video analysis and image processing of pre-recorded video feed;
- Multi-image analysis with live video feed;
- Integration with 5G edge infrastructures.

3.5. UAV enabler 4: Unmanned Systems Wi-Fi Access Point

3.5.1. Description

This is a hardware module to provide on-demand connectivity to end-users on the ground. Due to the unavailability of hardware for providing UAV-portable 5G hotspot connectivity on an ad-hoc basis, it will be used.

3.5.2. Features and functions

This module is mainly used for on-demand connectivity. Some significant features are provided below:

- Hardware setup;
- Network configuration & testing.

3.6. UAV enabler 5: Unmanned Systems Simulation Testbed

3.6.1. Description

UMS has developed a hybrid simulation testbed (HITL+SITL) for remotely developing, testing, integrating with APIs and measuring pre-defined KPIs over 5G networks. This simulation testbed consists of a set of companion computers installed with UMS' end node software used to control the drones. The companion computers are typically onboarded on the drones and act as a proxy for them within this setup. The setup aims to implement interfaces and mechanisms by which simulated data from drones can be injected via APIs into other systems, including UTM. Since the simulation testbed is trialed in a lab environment, it is not meant to replace physical trials but to act as a bridge allowing continuity in testing as we prepare for real-life demonstrations. Detailed information on the simulation testbed can be found in deliverable D2.3.

3.6.2. Features and Functions

The simulation testbed is mainly used as a validation tool for testing system functionalities. Some significant features are provided below:

- Gazebo-based [7] simulation environment
- Autonomous simulated drone flights
- Image processing & analysis
- Software tools to measure KPIs
- Integration with third-party platforms

3.7. UAV enabler 6: CAFA Tech Video Analyzer (VideoLyzer)

3.7.1. Description

CAFA Tech VideoLyzer allows identifying predefined objects/subjects of interest from drone photos and videos. Given that the field of view of a drone camera flying at an altitude of 100m is usually 120m × 120m, i.e., a total of 14,400 m^2, it is challenging for the drone operator or the Police officer to notice objects of interest (cars, people, drones in the air, Etc.). In addition, it must be taken into

account that when a drone flies in surveillance mode at a speed of, for example, 5 m/s, it is difficult for the human brain to process such variable information. That is why Computer Vision systems are used, which at the same time need GPUs to process this information close to real-time. Object detection requires pre-trained artificial neural networks.
The video analysing software, CAFA Tech VideoLyzer, is installed on the MEC. CAFA Tech VideoLyzer uses photos and videos that are streamed onboard the drone. The CAFA Tech VideoLyzer uses Object Detection based on YOLO v4 (2020) algorithms trained to detect drones or other suspicious objects/subjects.
CAFA Tech VideoLyzer is a Docker image that is installed on a 5G facility Edge server. For near real-time processing, it needs GPUs in MEC/Edge server.

3.7.2. Features and functions

CAFA Tech VideoLyzer uses photos and videos that are streamed onboard the drone. CAFA Tech VideoLyzer uses a pre-trained artificial neural network and identifies predefined subjects/objects of interest from photos or video, such as drones, cars, people. When CAFA Tech VideoLyzer detects a drone, car or subject whose class is predefined, the system marks a subject/object with a label. The drone operator or the Police officer can then assess whether the suspect is suspicious subject/object.
Such cooperation between CAFA Tech VideoLyzer and a human is the most effective because the Computer Vision system analyses about 99.9% of the information, and the person evaluates only about 0.01% of the information, which requires a decision.

3.8. UAV enabler 7: Drone flight plan enabler

This enabler is common for all use cases and is described in more details in section dedicated to the description of UC1.

3.9. UAV enabler 8: Geo-zones/AIM enabler

This enabler is common for all use cases and is described in more detail in the section dedicated to the description of UC1.

3.10. UAV enabler 9: Telemetry enabler

This enabler is common for all use cases and is described in more detail in the section dedicated to the description of UC1.

3.11. UAV enabler 10: Frequentis LifeX solution PoC activity

3.11.1. Description

The 3020 LifeX solution developed by Frequentis is a public safety product suite for emergency management. In the context of UC2:SC2, Frequentis will be performing a PoC activity to validate their technology.

3.11.2. Features and functions

During the trial, a Person in Distress (PiD) will send out an SOS signal to the Frequentis LifeX Dispatcher client (similar to 911). The dispatcher will then relay the information to the LifeX system hosted on the U-space. LifeX system is a control centre for the management of operations that will verify this information and provide the relevant first responder(s) with the location of the PiD for immediate dispatch.

As we will be emulating the scenario, UML could act as the artificial first responder during the trial. This activity will be fully managed by FRQ and will not interfere with the primary activities of the trial. Details of implementation are yet to be charted out. The objective is to test and validate this technology to be adapted to help people requiring assistance during emergencies in real-life scenarios.
A preliminary version of the planned/proposed architecture scenario is provided below (Figure 15).

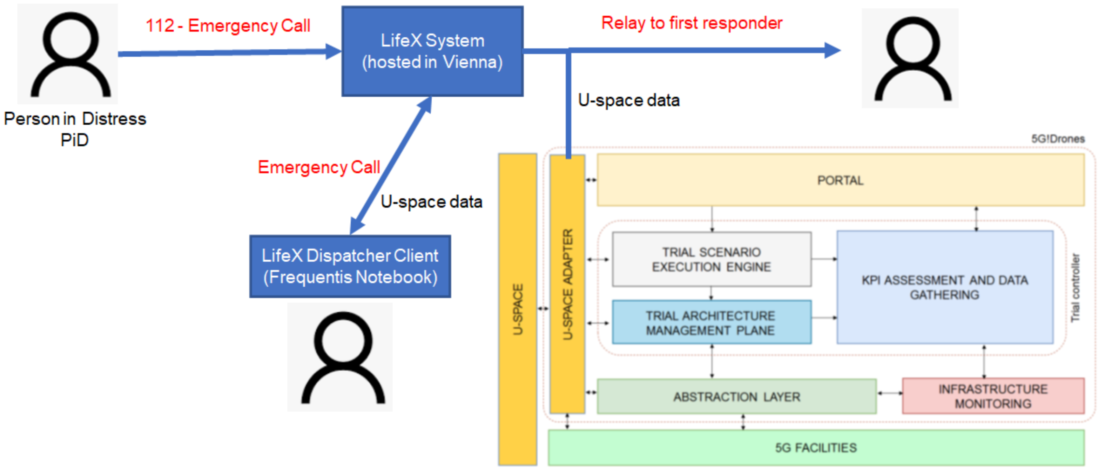

Figure 15. LifeX scenario

4. USE CASE 3: SITUATION AWARENESS

4.1. Description and list of scenarios

4.1.1. UC3:SC1 Infrastructure inspection

4.1.1.1. UC3:SC1:sub-SC1 3D mapping of 5G QoS

This use case will demonstrate how 5G QoS mapping is done using 5G MEC-based software. For measuring 5G QoS, a communication company ordered from a drone company for the 3D mapping of 5G QoS. At first, the drone operator uses a DJI Mavic drone to take photos which are then processed to point clouds. The point cloud is used for creating a 3D map. Then, the 5G base station icon will be placed on the 3D map.
The CAFA Tech cellular drone then carries 5G UE to measure the quality of 5G coverage from various positions with 3D coordinates (x, y, z) and timestamps. Measuring results are transferred to the server, and then results are visualised on the CAFA Tech 3D Analyzer.

4.1.1.2. UC3:SC1:sub-SC2 Long-range power line inspection

The purpose of this sub-scenario is to demonstrate how UAVs could be used in well-connected areas for power line inspection and fault detection. This is an essential and time-critical service, which can greatly benefit from the advantages of 5G networks, such as a power outage due to a storm. 5G networks with low latency and high bandwidth can help UAV operators carry out BVLOS operations transmitting LiDAR and camera payload data in near real-time, giving quicker and more efficient results.
The planned trial will focus on BVLOS operations and data-intensive payload transmissions. The UAV will be connected to a 5G network and be flying semi-autonomously. The UAV is equipped with one LiDAR for collision avoidance, one LiDAR for infrastructure inspection and one camera for high-resolution imaging. The operator will be connected to Hepta's cloud software to view image processing results and the point cloud processing VNF in the 5G edge server to view its results. The operator can control the drone over a 5G connection via a dedicated C2 VNF in the 5G edge server.

4.1.1.3. UC3:SC1:sub-SC3 Inspection and search & recovery operations in large body of water

This sub-scenario will demonstrate how 5G can be used for Search And Rescue (SAR) operations in a large body of water. During missions, Hydradrone (Alerion drone) may operate in both flight and navigation mode, alternating between each of them depending on the mission specifications.

During the missions, data will be captured by different sensors onboard the drone, which will be streamed through a 5G eMBB network slice to the Data processing application running at the edge. Next, the processed data (essentially, bathymetric data) will then be sent to the GCS running locally in Alerion laptop to visualise the analysed data. Commands for controlling the Drone operation are expected to be sent through the 5G uRLLC link.

4.1.2. UC3:SC2 UAV-based IoT data collection

The purpose of this scenario is to demonstrate how cellular-connected UAVs can enable on-demand access and deployment of IoT devices for achieving the IoT-as-a-Service (IoTaaS) vision. In this scenario, we distinguish two main actors:

a. **IoTaaS Provider:** plays the role of the UAV vertical, and is assumed to deploy a set of UAVs equipped with cellular-connectivity and IoT sensors on the top of a large service area (e.g., city of Brussels);
b. **IoTaaS Consumer:** plays the role of the end-user who seeks the collection of IoT data and measurements (e.g., images, videos, temperature, and humidity) from a specific region in the service area.

The IoTaaS consumer is provided with a platform to collect the IoT data from a particular *region of interest*. The data collection requests sent by the IoTaaS consumer are forwarded to UAVs that are either located within the confines of the region of interest beforehand or remotely directed by the IoTaaS provider to the region of interest to satisfy the end user's requests. However, in both cases, the end-user can enjoy transparently accessing IoT services without worrying about the process of deploying IoT devices. The architecture of the system developed for this scenario is illustrated in Figure 16.

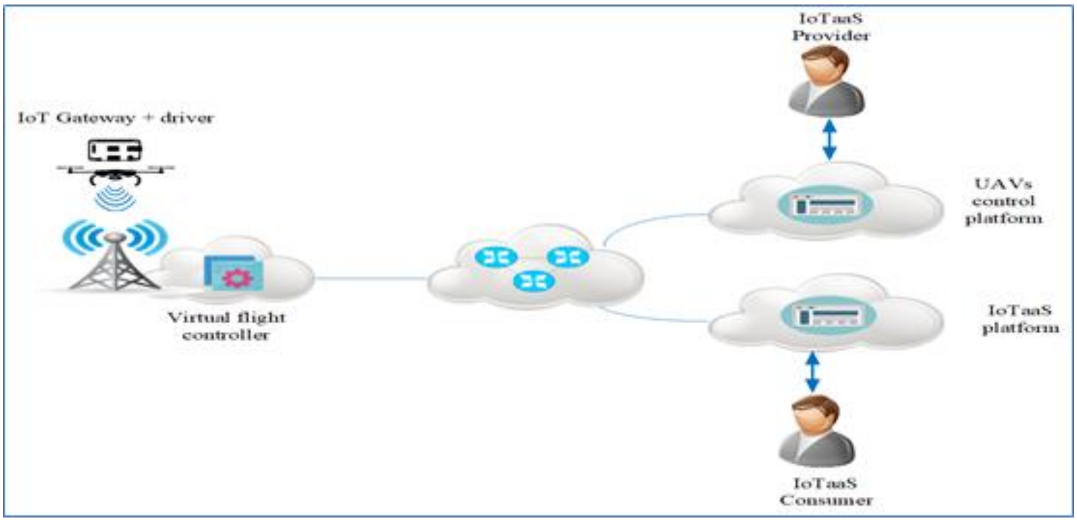

Figure 16. The high-level architecture of the system setup for UAV-based IoT data collection scenario.

We briefly introduce the set of enablers developed for the UAV-based IoT data collection use case, as depicted in Figure 17:

- **The UAVs control platform** allows the IoTaaS provider to track the UAVs and redirect them to the regions of interest. It is essentially hosted on the remote cloud, however, it can be deployed in the edge cloud.
- **The IoTaaS platform** allows the IoTaaS consumer to select regions of interest, send data collection requests, and visualize the received data.
- **The virtual flight controller** plays the role of interface between the UAVs and the control platform. It is essentially deployed at the edge of the network.
- **The IoT Gateway** is a pluggable module attached to the UAVs and includes multiple sensors and IoT devices.
- **The IoT Gateway driver** plays the interface between the IoT gateway attached to the UAV and the IoTaaS platform.

4.1.3. UC3:SC2 Location of UE in non-GPS environments

The purpose of this scenario is to demonstrate how UAVs could obtain position information in a situation where the Global Navigation Satellite System (GNSS) is compromised. An example of this kind of situation could be flying indoors or near high buildings.

As stated in D1.1, this use case scenario's main objective is to give the drone operator and GCS the possibility to know where the UAV is when the flying UAV is in VLOS or BVLOS mode. UTM also needs the same information. A secondary objective for the use case is to create a database for future development of positioning algorithms. This is possible, because during the scenario deployment, plenty of different sensory information will be collected in a synchronized manner and will be stored in a database.

4.2. UAV enabler 1: UWB-based drone positioning system enabler

4.2.1. Description

This enabler is used to provide the position for the indoor flying drone. GPS satellite signal is too varied to be used as it is indoors. Even though the signal could be obtained through windows and other openings, it is too unreliable, and thus, the position information must be obtained using other methods. The chosen method is the Ultrawideband-based system which consists of tags and anchors. Anchors are placed around the area where positioning is planned to take place, and inside that area, tags can then provide accurate position information.

4.2.2. Features and functions

For the trials, the selected system was Pozyx Enterprise [8]. According to the provider, the system can reach up to 10 cm accuracy with up to 75 Hz update rate for a single tag. The system supports two different working principles, TDoA (Time Difference of Arrival) and TWR (Two Way Ranging). Position can be visualized with Pozyx cloud UI, or real-time data can be obtained with MQTT messages.

Cloud UI is convenient when setting up and testing the system. The UI is illustrated in Figure 17. For near real-time drone positioning, MQTT messages are essential. In addition to the position information, the message includes other sensor data, such as IMU outputs. This data can be used to improve drone indoor navigation further.

Figure 17. Pozyx Enterprise Cloud UI

4.3. UAV enabler 2: 5G modem enabler

4.3.1. Description

The 5G modem provides a 5G connection to the drone. The modem can be either integrated into the drone directly or connected to it using a payload. If the payload is used, then the drone does not necessarily have to operate over 5G, which means that telemetry data can be communicated, for example, over LTE like in the Nokia drone. This type of approval is wise when ramping up the system and testing different things. This way, if something unexpected happens to the 5G connection, it does not affect the drone telemetry communication. On the other hand, when the 5G modem is integrated, sudden changes in the 5G connection can be investigated holistically when telemetry data is also in 5G.

4.3.2. Features and functions

For the enabler, there is both payload and the integrated version available. The payload consists of a Mediatek Apollo 5G chip, power connection, PC, and five antennas. The connector is the same as the other payloads intended for the Nokia drone. Therefore, the power is obtained from the Nokia drone. Used PC is small Lattepanda [9] with Windows UI. Antennas are Maximus FXUB66, which cover 700-6000 MHz frequencies. The integrated drone version includes on-board 5G modem from Quectel.

4.4. UAV enabler 3: 5G smartphone & camera holder

4.4.1. Description

5G Smartphone and camera holder is a backpack designed for the DJI Mavic 2 Pro commercial drone; see Figure 19. It can be used to carry a 5G phone, which can then make 5G measurements. This can be extremely useful in situations where quick and simple measurements are needed. Compared to bigger drones, which can carry heavier payloads, the Mavic 2 Pro is easier to setup and operate.

4.4.2. Features and functions

The 3D model was designed so that a GoPro camera or similar can be placed above the phone. If the camera is not needed, then, for example, small computer stick, and backup power supply can be placed there instead. In this way, more advanced measurements can be done compared to just using a 5G phone alone (See Figure 18).

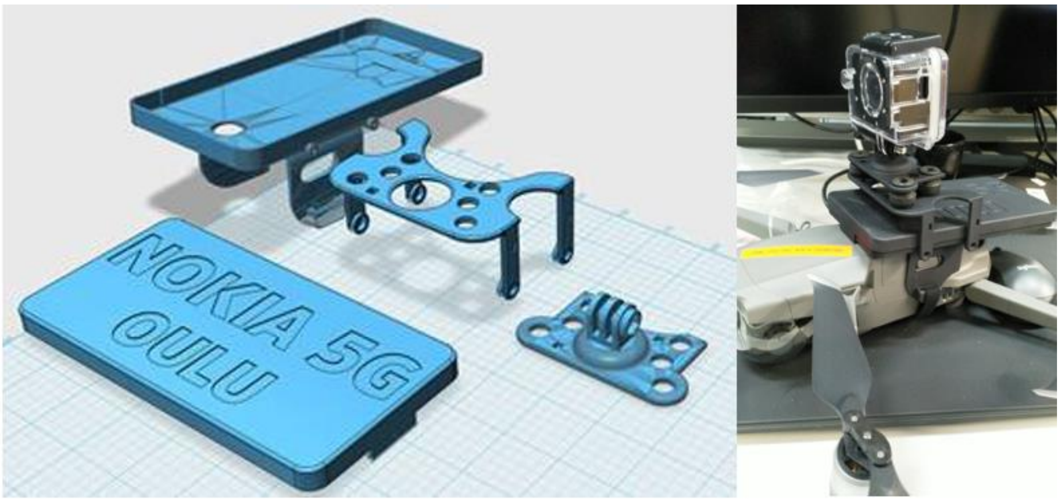

Figure 18. 5G smartphone & camera holder. Left side is the 3D model and right side is the ready component.

4.5. UAV enabler 4: DJI Matrice 600 payload adapter

4.5.1. Description

The payload adapter is an enabler, which acts as a connector between the Nokia drone payload and commercial drone. Without the payload adapter, other commercial drones cannot use Nokia drone payloads.

4.5.2. Features and functions

The payload adapter is designed for the DJI Matrice 600, and it is used for the Nokia drone payloads (See Figure 19). The Nokia drone has signature connector, which does not automatically fit different drones. With the adapter, different drones can utilise the same payloads as the Nokia drone. The adapter does not have an electrical connection needed from the drone. The adapter contains a remote communication box, 5G modem with antennas, computer unit and power unit with 6S LiPo battery.

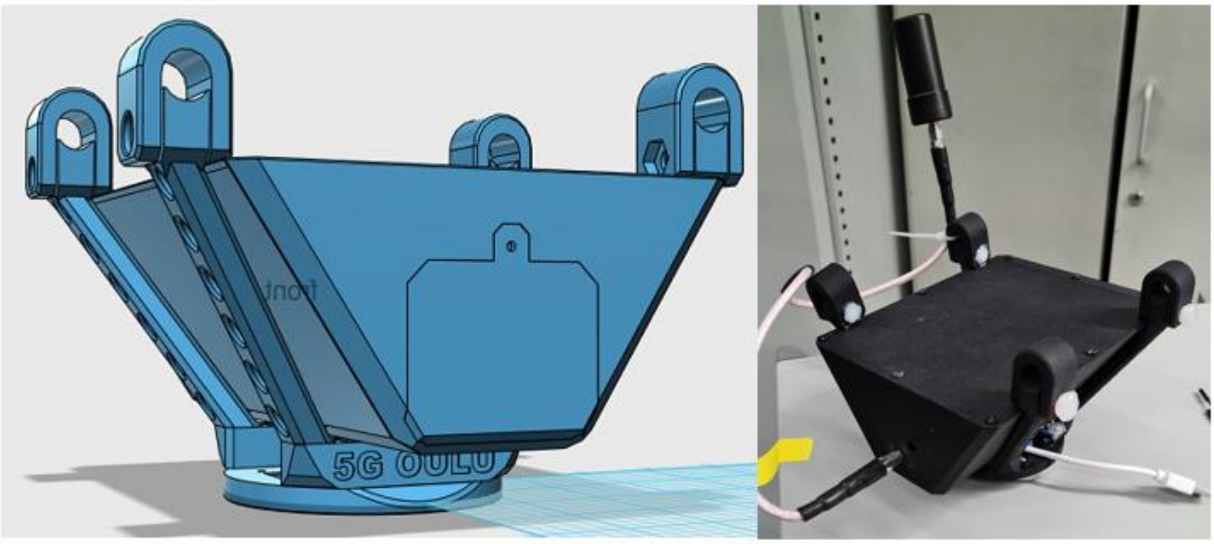

Figure 19. Payload adapter. Left side is the 3D model and right side is the ready component.

4.6. UAV enabler 5: LiDAR for mapping

4.6.1. Description

As UC3:SC1:sub-SC2 intends to trial using 5G to stream large amounts of data while inspecting electric power lines, a LiDAR was planned to be used together with a high-resolution camera. A LiDAR in this scenario would enable capturing the 3D structure of scanned objects in real-time and detecting significant faults, like fallen trees, quite promptly and effectively.

This enabler entails integrating a lidar scanning head, its interface board, inertial measurement unit (IMU), a dedicated GPS receiver, on-board computer and its related software onto the UAV. Physical mounting and power delivery for all hardware components, installing the Robot Operating System (ROS), and appropriate software configurations will need to be done to complete this enabler.

4.6.2. Features and functions

The main function of this enabler is to collect data during the flight for 3D mapping while enabling the ability to stream, process, visualize and store the collected data. This enabler is based on the Velodyne VLP-16 LiDAR sensor, Inertial Measurement Unit (IMU), On-Board-Computer (OBC) and ROS.

The VLP-16 sensor uses an array of 16 infra-red (IR) lasers paired with IR detectors to measure distances to objects. LiDAR sends data through its Ethernet port as User Datagram Protocol (UDP) packets. Then, ROS running on the OBC is utilized to:

- Capture the raw LiDAR and IMU data;
- Convert the data for building the point cloud;
- Optimize LiDAR odometry by using the IMU measurements;
- Store and replay the recorded data;

- Visualize point clouds and mapping process.

4.7. UAV enabler 6: Data streaming

4.7.1. Description

Live streaming of the scanned point cloud is needed to achieve real-time display for the operator and offload the OBC from resource-hungry data processing tasks. The stream should be able to adapt to different connection speeds, be secure and robust.

4.7.2. Features and functions

Live streaming of the point cloud to the GCS, and the Edge Server is implemented to achieve low delay between scanning and seeing the results. Rostopics containing the necessary information (point cloud data, IMU measurements, GPS coordinates) are streamed by deploying the ROS system across multiple machines. The connection is established by using Husarnet [10] – a global P2P network layer dedicated to robotics.
Dynamic data streaming has been implemented to lower the latency of the point cloud stream in varying connection speed situations. Down-sampling is done by using a voxelized grid approach, therefore reducing the total number of points streamed.

4.8. UAV enabler 7: Data processing

4.8.1. Description

The data captured during the trial of UC 3:SC1: sub-SC2 will need to be processed to be truly useful. Measurement points scanned with the LiDAR will need to be mapped to a coordinate system using the same reference for each point. Furthermore, the scanning output should also be available in the LASer (LAS) file format. The images captured during the trial would also need to be processed to detect specific objects and power line faults automatically. These processing results would need to be presented to the operator in a user-friendly manner.

4.8.2. Features and functions

A real-time mapping algorithm is planned to be implemented for visualizing the scanned infrastructure. Processed LiDAR, IMU and GPS data will be used to generate the map in a PCD file format. Then Point Data Abstraction Library (PDAL) will be used to convert the map to the LAS file. Results can then be viewed in any software supporting LAS format.
Hepta will also be using Convolutional Neural Networks (CNN) for object detection from photos. CNN is a Deep Learning algorithm that can take an input image, assign learnable weights and biases to various objects in the image, and differentiate one from the other. The architecture will incorporate two parts – the first one detects features of interest, like insulators, then the second part determines which objects are faulty and which are not. The model will be trained on images previously captured by Hepta and used in Hepta's cloud-based software uBird.

4.9. UAV enabler 8: Interface with autopilot

4.9.1. Description

The purpose of this enabler is to act as an interface between the telemetry stream and any third parties and to forward C2 data to enable multiple UAVs to be controlled by it and multiple control sources to be used.

4.9.2. Features and functions

MAVLink protocol architecture will be implemented. MAVProxy will be used to forward the messages. The main requirements of the enabler are to:

- Establish the communication between the drone and the operator’s station by sending the C2 and telemetry using MAVLink;
- Send telemetry to UTM;
- Enable remote monitoring by third parties.

Flight parameters are sent from ArduCopter running on Flight Controller to the OBC. Then these parameters are encrypted and proxied to an AWS EC2 instance using MAVProxy. On EC2, the stream is decrypted, and the required data is extracted using the Dronekit library. Finally, the data is written to a database to facilitate third parties' access and forwarded to UTM using the provided API interface.By reading the stored telemetry data and other relevant metrics (like OBC resource utilisation) from a database, third parties can further use it to display the UAV position on a map on a web page, replay the flight Etc.

4.10. UAV enabler 9: Data cloud

4.10.1. Description

Hepta has developed a software environment, called uBird, to analyse large amounts of data and images. The uBird platform can process photos and use machine learning to identify the common defects of power lines. Main features of the uBird include:

- Managing images gathered by drones;
- Map pole positions or other positions of interest;
- Find and annotate defects;
- Analyse and review outcomes on a powerful dashboard;
- Generate actionable reports for maintenance teams.

Before developing this enabler, there was no scalable way to upload and trigger data processing automatically.

4.10.2. Features and functions

The goal of this enabler is to automatically upload captured images to uBird and pass them through the fault detection mechanism. Photos are going to be sent directly using an HTTP POST request and token authentication. Authentication token (API key) permits uploading photos to a pre-created project in uBird.
Trained Machine Learning models will be incorporated into uBird. Individual images captured in the trial are planned to be uploaded into uBird via an API when they are captured. The detection model is then planned to be run on these images as batch jobs at set intervals. The results can then be seen in the uBird UI by the drone operator with minimal delay.

4.11. UAV enabler 10: GCS

4.11.1. Description

Hepta's GCS is a combination of software running on the operator's computer. GCS will give the operator flexible control over the UAV; it is sensor payload and the components needed for data processing and forwarding. It will also include tools for data visualisation.

4.11.2. Features and functions

GCS's main functions are to monitor the flight and give commands to the UAV. Additionally, it is going to include the following functionality:

- Mission planning and flight management;
- Interface for controlling the camera and LiDAR payloads;
- Interface for monitoring the photo analysis results (uBird);
- Receiving First-Person View (FPV) video stream and telemetry from UAV over the Internet;
- Interface for viewing LiDAR data;
- Software to stream the required data to a video server.

The mission plan is created and uploaded to the drone's flight controller using QGroundControl software. Flight interruption (if needed) is done with Guided mode commands for both altitude and position.

The camera parameters are set according to the light conditions using CameraGCS on the GCS computer and CameraCLI on the OBC. Software is used as a graphical user interface for libgphoto2. Geotagging for images is implemented using ArduCopter on the flight computer (Pixhawk) and connected using the Dronekit library. Exchangeable image file format (Exif) data of picture files is modified with ExifTool on OBC before uploading to uBird (AWS S3). The command to start image processing is sent via uBird REST API. Photo analysis results are displayed in the uBird web interface.

FPV video is being streamed from the drone to the GCS using Gstreamer in the OBC. For displaying the received video stream, a module based on Gstreamer is being used in QgroundControl.

OBS Studio [11] is used to stream screens from the GCS to AWS Elemental MediaLive video server using RTMP protocol. Further, the live video stream can be viewed using M3U8 format.

4.12. UAV enabler 11: Data processing

4.12.1. Description

This enabler aims at processing bathymetric readings that the Hydradrone provides. Bathymetric readings are used to map water depth; they are valuable data for seafloor terrain visualization and better knowledge of the operating environment.

However, raw bathymetric readings cannot be direct inputs to visual representation:

- They may involve abnormal values;
- They may be too scarce to provide a representative view of the underwater topography.

This enabler tackles both issues by means of Machine Learning techniques.

The data processing enabler focuses on bathymetric processing. It is thus specific to Alerion's scenario, namely UC3:SC1:sub-SC3 "Inspection and search and rescue in a large body of water".

4.12.2. Features and functions

A view of the execution context of the data processing enabler is provided in Figure 20. The interaction between the data processing module and the bathymetric sensor follows a polling pattern: the former is free to request Figure 20 new bathymetric data. The polling frequency depends on the sensor acquisition frequency. The deployment architecture leverages 5G possibilities: the data processing being a computational-intensive application, shall be performed on edge. This, however, requires secure communication channels, which is ensured using Alerion's *secu-router* for MAVLink messaging protocol [5].

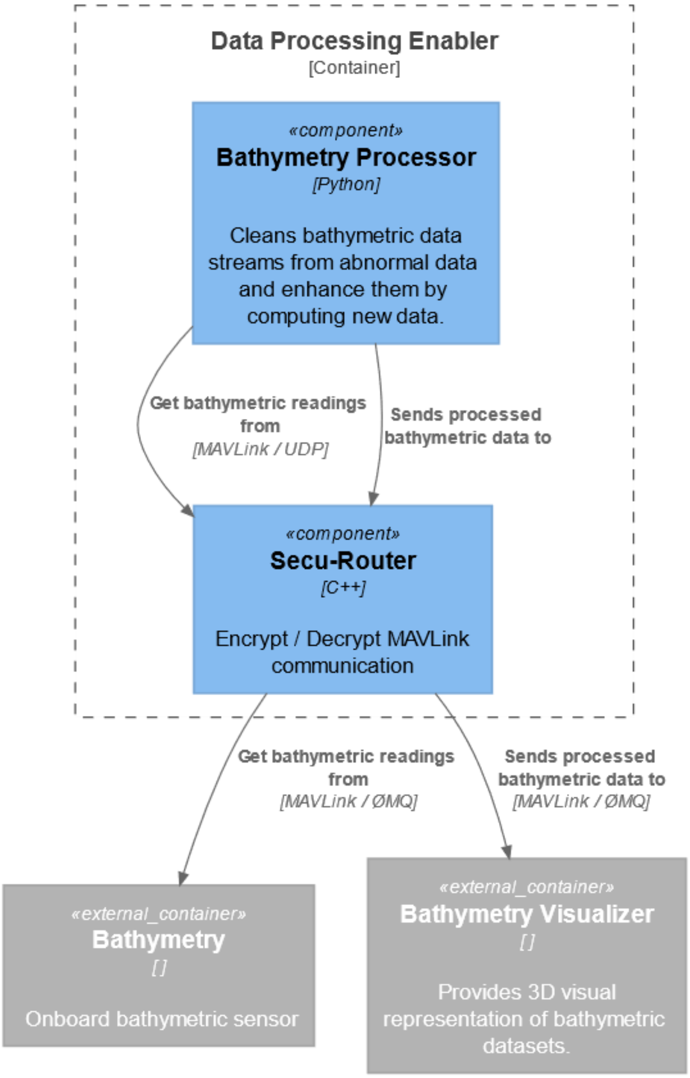

Figure 20. Component Diagram of the Data Processing Enabler

After processing a bathymetric reading, the bathymetric processor sends at least one new bathymetric data to the bathymetry visualizer.

4.13. UAV enabler 12: Sensor streaming

4.13.1. Description

This enabler is used to interface with the payload sensors on the drone, extract their data periodically and establish a connection to distribute it to the *Data Processing* enabler or a GCS. As the volume of data to be streamed can vary depending on the sensor loadout of the drone, scalability of data throughput is an important objective of this enabler. Latency can be important for other types of sensors such as video cameras and provisions to reduce it as much as possible are made.
Resiliency to a loss of connectivity is also integrated within this enabler in order to minimize data loss. Reliability of the data transmission is ensured as much as possible throughout the lifecycle of the enabler. Security is also of concern when handling data. The enabler provides sufficient security to prevent third parties from intercepting and decoding the data.
This enabler is used in Alerion's scenario. It will be used to provide the low-level sensor output capture as well as the transport from the drone (*Hydradrone* enabler) to the MEC, specifically to the *Data processing* enabler. The enabler is explicitly developed to interface with the bathymetry payload but could be readily extended to other payloads. Thus, it is an essential piece of Alerion's scenario.

4.13.2. Features and functions

There are two main functional software components involved in this enabler:

1. The first software component – named *SensorStream* – is responsible for low-level communication with the drone's sensor subsystems. It takes the form of a constantly running daemon-type application on *Hydradrone*'s payload computer. Note that An application is said to be a *daemon* when it does not need any user input nor does it produce any output for users. It can thus be run as a background process. Although it runs continuously from drone power-up, it does not stream any data until requested to do so on its secured network connection. When a request is received to start the streaming process for a particular payload, it starts the necessary module for interfacing with the payload driver and emits the data towards the second software component: *secu-router*. This component also handles the configuration of the payloads before and during the execution of a scenario. Drivers for the following payloads are available:
    - The power LEDs on each arm of the drone;
    - The main status LED of the drone;
    - The sonar ranging probe;
    - The electric actuator responsible for lowering payloads into the water.
2. The *secu-router* software component is responsible for establishing and maintaining a secure connection to peers on the MEC and elsewhere. It takes the form of a dynamic library with a simple C API. It is integrated into other Alerion enablers and takes on the same role of providing secure communication using the *MAVLink* messaging system. The connection is initially established using a hostname and port number. All the peers on the network are then identified using the Heartbeat mechanism provided by *MAVLink*. Proper routing of the message by *secu-router* is enabled by a combination of system and component IDs which uniquely identify each component of the whole *MAVLink* network. Although Alerion has previously developed secu-router, there is a need to adapt it to this context.

4.14. UAV enabler 13: Alerion's GCS

4.14.1. Description

This enabler is used to show the payload data clearly to the ground crew. It presents necessary information for the flight (be it automatic or manual), the payload status, and all sensor retrieved data. It is robust against a loss of connectivity with the drone through message queuing and automatic reconnection. It also provides for the reception of the secure data streams coming from the drone and MEC components. As some data are required in the short-term decision-making process for mission execution, the latency from data reception to display has to be kept low. Any communication failure is also readily shown to operators so that they may avoid relying on stale data. Drone and payload control before, during and after the flight is an important part of any UAV scenario. This enabler aims to display valuable information to the pilot, pilot in command (AIRBOSS), and the payload specialist roles. Depending on environmental conditions, this enabler may also be required to conduct the mission safely and effectively. Finally, this enabler produces the visible data that will be exploited for the outreach of this scenario.

4.14.2. Features and functions

The large scope of *Alerion's GCS,* illustrated in Figure 21, necessitates the use of multiple software components:

1. *QGroundControl* is the common ground control element for many drone scenarios. It provides a way to adjust flight parameters on the fly. It also provides a map/tool to prepare a waypoint mission as well as a real-time map of the drone and its environment during the mission. It can also show video feeds coming from the *Sensor stream* enabler. It has been customized to work with the *Hydradrone* enabler by adding special waypoints during missions that signal the hybrid drone to change its configuration from aquatic to aerial and *vice-versa*.
2. *PayloadManager* is an application running on the GCS alongside QGroundControl. It is responsible for the payload management and control before and during the mission as well as for showing the payload data in an intuitive format. It includes the *secu-router* plugin to establish secure *MAVLink* communications with the MEC or UE. This secure link is used to receive some payload data directly from the UE and some data that the Data processing enabler has processed. *PayloadManager* is also responsible for the redistribution of *MAVLink* messages to and from *QGroundControl*.

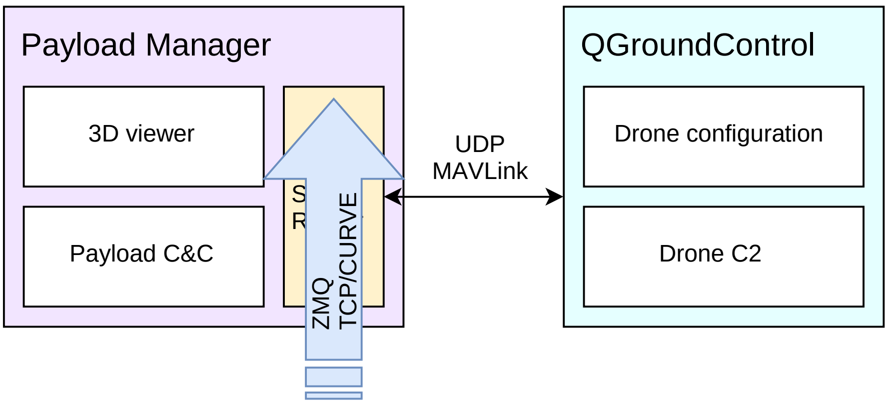

Figure 21. High level overview of Alerion's GCS architecture

4.15. UAV enabler 14: Hydradrone

4.15.1. Description

This enabler aims at extending Alerion's Hydradrone to support 5G connectivity. The Hydradrone is an amphibious Unmanned Aircraft; that can take off and land on both solid ground and water. After landing on water, the aircraft features a sailing mode enabling operation on low battery consumption. This enabler provides means to communicate with the Hydradrone using the 5G network for Command and Control and state monitoring.
The Hydradrone is a custom Unmanned Aircraft built for both flying and sailing. It is thus specific and necessary to Alerion's scenario involving a body of water, namely UC3:SC1:sub-SC3 "Inspection and search & rescue in a large body of water".

4.15.2. Features and functions

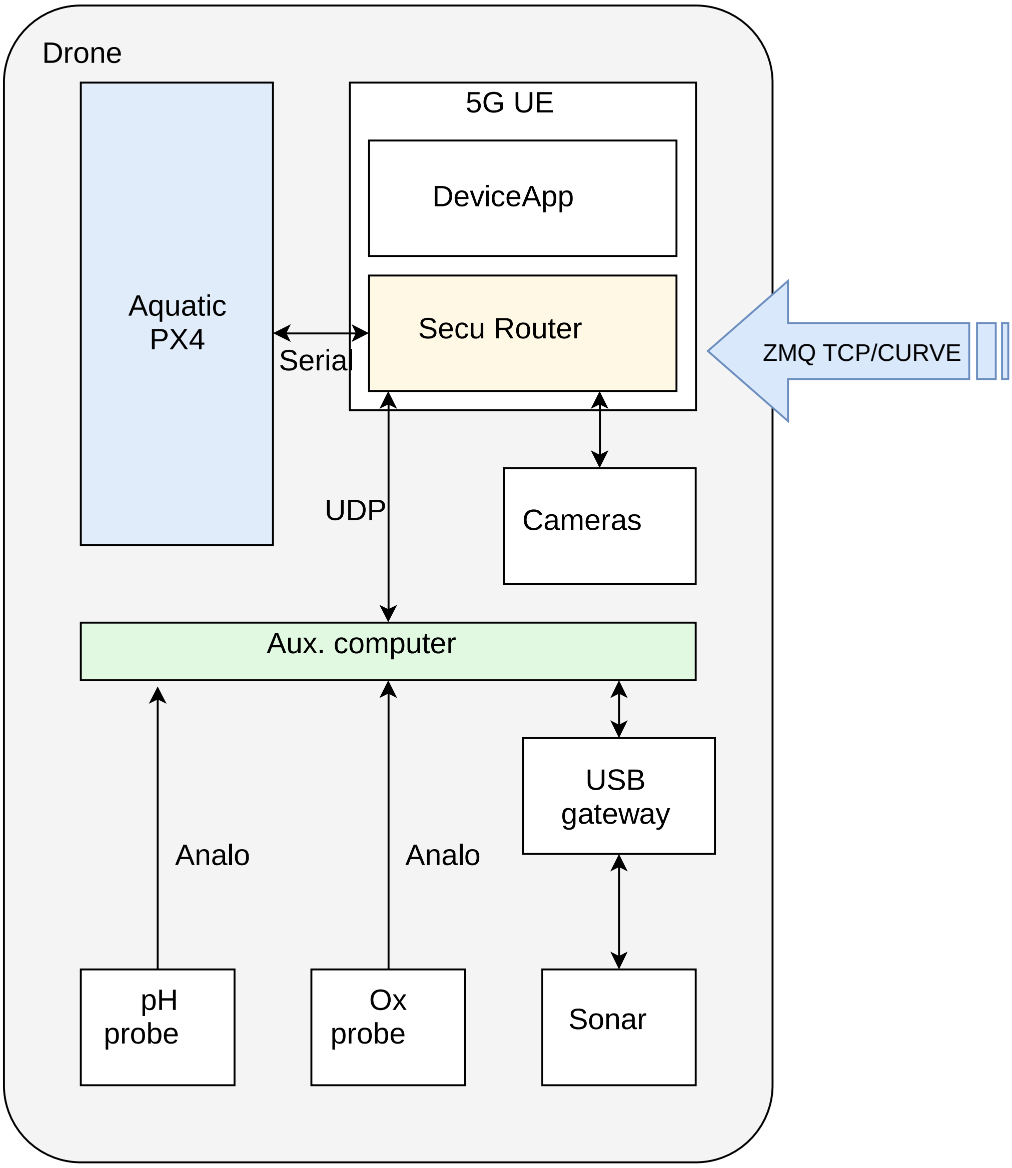

Figure 22. Hydradrone simplified internal structure

The basic principle of operations of *Hydradrone* is simple. When an inspection is required at a certain point or surface of a body of water, the UAV is set up at the closest accessible access point to the target. It is then programmed through *Alerion's GCS* to take off and fly to the nearest free water surface connected with the location of inspections, taking care to avoid any low-altitude obstacles such as tree branches. After landing, it uses a proprietary arm reconfiguration mechanism that enables thrust in the forward (+X) direction using its flight propellers. This configuration change then allows it to navigate to its destination and undertake the operational portion of its mission.
The aforementioned process is monitored by pilots through a direct line-of-sight if possible and through its onboard video system consisting of a forward-facing camera for general navigation and a downward facing camera for take-off and landing.
Once at the operational part of the mission, the probe(s) is deployed into the water, and measurements are started. The collected data is sent back to the *Data processing* enabler through the 5G network.
At the end of the operational part of the mission, probes are retracted as required, and water navigation begins towards the location of the water landing earlier in the mission. A take-off is initiated from the water, followed by a flight to the first take-off position of the mission – called the home point. Figure 22 shows a summary view of the internal architecture of *Hydradrone.*

4.16. UAV enabler 15: UgCS C2 cloud native application enhanced by CAFA Tech

This enabler is common for all use cases and is described in more detail in the section dedicated to the description of UC1.

4.17. UAV enabler 16: CAFA Tech cellular drone (PX4 platform-based) supporting onboard 5G commands via 5G UE

This enabler is common for all use cases and is described in more detail in the section dedicated to the description of UC1.

4.18. UAV enabler 17: 3D map for visualising QoS of 5G (CAFA Tech Analyzer)

4.18.1. Description

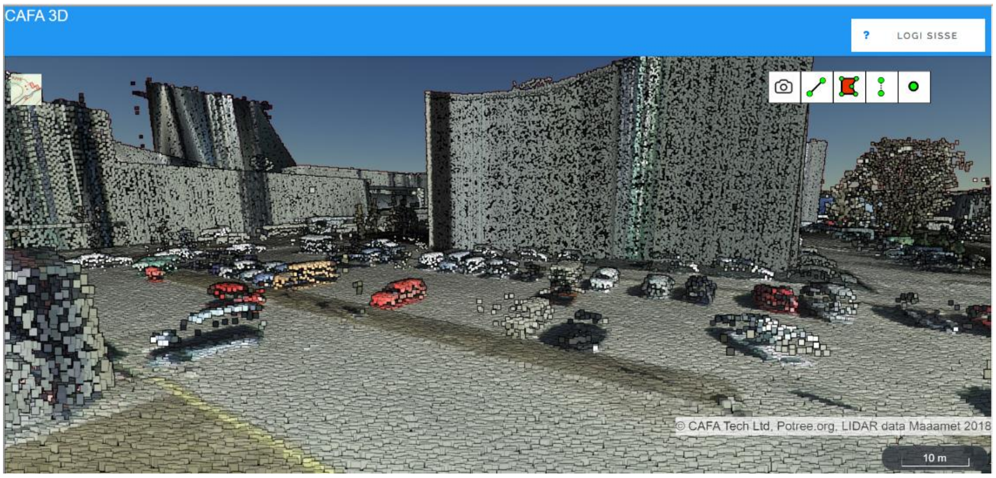

Figure 23. CAFA Tech Analyzer 3D map

CAFA Tech uses a 3D map which is using Potree-based point-cloud converter [12] on background. At first, the user needs a 3D map point cloud in LAS or LAZ format processed from LIDAR data or drone photos. Then the point cloud will be visualised on a 3D map. Then, the 5G base station(s) icons will be placed on the 3D map. The CAFA Tech cellular drone then carries 5G UE to measure the quality of 5G coverage from various positions with 3D coordinates (x, y, z) and timestamps. Measuring results are transferred to the server, and then results are visualised on the CAFA Tech 3D Analyzer. CAFA Tech Analyzer screenshot is shown in Figure 23.

4.18.2. Features and functions

The 3D map visualizes 5G network coverage in 3D to support planning drone routes.
The drone flight route can then be plotted in the CAFA Tech Analyzer to stay within 5G coverage.
The designed route can be exported and, in turn, imported into the CAFA Tech UgCS C2 platform.
5G Quality of Service data is displayed in colour on the 3D map (points with weaker signal quality in red and points with a quality above the threshold in green, and points with an average value in yellow). This way, in 3D space, the user can understand where 5G coverage is expected for the next drone flights and in what quality. The points of the measurement results are located in the air (based on 3D coordinates). The CAFA Tech Analyzer can be used with the Google Chrome web browser and the 3D map can be easily rotated in the 3D Analyzer.

4.19. UAV enabler 18: Drone flight plan enabler

This enabler is common for all use cases and is described in more detail in the section dedicated to the description of UC1.

4.20. UAV enabler 19: Geo-zones/AIM enabler

This enabler is common for all use cases and is described in more detail in the section dedicated to the description of UC1.

4.21. UAV enabler 20: Telemetry enabler

This enabler is common for all use cases and is described in more detail in the section dedicated to the description of UC1.

4.22. UAV enabler 21: UAVs control platform

4.22.1. Description

This enabler allows the IoTaaS provider presented in section 4.1.2 to track the set of UAVs deployed in the service area and control them in a real-time fashion. It is implemented as a three-tier web application composed of:

1. An interactive Web User Interface (WUI) that allows the IoTaaS provider to manage its UAVs.
2. A backend service that receives requests from the IoTaaS provider and either process them locally (e.g., request of listing the registered UAVs) or forward them to the virtual flight controller described in section 4.26 (i.e., requests related to UAVs control command), this service is also reasonable for collecting the telemetry data sent by the UAVs.
3. A database that stores information about the registered UAVs and the received telemetry data.

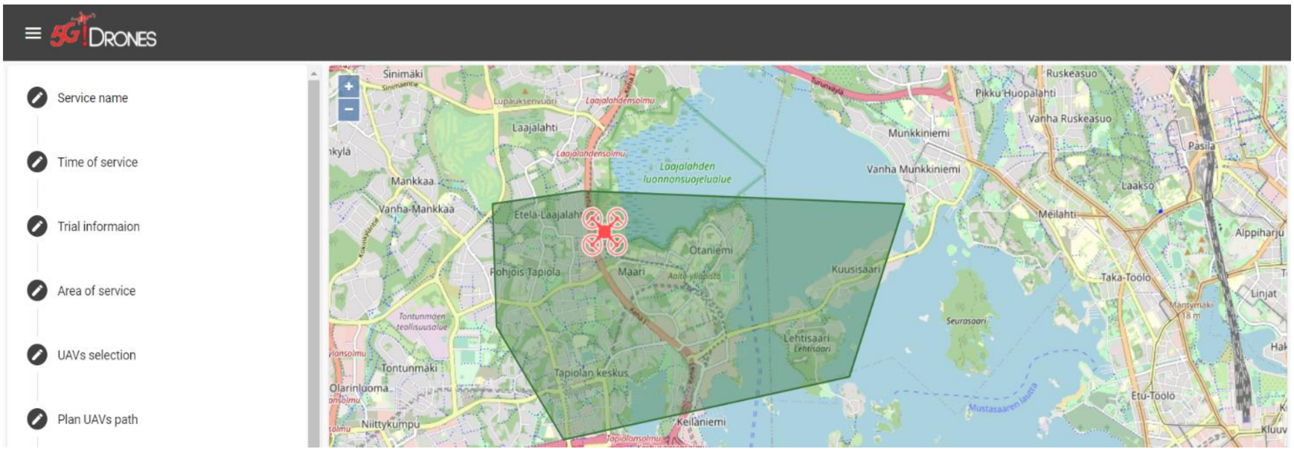

Figure 24. The Dashboard of the UAVs control platform developed for UC3:SC2

4.22.2. Features and functions

The UAVs control platform shown in Figure 24 ensures the following functionalities:

- **Users' management**: it is possible to register and authenticate several IoTaaS providers;
- **UAVs registration**: each IoTaaS provider can register its UAVs to the platform, describing the IoT services provided by each UAV (i.e., type of data and measurements that the UAV can collect);
- **Telemetry data collection**: the UAVs' telemetry data (e.g., GPS locations, speed, battery level, Etc.) sent by the virtual flight controller is parsed and made available to the IoTaaS provider;
- **UAVs control**: the IoTaaS provider can send control commands to its UAVs to redirect them to specific service areas.

4.23. UAV enabler 22: IoTaaS platform

4.23.1. Description

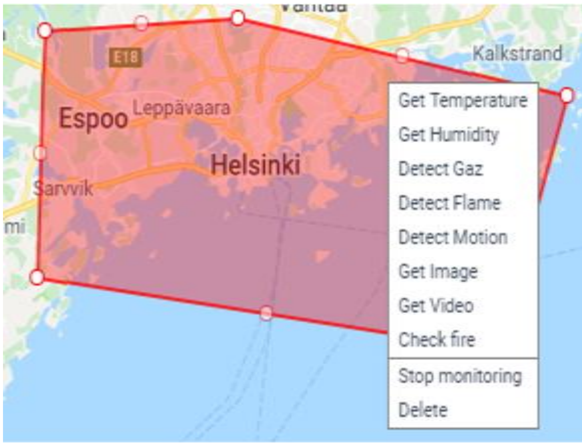

Figure 25. Requesting IoT service in Helsinki region

The IoTaaS platform allows IoTaaS consumers to access IoT services without configuring or deploying any IoT devices. As depicted in Figure 25, users can select a region of interest on the map present in the platform's dashboard and select the type of measures they wish to collect from that region. The platform will automatically take care of redirecting users' requests to the UAVs equipped with the appropriate IoT sensors and present in the selected region of interest. Whether no UAVs are available in the region of interest, the IoTaaS provider can remotely direct one or more UAVs to that region using the UAVs control platform.

4.23.2. Features and functions

The IoTaaS platform ensures the following functionalities:
Users' management: only the registered end-users and third parties can access the IoT services provided by the UAVs;

- **IoT service selection**: as shown in Figure 26, users can select an area of interest to seek a given IoT service (e.g., temperature, humidity, air quality, images, etc.);
- **Service orchestration**: the platform leverages a smart orchestrator that selects the UAVs that can satisfy the criteria of the user's request (i.e., the region of interest and type of sensors);
- **Data collection**: the IoT data can be collected in three modes: i) instantly by sending one request to the concerned UAVs; ii) periodically by collecting periodic data measurements from the concerned UAVs; iii) eventually by collecting data measurements from the concerned UAVs only upon the occurrence of some event (e.g., the sensed value of temperature exceeding a threshold);
- **Data management:** users can visualize and manage the collected data.

4.24. UAV enabler 23: Virtual flight controller (AU)

4.24.1. Description

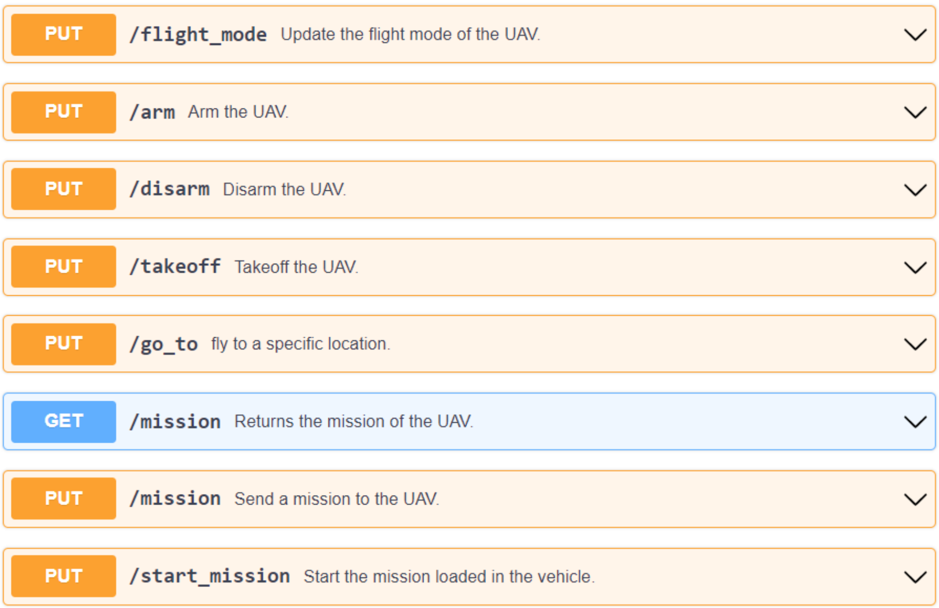

Figure 26. Example of APIs exposed by the virtual flight controller

It runs as a containerized application that exchanges C2 traffic with one UAV using the UAV telemetry protocol MAVLink. The UAV controller publishes the telemetry data (location, speed, battery level, Etc.) sent by the UAV to the control platform, which is made available to the IoTaaS provider. Moreover, as shown in Figure 26, the virtual flight controller exposes a set of APIs that allow the IoTaaS provider to interact with the UAVs in real-time.

4.24.2. Features and functions

The virtual flight controller enabler ensures the flowing functionalities:

- Exchanging C2 traffic with UAVs using the MAVLink protocol;
- Publishing the telemetry data toward the UAV control platform;
- Exposing a set of RESTful APIs for performing the following action on the controlled UAVs:
    - Checking the status of the telemetry connection to the UAV (i.e., established or failed);
    - Checking and updating the current flight mode of the UAV (e.g., AUTO, MANUAL, Etc.);
    - Arming and disarming the propellers of the UAV;
    - Taking off the UAV;
    - Landing the UAV;
    - Sending “Go-To” commands to the UAV for directing it to a specific location;
    - Checking and updating the current mission of the UAV (i.e., the trajectory to follow by the UAV).

4.25. UAV enabler 24: IoT gateway

4.25.1. Description

Figure 27. UAV equipped with IoT Gateway

As shown in Figure 27, the IoT sensors and devices are attached to the UAVs as an IoT Gateway. The IoT Gateway developed for this scenario consists of two components: i) a System on Chip (SoC) board (i.e., Raspberry Pi) that allows the establishment of connectivity to the IoTaaS platform and that runs the IoT Gateway driver described in section 4.28; ii) a Hardware Attached on Top (HAT) board that embeds the set of sensors directly plugged into the Raspberry Pi SoC. Two HATs have been developed, the first one includes Temperature, Humidity, and Gas sensors, whilst the second HAT includes Gas and Flame sensors. Moreover, optional cameras can be plugged into the IoT Gateway. An example of the developed HATs is shown in Figure 28.

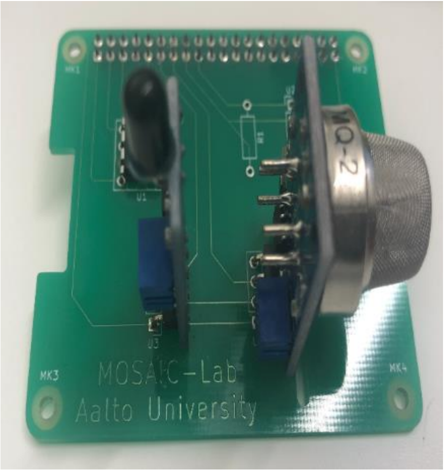

Figure 28. IoT HAT developed at AU

4.25.2. Features and functions

The IoT Gateway enabler ensures the following functionalities:
Provides the UAV with cellular connectivity;

- Embeds the IoT sensors to the UAV;
- Runs the software that allows the collection of IoT data;
- Supports a variety of sensors and HATs in a plug-and-play manner.

4.26. UAV enabler 25: IoT gateway driver

4.26.1. Description

It is the piece of software that runs in the IoT Gateway and communicates with the IoTaaS platform. It exposes a queening API using the Advanced Message Queuing Protocol (AMQP) protocol to receive data collection requests and publish the collected data measurements.

4.26.2. Features and functions

The IoT Gateway driver ensures the following functionalities:

- Communicates with the IoT HAT via low-level electronic buses: I^2C, SPI, UART for performing the data measurements;
- Exposes queuing APIs to the IoTaaS platform for collecting IoT data from the IoT HAT;
- Supports three data collection modes:

- **Instantly**: send one data measurement to the IoTaaS platform;
- **Periodically**: send periodic data measurements to the IoTaaS platform;
- **Eventually:** send data measurements only upon the occurrence of some event (e.g., the sensed value of temperature exceeding a threshold).

5. USE CASE 4: CONNECTIVITY DURING CROWDED EVENTS

5.1. Description and list of scenarios

The purpose of this scenario is to demonstrate how UAVs can improve connectivity services through 5G network capabilities in a highly crowded environment, e.g. during large events. The solution capabilities include autonomous flight planning and navigation, live-video streaming, utilising 5G User Equipment (UE) to provide ad-hoc connectivity to people.
UC4:SC1 is planned to be performed at the Egaleo stadium, where the deployed infrastructure and the necessary components will be utilized. These components are comprised of the 5G system and the UAS deployed in the Edge cloud, the UTM deployed off-site, the Streaming server deployed in a private cloud and three drones, one for patrolling, one for infrastructure and one for streaming HD video.

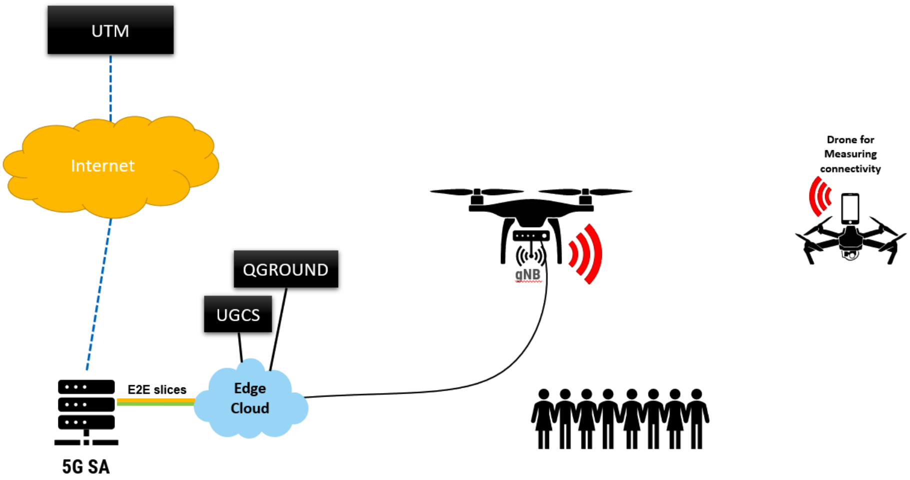

Figure 29. A high-level illustration of UC4:SC1

In the variant that will be tested during the trials, the drone will carry a 5G base station (gNB) and have an RF backhaul link to the ground 5G Core. This approach aims to expand the connectivity to the stadium in case that a crowded event takes place or other stadium patrolling services require dedicated private connectivity. A high-level illustration is shown in Figure 29.
The demonstration of the scenario is envisioned to be performed in two phases. During the first phase, the base station will be located at a specific position in the stadium focusing on the 5G propagation related to the direction and pitch of the 5G antenna. The patrolling drone will perform 5G network QoS measurements, and the surveillance drone will stream HD video. Based on the network quality situation and given the analysis of UL-VA (e.g., number of people in the stadium), the Event Command Centre can decide to deploy additional temporary Infrastructure drones with a 5G base station.
The second phase describes the flight that the infrastructure drones will perform to expand the 5G coverage to the stadium and, consequently, the connectivity for any additional services that require enhanced capabilities. Likewise, to the flight of the first phase, the patrolling drone will also perform 5G network QoS measurements, and the surveillance drone will stream HD video. The relative architecture is illustrated in Figure 30.

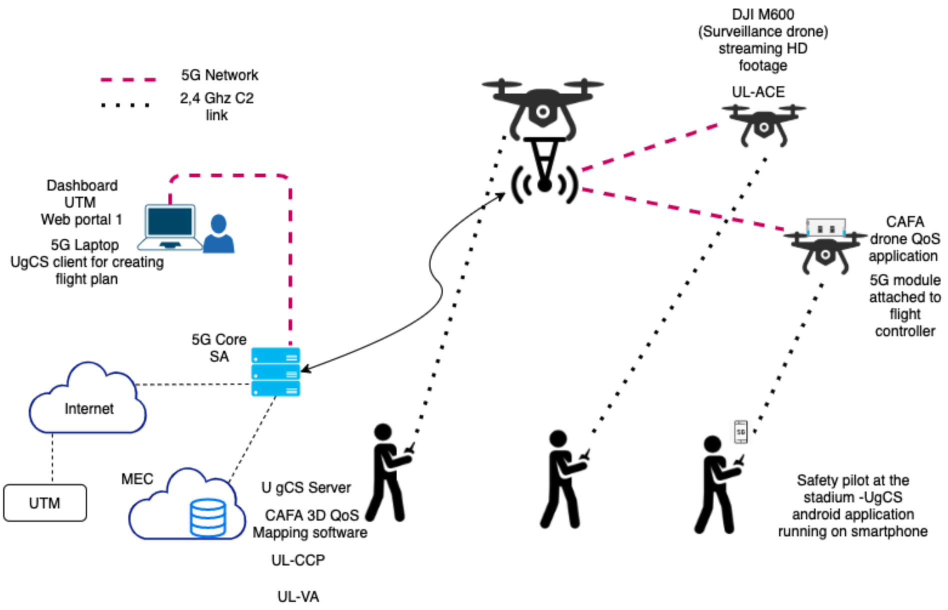

Figure 30. The relative architecture of UC4:SC1

Towards these goals and depending on the needs of this particular Use case/Scenario (UC4:SC1), the following UAV enablers are being introduced:

5.2. UAV enabler 1: UgCS C2 cloud native application enhanced by CAFA Tech

This enabler is common for all use cases and is described in more detail in the section dedicated to the description of UC1.

5.3. UAV enabler 2: CAFA Tech cellular drone (PX4 platform-based) supporting onboard 5G commands via 5G UE

This enabler is common for all use cases and is described in more detail in the section dedicated to the description of UC1.

5.4. UAV enabler 3: 3D-map for analysing QoS of 5G (CAFA Tech Analyzer)

This enabler is common for UC3 and is described in more detail in the section dedicated to the description of UC3.

5.5. UAV enabler 4: Geo-zone support enabler

This enabler is common for all use cases and is described in more detail in the section dedicated to the description of UC1.

5.6. UAV enabler 5: Telemetry enabler

This enabler is common for all use cases and is described in more detail in the section dedicated to the description of UC1.

5.7. UAV enabler 6: Drone flight plan enabler

This enabler is common for all use cases and is described in more detail in the dedicated to the description of UC1.

5.8. UAV enabler 7: Hepta tethered drone

5.8.1. Description

A heavy-lift drone is required to lift a 5G mobile base station to establish an *ad hoc* coverage area for UC4. Hepta's H19 helicopter platform in all-electric configuration is a suitable solution for this purpose. For a complete solution, it would need to be powered via a tether from the ground to allow for long airborne times, be able to monitor the power systems, be thoroughly characterized for knowing the operational limits and allow data transfer over the cable.

5.8.2. Features and functions

Hepta's H19 is required to lift gNodeB (5G mobile base station) or its antennas to establish a 5G connected area. H19 will be used in a fully electric configuration, and a power tether system will be attached to allow for maximum payload capacity and playtime. Necessary equipment for the enabler includes an onboard data link module, onboard converter, onboard UPS, ground power unit and the power cable. There are two RS-232 ports and two Ethernet ports available onboard to send data through the tethering cable.

Flight tests of H19 powered by AIM-Atlanta's tether have been performed to achieve confidence in-flight safety with tether and document payload capacity vs tether height. Back-up batteries have been installed and tested for the power failure scenario with the low voltage alarm trigger. Two tests were accomplished successfully with a stable tethered flight at 40 m for 6.5 min & 30.5 min with a 10 kg payload attached.

Ethernet connection through the tethering cable was tested by achieving the connection between the on-board computer (Raspberry Pi) and the ground computer. Through the datalink system, it is possible to see the state of the tethering system power components on both sides of the cable. Bandwidth test done with IPerf gave a constant rate of 21 Mbit/s.

5.9. UAV enabler 8: UL-ACE

The enabler is common with UC2:SC2. Please refer to section 3.5.

5.10. UAV enabler 9: UL-CCP

The enabler is common with UC2:SC2. Please refer to section 3.6.

5.11. UAV enabler 10: Unmanned Systems Video Analysis

The enabler is common with UC2:SC2. Please refer to section 3.7.

5.12. UAV enabler 11: Unmanned Systems Simulation Testbed

The enabler is common with UC2:SC2. Please refer to section 3.6.

6. CONCLUSIONS

This deliverable described the list of UAV vertical enablers for each use case of the 5G!Drones project. The list of enablers includes enhancement to existing UAV software and hardware and recent software development to support 5G!Drones UAV use-cases. These enablers pertain both to onboard units and include both control functionality and application-level one. The list also includes necessary software and hardware components to integrate 5G technology on UAVs (e.g., installation and integration of User Equipment onboard). After recalling the objectives and describing the four UAV use cases and their scenario, the deliverable presented a detailed description of the UAV enablers supporting the use case trial. For each UAV enabler, the deliverable provided: 1) a detailed description of the UAV enabler; 2) its functions and features.

Table 2. Summary of the UAV enablers and related use-cases

Enabler	Use Case 1	Use Case 2	Use Case 3	Use case 4
3D map for visualising QoS of 5G (CAFA Tech Analyzer) (CAF)			X	X
4K Video streaming system from drone to MEC/Edge server (CAF)	X			
5G modem enabler (NOK)			X	
5G smartphone & camera holder (NOK)			X	
Alerion’s GCS (ALE)			X	
CAFA Tech cellular drone (PX4 platform-based) supporting onboard 5G commands (CAF)	X		X	X
CAFA Tech Field GIS C2 system for Police operations and Drone Logistics (CAF)	X			
CAFA Tech UgCS-based drone flights C2 platform (CAF)	X		X	X
CAFA Tech Video analyser (VideoLyzer) (CAF)		X		
CCS (HEP)			X	
Data cloud (HEP)			X	
Data processing (ALE)			X	
Data processing (HEP)			X	

Data streaming (HEP)			X	
DJI Matrice 600 payload adapter (NOK)			X	
Drone flight plan enabler (DRR/FRQ)	X	X	X	X
Frequentis LifeX solution PoC activity (FRQ)		X		
Geo-zones/AIM enabler (DRR/FRQ)	X	X	X	X
Hydradrone (ALE)			X	
Interface with autopilot (HEP)			X	
INVOLI K-1090 receiver (INV)	X			
INVOLI.live data stream to U-space (INV)	X			
IoT gateway (AU)			X	
IoT gateway driver (AU)			X	
IoTaaS platform (AU)			X	
LEMAN (INV)	X			
LiDAR for mapping (HEP)			X	
Sensor streaming (ALE)			X	
Telemetry enabler (DRR/FRQ)	X	X	X	X
Trajectory planning for a fleet of 5G drones (THA)	X			
UAVs control platform (AU)			X	
UL-ACE (UMS)		X		X
UL-CCP (UMS)		X		X
Unmanned Systems Video Analysis (UMS)		X		X

Unmanned Systems Wi-Fi Access Point (UMS)		X		
UWB-based drone positioning system enabler (NOK)			X	
Virtual flight controller (AU)			X	

Table . summarizes the list of the UAV enablers and for which use-cases they are used. Most of these enablers allow the deployment of UAV components to execute each use-case and its related scenario. We remark that use case 3 involves the highest number of enablers, including several complex scenarios. Use-case 1 needs the lowest number as it includes a basic scenario related to UTM.

The involvement and evaluation of the presented list of UAV enablers will be conducted in WP4 and presented in the WP deliverables.

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