“NOVEL INTEGRATED SOLUTION OF OPERATING A FLEET OF DRONES WITH MULTIPLE SYNCHRONIZED MISSIONS FOR DISASTER RESPONSES”

ResponDrone

D7.1 General Architecture Design

Project Deliverable Report

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Glossary of terms and abbreviations used	
Abbreviation / Term	**Description**
ADS-B	Automatic Dependent Surveillance Broadcast
ADS	Air Data System
AES	Advanced Encryption Standard
AHRS	Attitude and Heading Reference System
ANC	Airborne Network Control
API	Application Programming Interface
ARP	Address Resolution Protocol
CEA	Commissariat à l’énergie atomique et aux énergies alternatives
CPU	Central Processing Unit
DHCP	Dynamic Host Configuration Protocol
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Center)
DNS	Domain Name System
DSS	Decision Support System
FLARM	Flight Alarm
FTP	File Transfer Protocol
GIS	Geographical Information System
GCS	Ground Control Station
GPS	Global Positioning System
GPU	Graphical Processing Unit
HMI	Human-Machine Interface
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
HW	Hardware
IAI	Israel Aerospace Industries
IAS	Indicated Air Speed
ICD	Interface Communication Document

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Glossary of terms and abbreviations used	
Abbreviation / Term	**Description**
ICMP	Internet Control Message Protocol
IMU	Inertial Measurement Unit
INESC TEC	Institute for Systems and Computer Engineering, Technology and Science
INHA	Inha University
IP	Internet Protocol
LTE	Long Term Evolution Network, 4G wireless communications standard
MVP	Minimum Viable Product
NCC	National Command Center
OSCC	On-site Command Center
PWA	Progressive Web Applications
PWM	Pulse-Width modulation
PFD	Primary Flight Display
RAM	Random Access Memory
RCC	Regional Command Center
RF	Radio Frequency
RPM	Revolutions Per Minute
RS	Recommended Standard
RTSP	Real-Time Streaming Protocol
SDR	Software Defined Radio
SNMP	Simple Network Management Protocol
SQL	Structured Query Language
SSH	Secure Shell
SSL	Secure Sockets Layer
SW	Software
TCP	Transmission Control Protocol
TLS	Transport Layer Security
TMM	Team and Mission Management

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Glossary of terms and abbreviations used	
Abbreviation / Term	**Description**
TX	Transmission
UAV	Unmanned Aerial Vehicle
UDP	User Datagram Protocol
USB	Universal Serial Bus
UTM	Universal Transverse Mercator

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1. Executive Summary

This report on General Architecture outlines the planned configuration, components and interfaces of the ResponDrone platform. Aiming to build a consistent and usable platform, the General Architecture laid out in this document is elaborated based on the different requirements gathered and established in the previous phases of the project (see section 9: References)

The platform architecture is structured into four major groups. The groups and their major components and stakeholders can be described as follows:

1. Remote decision makers and other remote stakeholders.
2. Web Interface, Services and Repositories:
   - Access control.
   - Web Interface and microservices.
   - Data repositories.
3. On Site – Ground:
   - On-site decision makers.
   - First responders' brigades.
   - Traffic and mission management.
   - Video Processing, displaying and broadcasting.
   - Airborne Network Control.
   - Ground Control Station (GCS, for UAVs control).
4. On Site – Air:
   - UAV Configuration 1: Alpha 800 + EO/IR cameras.
   - UAV Configuration 2: Alpha 800 + Communication relay.
   - UAV Configuration 2: Alpha 800 + Payload release system.

For the interconnection of the different components of the ResponDrone designed platform, the default communications protocol will be TCP/IP. Some exceptions are made, due to the limited number of physical ports available on some of the components (i.e. UAVs).

The platform has been designed to be modular, to ease its upgradeability and expansion with updated or new components, as it is captured in the graphical description of the architecture (section 4: Architecture).

2. Introduction

Deliverable 7.1, General Architecture Design, gives an overview of the different components of the system and their interrelationship, to provide a comprehensive image of the platform and its functionalities that the consortium intends to develop.

We present the different items that comprise the envisioned Minimum Viable Product of the ResponDrone platform using diagrams as well as descriptive text.

The platform architecture is structured in three major groups, depending on the location and nature of their assets:

1. **Web Interface, Services and Repositories:** This group entails the interface and services that all decision makers and commanders will use to improve their situation assessment. Its configuration will be designed to work as a cloud service, which means that the services are available independent of the end-user's location.
2. **On Site – Ground:** Brigades and components necessarily present at the emergency location.
3. **On Site – Air:** drones and payloads.

3. Methodology

The architecture is a step forward in the ResponDrone Platform design. It has been designed based on the results presented in "D15.4 ResponDrone Concept/Mock-ups" and "D15.5 Functional Design", which were built on top of "D15.2 Report of Field Studies" and "Summary of the Design Thinking Workshop" (see Annex of D15.4).

The proposed architecture is the result of consortium discussions and iterations over the basic architecture, presented also in "D15.5 Functional Design". As a result, we obtain a more detailed and precise model, presented in Figure 1, that is split into 3 images to enhance readability in figures 2-4.

In future tasks, the architecture will serve as a basis and a reference to plan the integration of the different components and as a reference in terms of educating and explaining the system.

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4. Architecture

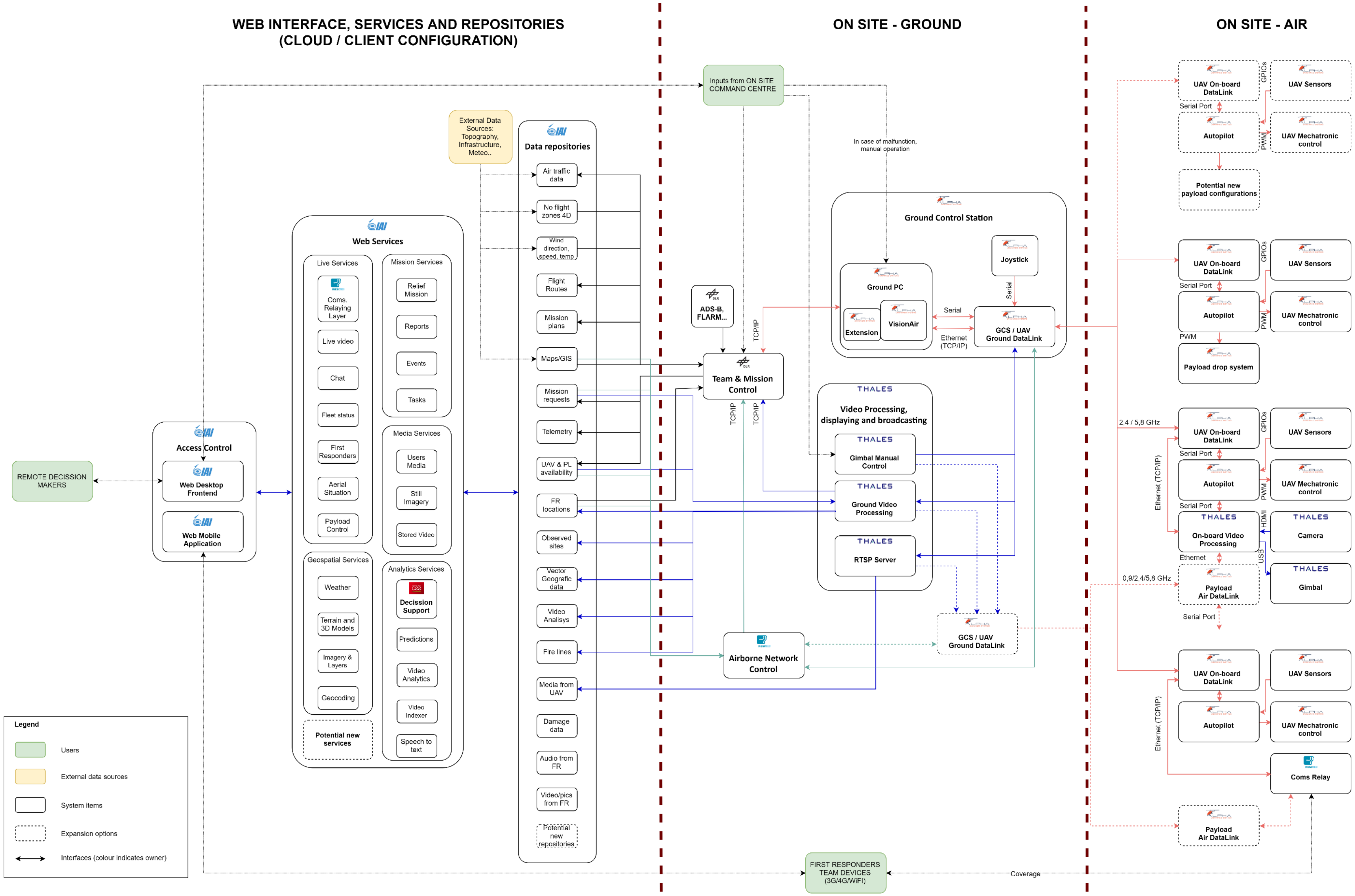

Figure 1: General Architecture – full overview

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4.1 Web Interface, services and repositories

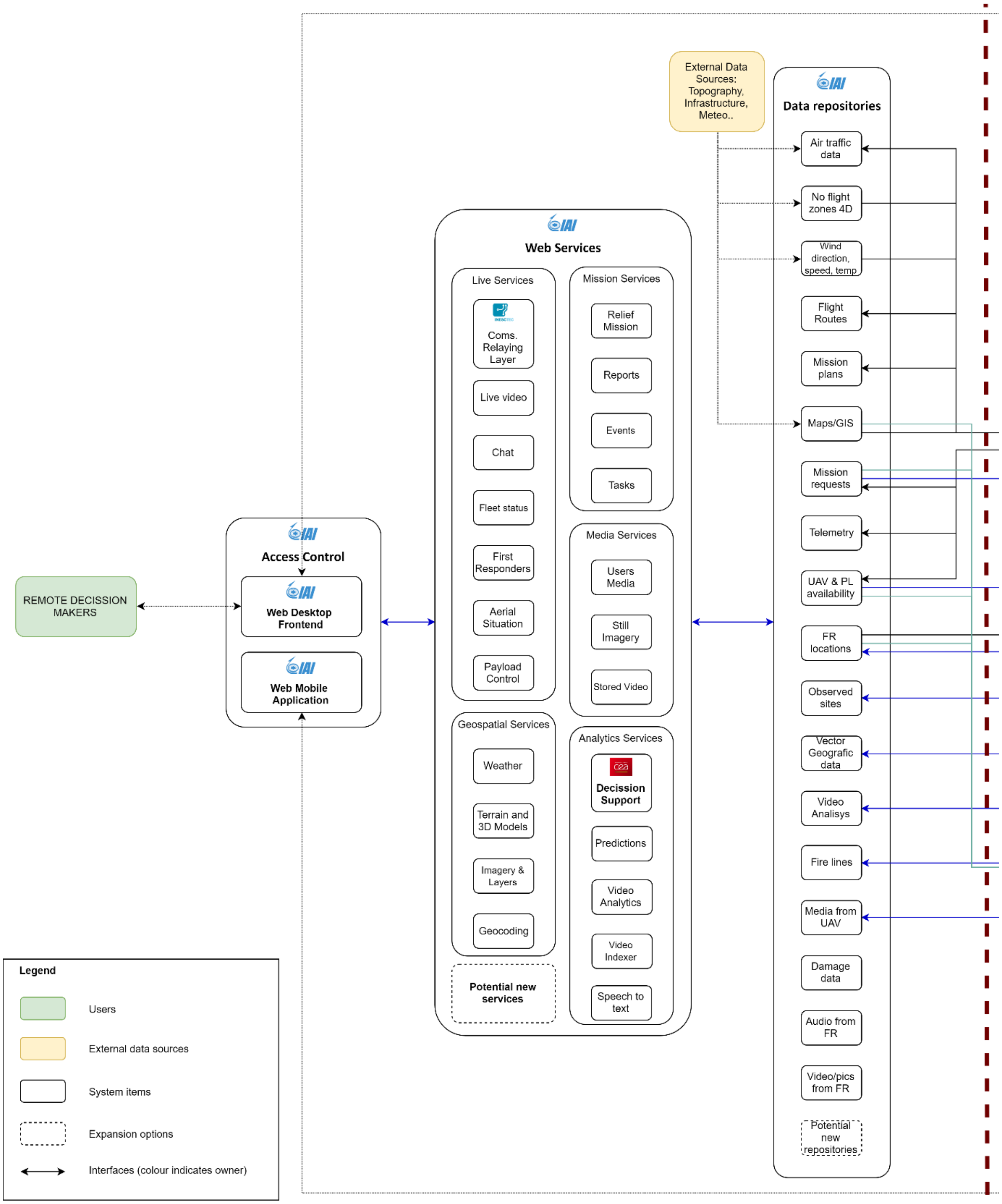

Figure 2: General Architecture detail: Web Interface, services and repositories

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4.2 On-site - Ground

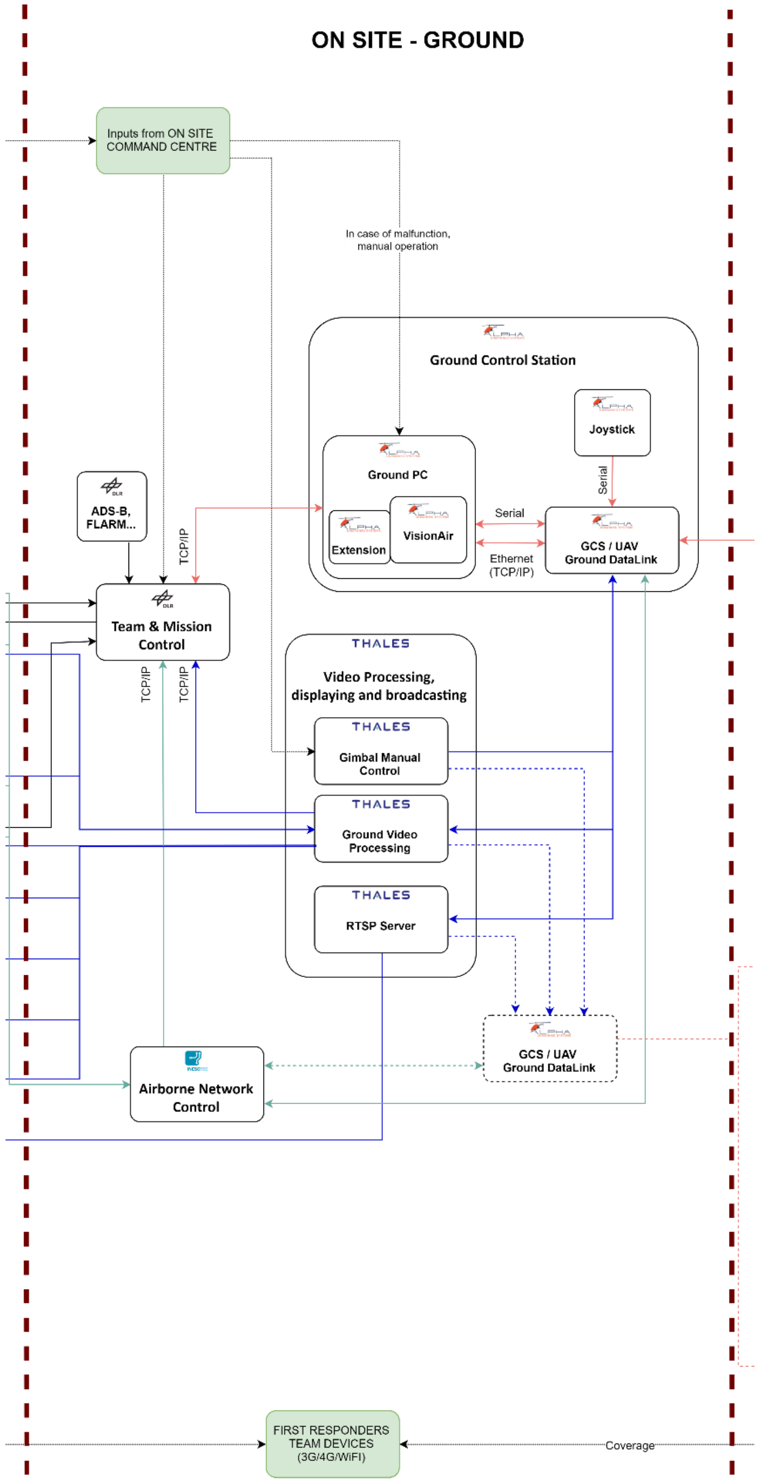

Figure 3: General Architecture detail: On-site – Ground

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4.3 On-site - air

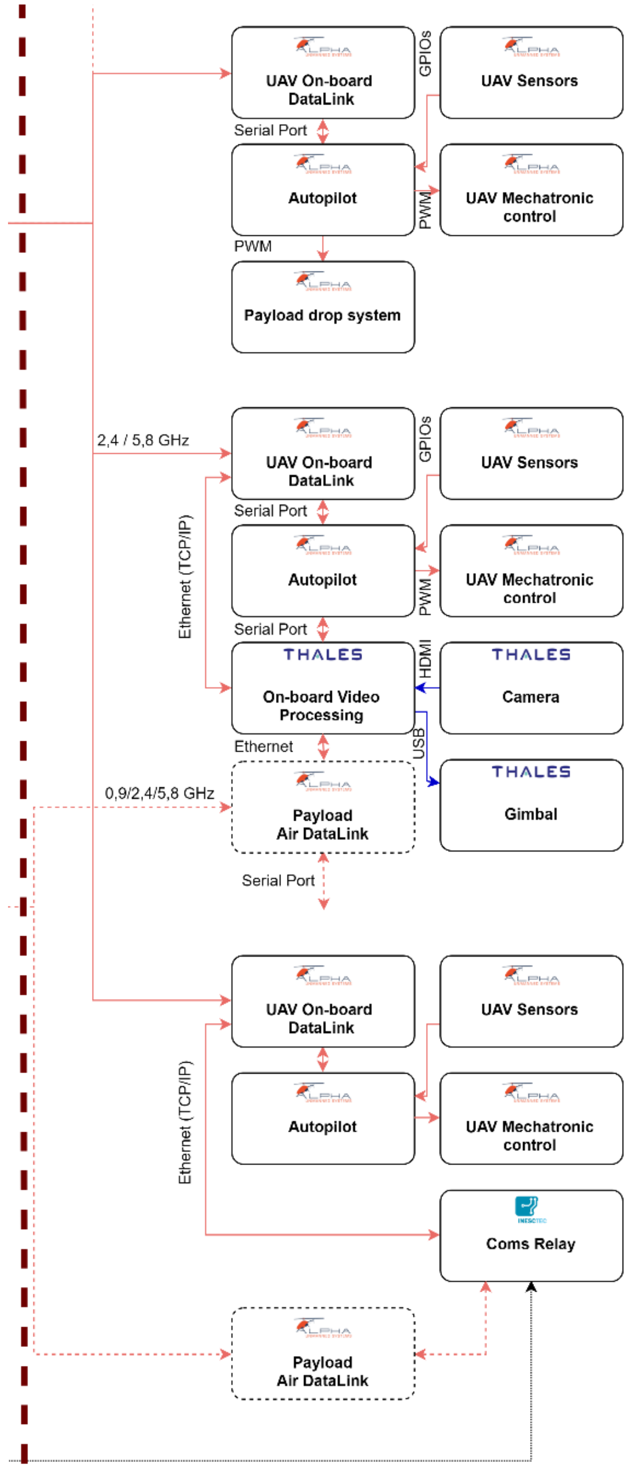

Figure 4 General Architecture detail: On-site - air

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5. Applications services and repositories

The ResponDrone system includes two web-based command and control applications in the cloud for two user groups:

1. The NCC/RCC/OSCC for the national, regional and on-site headquarters users.
2. The first responders' application for the mobile first responder users.

The control centers command the on-site services which transmit live data to the cloud and use the cloud repositories. This drastically increases access to the platform for stakeholders, and allows for much more scalable processing power. Additionally, mobile users and civilians (e.g., victims) can use the cloud services and transmit or receive data. This data can be text, pictures or video clips from the disaster area.

Internet connection might not be available in all the emergency locations, but the platform still needs to be functional. In order to create a platform that can work without internet connection but still benefit from it when available, a cloud-client configuration could be used.

Given that we aim to ensure the ResponDrone platform operability in all scenarios, some of the services and applications could be deployed in an on-site deployed instance of the cloud and therefore be accessible and usable even when there is no internet connection or when the connection is intermittent.

Additionally, repositories would also be deployed in on-site instances, enabling continuous access to data with minimum latency. The data gathered during missions would be first stored in the local instances, where lag requirements are more demanding while an uploading and synchronizing process will be running in parallel that will allow to have updated data in the cloud when internet connection is available.

Through this approach we achieve a reliable, uninterrupted and efficient access to the process and information on-site, where they are more needed while the information would be still accessible for remote decision makers.

Given the complexity of creating such a resilient configuration and the limited time-frame of the project, only the cloud version will be developed for the Minimum Viable Product that we intend to showcase. Nevertheless, it will be built taking into consideration design criteria that ease its future adaptation to the cloud-client configuration in further iterations.

5.1 Access Control

Applications and services (cloud and on-site) shall log into a centralized logging system. Logging shall include user interactions, service operations and authentication/ authorization audits. Logging shall allow developers and integrators to easily follow the flow of multiple and concurrent operations/logics which can involve multiple micro-services. Therefore, each log shall contain a globally unique trace ID per executed operation flow. The ID shall be generated at the start of the operation and passed along to all involved micro-services.

Services shall be deployed in an isolated, secured sub-network with an API Gateway allowing authentication, authorization, rate limiting and SSL/TLS termination. All communication, including publish/subscribe, shall be encrypted to and from the sub-network via certificates signed by a known certification authority.

5.2 Web applications

Applications shall be developed using Progressive Web Applications (PWA) technologies and principles. Applications are driven by incoming data and users' interactions. Applications and services shall be configurable via files and overridden by environment variables. This paragraph describes the web platform software architecture in brief, while the full description is developed in the D3.2 report.

5.2.1 NCC/RCC/OSCC Application

The command centers – National, Regional and On-Site – are used to command and control the relief missions. The users are securely authenticated and authorized via roles. The roles limit which commands they can execute and which data they can view.

The application is web-site based on Progressive Web App (PWA) principles. A Progressive Web Application is a type of an application software delivered through the web, built using common web technologies including HTML, CSS and JavaScript. It is intended to work on any platform that uses a standards-compliant browser. Functionality includes working offline, push notifications, and device hardware access, enabling creating user experiences similar to native applications on desktop and mobile devices. Since a Progressive Web App is a type of webpage or website known as a web application and there is no requirement for developers or users to install the web apps via digital distribution systems like Apple App Store or Google Play.[1]

The mock-up for the command centers is shown in Figure 5. It has been adopted from D15.4.

[1] https://en.wikipedia.org/wiki/Progressive_web_application

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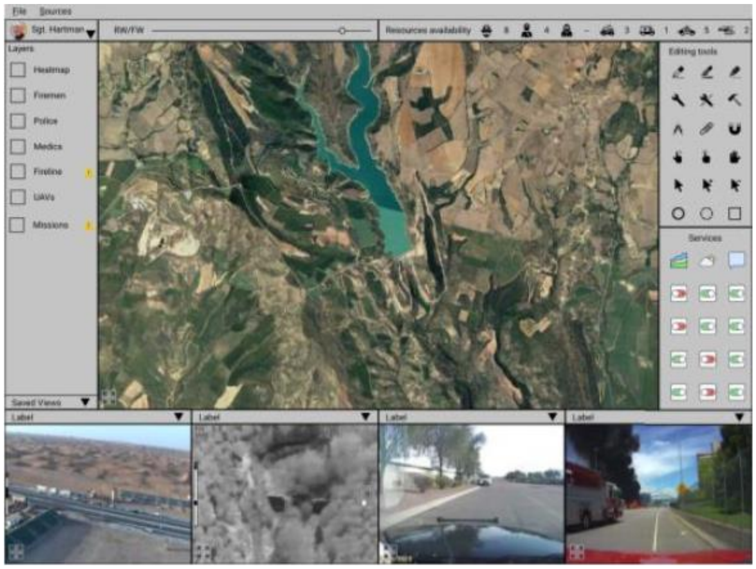

Figure 5: Desktop Main Interface Mock-up

The main components of the application are as follows:

a) Log-in interface.
b) Maps showing live mission information including[2] analytics and predictions.
c) Video showing live video from drones and First Responders.
d) Tables showing events, reports and tasks.
e) Control interfaces allowing creating reports, tasks and payload cueing.
f) Alerting mechanism that pushes data to the application and notify the user on important new data.[2]
g) Timeline allowing to view a snapshot of a point in time.[2]
h) Chat with other users. [2]

5.3 Web and Cloud Services List

The cloud architecture is composed of different layers of responsibility as it can be seen in Figure 6. The architecture, which includes the different services protected by a virtual network (Azure VNET), supports multi-region and availability zones. The access and frontend layers are closer to the edge and route data to the appropriate zones. The development (DevOps) layer controls and orchestrates the entire solution. The responsibility of each layer is detailed as follows:

[2] Items included in concept and design, but not foreseen to be implemented for ResponDrone MVP.

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1. **Development** - This layer is responsible for the development and operation of the deployed solution. The layer includes security, orchestration, development and management capabilities controlling all the deployment regions/zones.
2. **Databases and Storage** - This layer is responsible for hosting data. For each database/storage a dedicated service/API is used to expose it to the system abstracting the underlying technology.
3. **Events and Notifications** - This layer is responsible for orchestrating asynchronous/pushed data between services and applications. This also enables notifying mobile users of required actions even when their application is closed (push notifications). Note that the web-based application uses Apollo (A GraphQL service which allows frontend applications to query and retrieve relevant data) as mediator for receiving events and notifications.
4. **Geospatial Services** - Geospatial oriented services including map imagery, vector layers, terrain, 3D models and weather.
5. **Analytics Services** - Data analytics used to enrich raw data allowing users to make better decisions.
6. **Media Services** - Mission specific media originated from the system users (command centers, first responders, on-site fleet and civilians).
7. **Live Services** - Services that ingest and orchestrate live low latency data from end to end including video, chat, situational awareness and payload control (cueing).
8. **Mission Services** - Mission operational data from the users required to orchestrate and manage the relief missions.
9. **Frontend** - Applications hosting and services querying via Apollo (GraphQL). This layer is behind the access layer and is used as a distribution point for serving content closer to the edge.
10. **Access** - System access layer, which is used to authenticate and authorize users, route them to the fastest deployment zone and securely connect to the zone.

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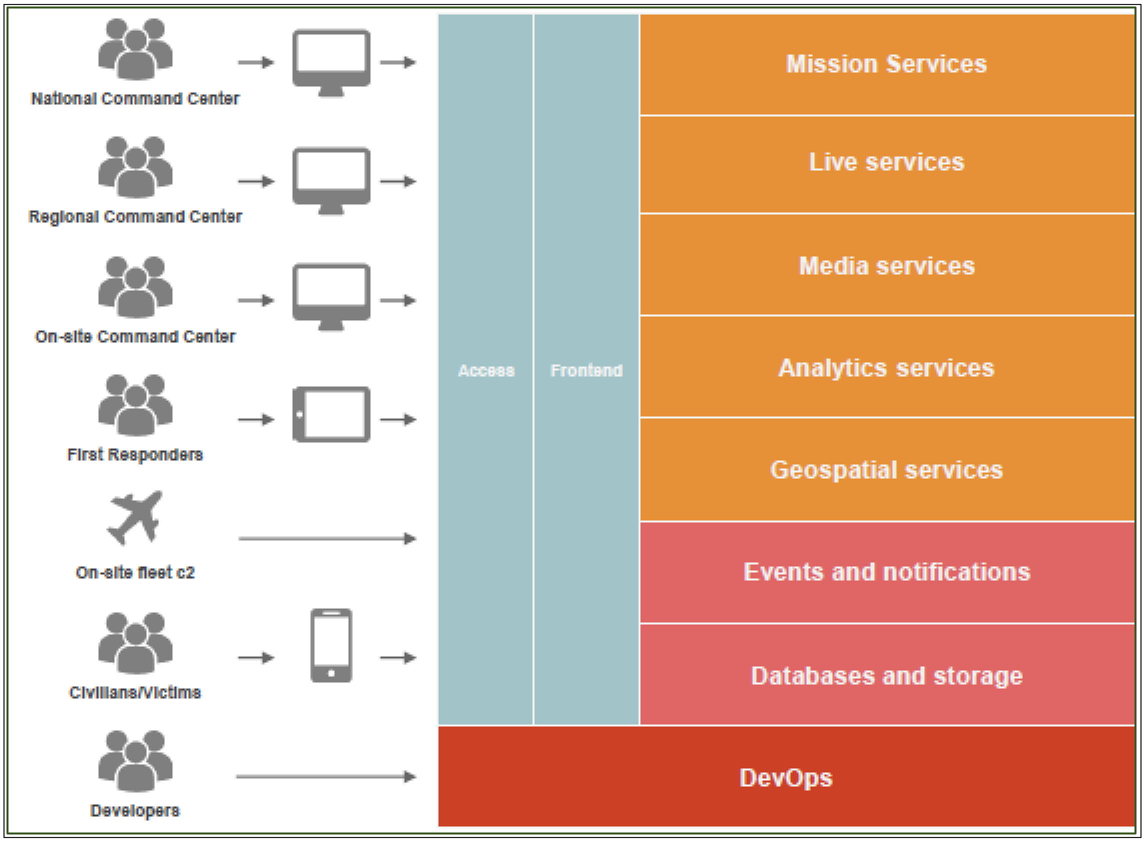

Figure 6: Software web applications architecture

Figure 6 shows the web application software architecture for the ResponDrone platform.

The following list describes the services main usage in each layer. For detailed description on the web-based architecture and its terms, please refer to D3.2 document:

1. Geospatial Services:
    1.1. Weather service. [2]
    1.2. Cesium ION - processing and serving 3D content such as terrain and surface models.
    1.3. Imagery and Layers service.
    1.4. Geocoding service [2] - used to transform location (latitude and longitude) into an address and vice-versa.
2. Analytics Services:
    2.1. Predictions service. [2]
    2.2. Video Analytics service.
    2.3. Video indexer service.
    2.4. Decision Support service
    2.5. Speech-to-text service. [2]

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3. Media Services:
    3.1. Users Media service.
    3.2. Stills imagery service.
    3.3. Stored video service.
4. Live Services:
    4.1. Coms. Relaying Layer
    4.2. Live video service.
    4.3. Chat service. [2]
    4.4. Fleet status service.
    4.5. First responders service.
    4.6. Aerial situational picture services.
    4.7. Payload control (cueing) service.
5. Mission Services:
    5.1. Relief missions service.
    5.2. Reports service.
    5.3. Events service. [2]
    5.4. Tasks service.
6. Frontend Services:
    6.1. Apollo - A GraphQL service that allows frontend applications to query and retrieve only relevant data
    6.2. Media Services.
7. Access Services:
    7.1. Application Gateway for data communications using HTTP protocol.
    7.2. Traffic Manager for data communications using non HTTP like TCP/UDP protocols.
    7.3. Active Directory B2C - Highly secured identity management service of system users. The service facilities single-sign-on between the users and the APIs (services) using open standards.
    7.4. Front Door - Scalable and secure entry point of requests to the system. The system can be deployed on multiple regions and zones. For better performance and recovery, the Front Door service load balances users' requests based on their proximity to a deployment region/zone and based on overall system load.
    7.5. CDN - Content Delivery Network that distributes static content to multiple regions.

5.3.1 Communications Relaying Layer

The Airborne Network Control (ANC) component outputs relevant state information to the On-Site Command Center, presenting, for example, the Current Mission Plans being executed and the expected network coverage. This information can be used by “Comms coverage” layer of the ResponDrone Graphical User Interface (GUI). Complementary, this information will be published in a data repository in order to help feeding the “Comms coverage” layer of the ResponDrone GUI.

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5.3.2 Decision Support Service

The Decision Support Service (DSS) developed by CEA is planned to be provided as:

- A web site that will serve for rule authoring that configures the decision-making process
- A web service that will provide the Decision Support Service during an ongoing crisis

The two components will be used in two different phases as shown in Figure 7.

- Rule authoring is done during **the preparatory phase**. Predefined rules will be available during the ResponDrone project. Thus, rule editing is optional. With the web-based editor, the predefined rules can be updated, changed, customized by deciders before a crisis. New use cases can be added as well.
- Decision support service will be used **during an ongoing crisis**. It will provide the decisions by applying automatically the rules to the situation. The supervisor will call the decision-making service that will contact the other services, databases, including the GIS, weather forecasts and video analytics results, to fetch all information needed. It may assess the situation, compute scores, raise alerts or recommend actions according to the predefined rules. The results will be computed on the fly and may, in some cases, change from time to time. The results of the decision-making service will be sent back to the ResponDrone GUI to be made available to the end-users and registered in a data repository.

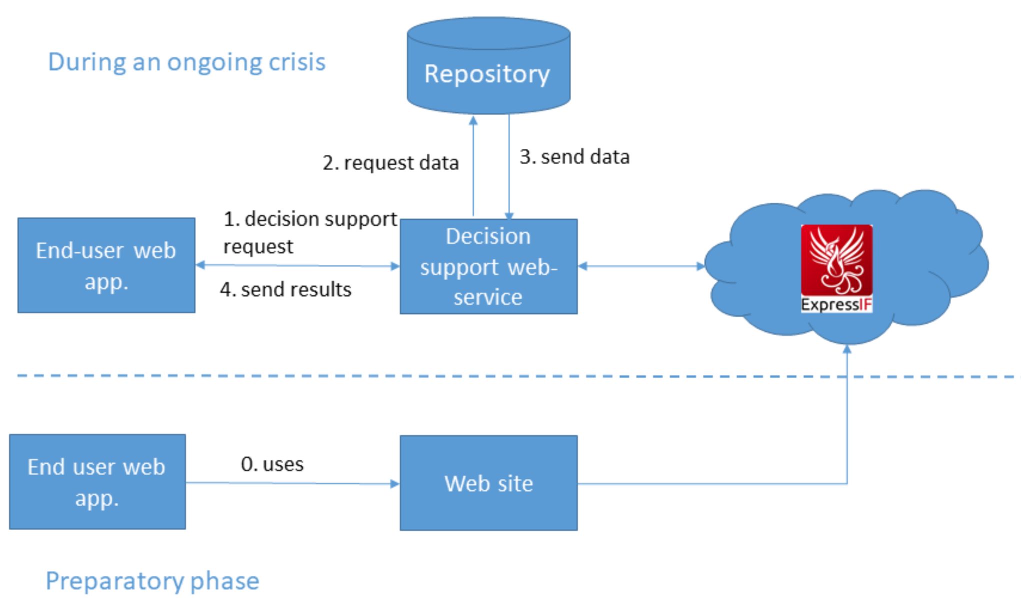

Figure 7: From decision support request to results

The results of the Decision Support System could be presented in different forms. There will be a key associated with a value that can be displayed in different formats:

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- **A map of numerical values** of the area of interest (e.g. a situational assessment map).
- **Numerical value associated to identified objects**: the object could either come from a GIS layer or be identified by video processing for instance.
- **Textual information** associated or not to identified objects (e.g. a recommendation, level of an alert, etc.).

The decision support web-service will be hosted on a local machine in order to prevent the effects of internet connectivity problems, or on a server of CEA.

5.4 Data Repositories List

The data repository is a data infrastructure that collects, manages, and stores data sets for data analysis, sharing and reporting. The data can be managed using various database tools, such as Mongo-DB, SQL-Server, etc. The data can be either structured i.e. SQL tables, or non-SQL such as XML/JSON documents. The data repository is accompanied with a micro-service that provides REST API for CRUD (Create / Read / Update / Delete) operations on the data. The data is accessed only through the micro-service which handles permissions and synchronization of the data. The repository is saved in the cloud. The following are the data repositories that shall be used:

1. Reports.
2. Disaster relief Missions.
3. Tasks.
4. Events.[2]
5. Flight Routes.
6. Data layers.
7. Resources availability.
8. Weather data[3].
9. Media Data (Video, Stills, Audio).
10. Aerial picture.
11. Terrain.
12. Maps/GIS.

For more details, please see deliverable D3.2 Preliminary Architecture and Concept.

6. On-site ground systems

6.1 Traffic & Mission Management

The Traffic and Mission Management (TMM) component is planned as a ground-based software system responsible for managing the individual UAV trajectories and ensuring their deconfliction

[3] Full weather support in future, partial weather interface in this platform

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and conformance with regulations, minimizing of risks and integration into a potential higher-level unmanned traffic management (UTM) system such as U-space.

The TMM component will be running on a stand-alone machine on the disaster site. On a conceptual level, the TMM component is responsible for the creating of UAV trajectories (defined as a list of 4D points) based on requests from the end users.

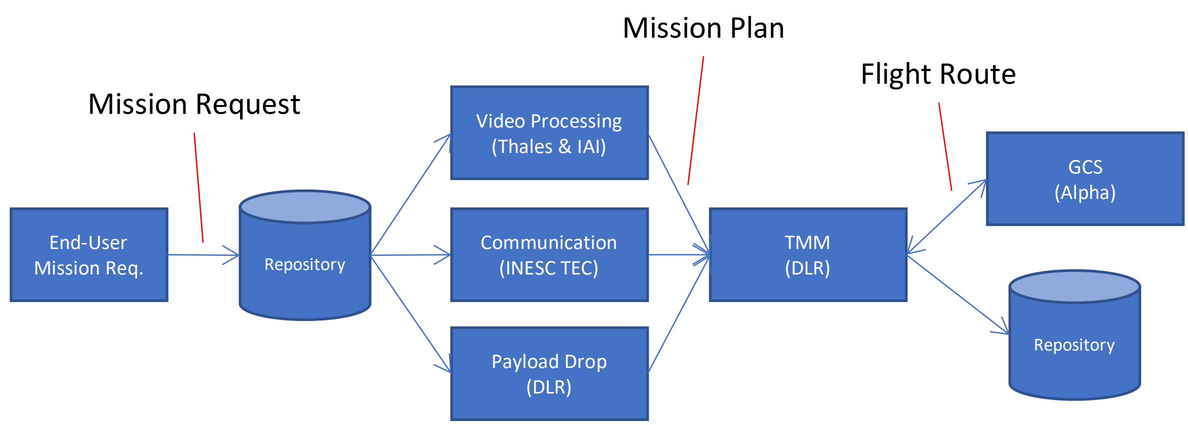

Figure 8: From mission requests to flight routes

Figure 8 above shows the planned workflow from the end user to the GCS. The end user submits a mission request using the web-based frontend. This request is stored in the repository. From this, the components of the individual use cases (e.g., video processing, communication, or payload drop) create a concrete mission plan to perform the mission. The mission plan is a more detailed version of how to execute a mission: For instance, a mission request could be "provide video footage of building X from the east". The mission plan to realize this mission could be "move UAV to lat/lon position X° XX' XX'' E Y° YY' YY'' N". From this mission plan, the TMM component generates a concrete flight route, which is used to position the UAV from its current position to the target position. This route must take into account the risk model (described in deliverable D2.1), including regulatory restrictions, risks to people and property, the UAV flight performance parameters etc.

The result of the TMM is therefore a list of 4D points describing the planned UAV trajectories to perform the mission submitted by the end user.

For this, the TMM will maintain several interfaces to its surrounding components, as described in Section 8, "Relevant Logic Interfaces".

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6.2 Video Processing and streaming

Figure 9 details the configuration of the information flow concerning video processing:

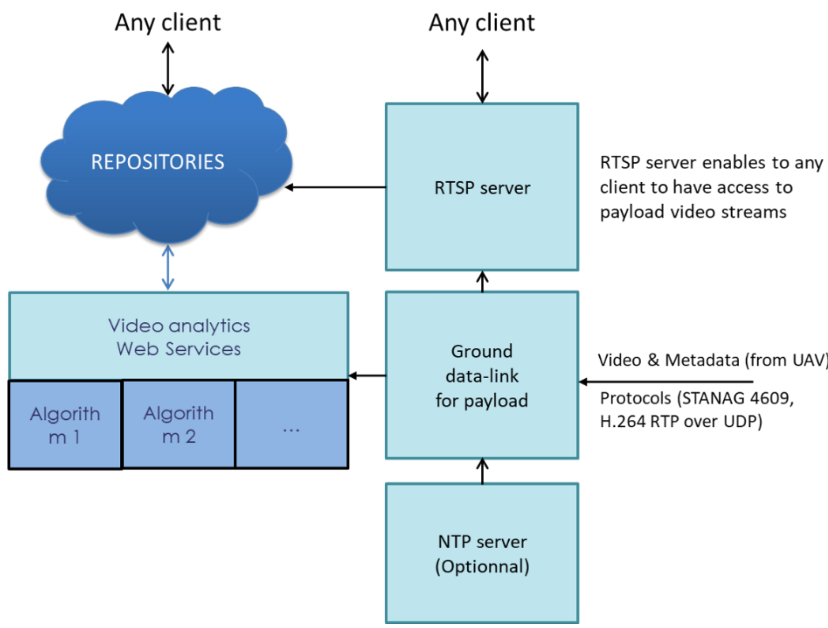

Figure 9: Video Processing & streaming: architecture overview

Each UAV equipped with a video payload will be able to send two video streams (one video stream for the visible camera and another one for the IR camera) and associated metadata (if any) to the ground through the data-link. All the streams will be broadcasted to Ground Video Processing module for live video analysis and to a Real-Time Streaming Protocol (RTSP) server for video serving. Any client should be able connect to this RTSP server to select the streams it wants to display.

6.2.1 Ground Video Processing

The Ground Video Processing module will offer various video processing services used by First Responders in order to help them to efficiently handle plural videos stream. Videos could be processed live or on-demand. Typical processing modules are, for example, people detection for Search & Rescue mission, vehicles detection and analysis of fire or flooded areas. Even if diverse processing algorithms are available to use, the system will use a generic image as input, and will output bounding boxes, masks, segmented images or other types of data clearly defined and related to the type of algorithm. This will allow to easily integrate other processing algorithms (having the same type) into the system without any change on the interface side.

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6.2.2 Gimbal Control

The *gimbal control* component is the software module that provides an interface between the Graphical User Interface (GUI) and the embedded computer on the camera payload. This allows an end-user to control not only the gimbal orientation but also camera options like its zoom. Please refer to section 7.3 for more details concerning camera option.

The gimbal control module will enable three types of control, depending on the level of automatism required by the end-user:

1. Full manual control
2. Point to coordinate
3. Visual serving, or tracking, mode

On *full manual control*, the end-user will send commands directly to the gimbal. In this mode, two types of commands are available: rate and orientation. Rate commands are usually adopted for pointing devices like joysticks, since this kind of devices has a mechanical return to the neutral position when released. Therefore, for the gimbal manual control using other devices likes a mouse or tactile screens, it is recommended to use orientation commands.

On *point to coordinate control*, the end-user will select a point and an orientation, on a map indicating in which direction the gimbal should point at. In order to compute the right angles to be sent to the gimbal, this mode requires additional data like the UAV geographic position as well as the AGL (Above Ground Level) height from the autopilot telemetry. A Digital Elevation Map (DEM) will also be required, if the terrain around the UAV position cannot be approximated by a plane (flat terrain).

On *visual serving, or track mode*, the gimbal control will rely on video analytics in order to automatically track a target of interest (person, vehicle, etc.) during the movement of the UAV, of the target itself or even both. We assume here that the UAV flies high enough in order to avoid collisions with potential obstacles (trees, buildings, power lines, etc.). If latency constraints allow us to do it, this will be achieved by sending control commands to the UAV, through the TMM module in order to follow the target, e.g. a person drifting in a flooded river. Otherwise, the loop will be executed into the UAV, only the position of the UAV will be sent to TMM, which will define a no flight area for the rest of the UAVs around the tracking UAV that will enable safe operation. To that end, parameters such as communications latency, flight speed and altitude will be considered, so that the flight deconfliction can be executed accurately.

6.3 Airborne Network Control

ResponDrone platform will offer a *Communications Relaying Service* that uses UAVs to transport *INESC TEC's Communications Payload* and deploy, on demand, an airborne private wireless

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network infrastructure (LTE + Wi-Fi) for First Responders. This private and independent network will allow the First Responders to communicate among themselves as well as to access the ResponDrone platform and use its services. The *Communications Relaying Service* will be requested on-demand by an On-field Commander to fulfil the dynamic communications needs of the scenario.

The *Airborne Network Control (ANC)* component, which is one part of the on-site ground systems, is responsible for processing the *Communications Relaying* missions, requested by the On-field Commander. It calculates the necessary number of UAVs equipped with the *Communications Payload* and creates the related Mission Plan, i.e., the number of drones and the positions where the they should be hovering to offer communications coverage.

The ANC is triggered when a new *Mission Request* related to the Communications Payload is created. Two types of missions will be supported by the ANC component, which are already detailed in Section 5.5 of D15.4: “Area Coverage” and “Follow First Responders”. Depending on the type of mission, the ANC consults the Maps/GIS, the First Responders locations, the “no flight zones” (including fire locations), and the number of available UAVs and Communications Payloads. With this information, the ANC calculates the number of drones needed and their optimal locations (e.g., being as close as possible but not on top of First Responders, avoiding also the no flight zones) and creates the respective Mission Plan, which is then delivered to the TMM (from DLR). Depending on the type of mission, new Mission Plans will be created/updated periodically by the ANC, adjusting the position of the UAVs transporting the Communications Payload to optimize the overall quality of service offered by the Radio Access Network. This is an important feature considering the dynamic needs of the scenario (e.g., First Responders mobility to follow the fire as it evolves).

The interfaces of the ANC with the other components are described in more detail in section 8 of this document.

6.4 Ground Control Station for UAVs

The Ground Control Station (GCS) is the ground system and interface for direct control of the flying aircrafts. It is composed of several items:

- G-Case: a dual screen computer system mounted into a heavy duty case
- Ground Control Station and UAV Ground Datalink
- Joystick for manual override

6.4.1 G-Case

The G-Case Duo (Figure 10) contains a complete two-screen Ground Control Station housed in a compact and robust case. It includes the communications system, a rugged PC for GCS software, several communication interfaces and the joystick for calibration and manual flight as well as a gamepad for a simple manual command of the Alpha 800.

Figure 10: G-Case Duo render.

6.4.1.1 Visionair

Visionair is UAV Navigation's flight control software. It is installed in the G-Case PC and its function is to command the UAVs. From Visionair, it is possible to control the UAV status, view the location of all the UAVs over a map or a geo-referenced picture. It is also the only tool available to send orders and flight plans to the UAVs.

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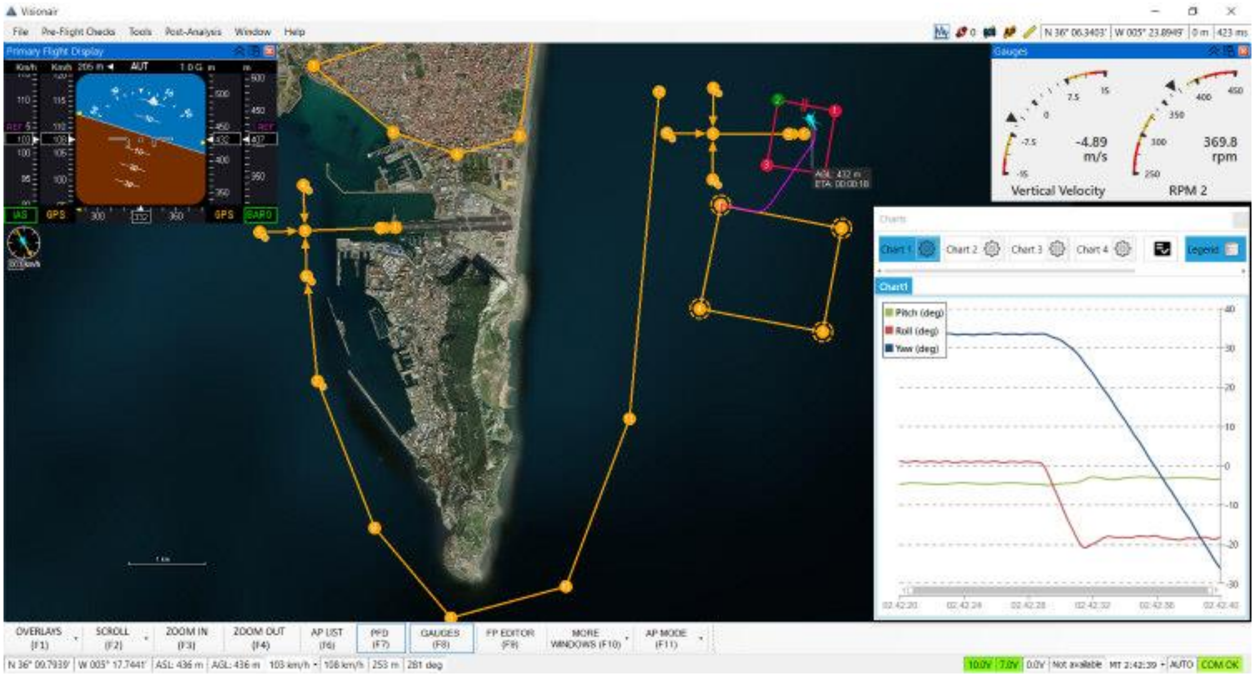

Figure 11: Visionair interface

Its basic capabilities are as follows:

- Mission-oriented interface.
- Fully featured UAV mission planning and execution application, with GUI
- Platform: PC/laptop (with keyboard + mouse).
- Main Flight Modes: Auto, Manual, Nav-To, Loiter (Hover), Safe (Return To Base).
- Fully Auto Take-Off.
- Fully Auto Landing.
- Full Digital Elevation Model support.
- Link Quality panel.
- Target Editor.
- Fly/No-fly Zones.
- Rulers.
- Full range of configurable alarms.
- Compatible with all kinds of digital mapping.

6.4.1.2 Extension

An extension to VisionAir will be developed, in order to enable VisionAir to communicate with external software. This extension will be developed during the project and will allow the bidirectional communication between VisionAir and the Traffic & Mission Management (TMM) component.

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6.4.2 GCS / UAV Ground data link

The GCS (Figure 12) is the interface hardware used to communicate with UAV Navigation's autopilots. As such it is normally connected via Ethernet to a PC running Visionair, which provides the human interface software for the Internal Pilot to control the UAV. It is usually mounted into the G-Case.

The UAV ground datalink is embedded in the GCS (Figure 13).

Figure 12: GCS03, UAV Navigation

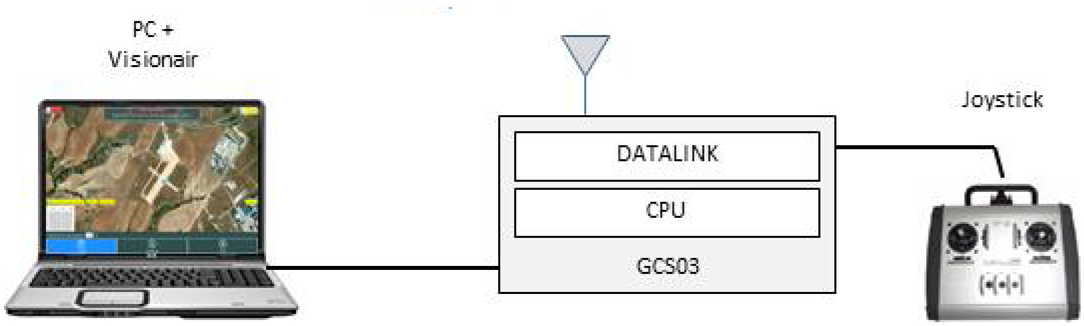

Figure 13: GCS03 Block diagram

The GCS03 provides the following functions:

- Bi-directional communications between Visionair (on the ground) and the onboard autopilot (in the air).
- Connection point for the joystick to allow manual override by Pilot if necessary.
- GPS (to locate the GCS; the position is shown in the top right corner of the GCS Config Tool window).
- Pan and tilt antenna steering (for installation where a steerable antenna is used).
- Low-level message integrity verification.
- Built-in standby battery in case of external power failure.

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6.4.3 Joystick

Joystick (Figure 14) is used to take full manual control of the Alpha 800 during a flight.
It can be also used for calibration purposes.

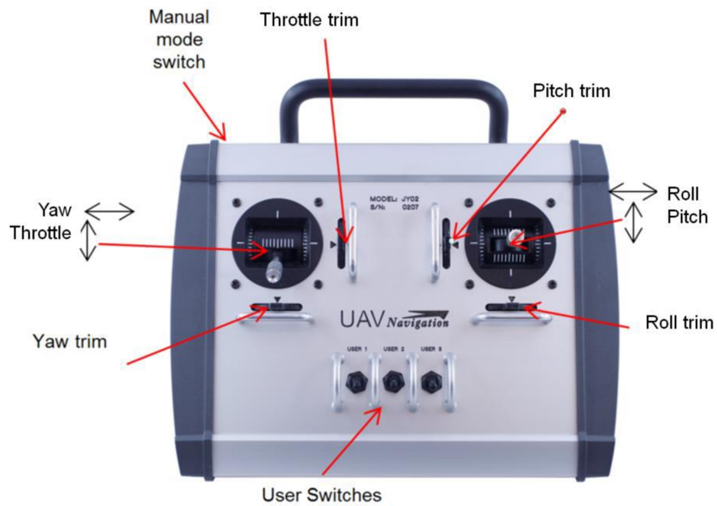

Figure 14: Joystick

7. On-site air systems

7.1 UAV Alpha 800

The UAVs used within Respondrone will be the Alpha 800 helicopter UAV. The Alpha 800 is composed of several subsystems that are relevant for the architecture purpose. These items are:

- UAV On Board Datalink.
- Autopilot.
- UAV Mechatronic control.
- UAV Sensors.
- Other systems.

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Figure 15: Alpha 800 helicopter UAV

7.1.1 Technical specifications

Power Plant	
Two stroke gasoline engine	
Displacement	32 cc
Maximum output	2.4 kW
Maximum torque	2.0 N-m
Dimensions	
Length	1.7 m
Height	0.6 m
Rotor diameter	1.8 m
Performance	
Cruise speed	55 km/h
Max speed	90 km/h
Endurance	2.5 h
Ceiling	3.000 m ASL
Weight	
Max. take-off weight	14 kg
Max. payload	3 kg

Launch & Recovery

Vertical take-off & landing (VTOL)

Payloads

EO/IR, gyrostabilized, geo-referenced

LIDAR, infrared or multispectral

Radio relay, Laser Altimeter, Transponder

Structural Material

Carbon fiber

Complete System Transport Case

Dimensions 1.80 m x 0.7 m x 0.9 m

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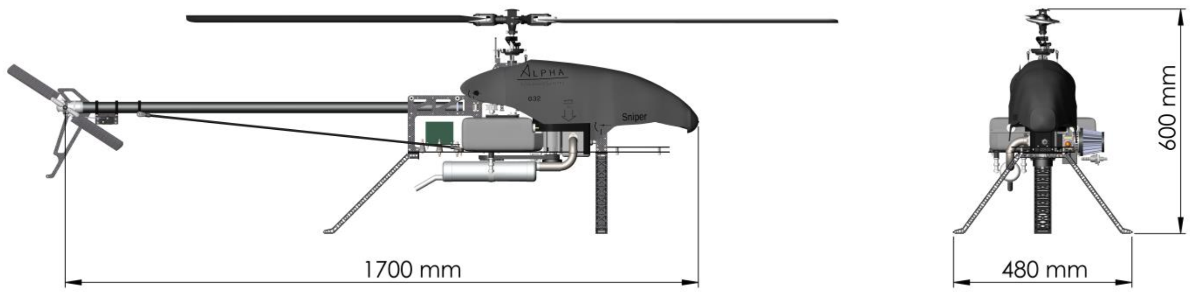

Figure 16: Alpha 800 helicopter UAV dimensions

7.1.2 UAV On Board Datalink

The UAV On Board Datalink is responsible, for the UAV's side, of the communications between the UAV and the ground control station. The selected datalink for ResponDrone is a Microhard pMDDL2450 2x2 MIMO OEM Wireless Digital Data Link.

This radio is capable of sending and receiving information using 2.4 GHz via both serial and Ethernet ports at the same time, which allows ResponDrone to control the UAV via serial port whilst the information from the main payloads (Camera and Communications) is sent via the Ethernet port.

The chosen radio also accepts the most used network protocols, such as TCP, UDP, ARP, ICMP, DHCP, HTTP, HTTPS, SSH, SNMP, FTP, DNS and Serial over IP. Regarding the encryption, it offers 128-bit AES.

7.1.3 Autopilot

The autopilot is the most important part of the UAV. It is a combination of advanced hardware and software and its mission is to autonomously operate the UAV, including take-off, execution flight plans and landings.

To control the UAV, the autopilot commands the different actuators (mainly servos) based on (1) the UAV sensors readings, which give the autopilot information about the current situation and orientation of the UAV and (2), the uploaded flight plans or flight orders, which tells the autopilot which path to follow, where to go and at which speed or other flight parameters.

The UAV autopilot is a Vector Autopilot by UAV Navigation. This autopilot has been proven to be a reliable, resilient and effective solution. The Vector additionally brings added values such as autorotation, GPS-denied navigation, etc.

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7.1.4 UAV Mechatronic control

The UAV Mechatronic control is formed of a set of servos that control different mechanic parameters of the aircraft. The different servos actuate on different mechanisms such as the swash plate, the angle of attack of the tail rotor, or the engine intake.

The servos responsible of the UAV control are commanded by the Autopilot using PWM signals.

7.1.5 UAV Sensors

The Alpha 800 carries different types of sensors that are used to provide both the autopilot and the pilot's awareness of the UAV status at any time.

The main sensor on board of the Alpha 800 UAV is the IMU (inertial measurement unit). The IMU is a set of sensors (such as magnetometers, gyroscopes and accelerometers) that measure attitude and heading of the aircraft,

The ADS (air data system), on the other hand, measures the static and dynamic pressures. With these measurements, it calculates the altitude and the indicated air speed (IAS) of the Alpha 800.

Another important sensor of the Alpha 800 is the GPS, in charge of providing the location of the UAV to the autopilot.

The sensor kit chosen for the Alpha 800 is Polar, by UAV Navigation. It includes all the aforementioned sensors. Other sensors of the aircraft include fuel sensors, engine temperature, RPM, air temperature, and voltage sensors. All the sensors continuously feed the autopilot to allow a precise control of the aircraft and an accurate awareness of its status.

Most of these measurements are later displayed in the PFD (Primary Flight Display), also known as AHRS (Attitude and Heading Reference System) of the aircraft. The ones that are not displayed in the PFD can be displayed in separated gauges.

7.2 Communications Payload

The *Communications Payload* is a set of communications hardware components to be installed in the UAVs, being capable of providing private Cellular (LTE) and Wi-Fi network coverage for the First Responders, allowing communications among themselves and access to the ResponDrone services. Being a private network, it works independently of the state of existing communications infrastructures. The *Communications Payload* is connected to the Airborne Network Controller using the *GCS/UAV Ground DataLink*, or using an optional dedicated *Payload DataLink,* to transport the Radio Access Network traffic between the First Responders and the ResponDrone system.

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The hardware and software selection for the Communications Payload is in line with the objectives of the ResponDrone platform of being affordable, modular and upgradable. In view of these objectives, the deployment of the Radio Access Networks, Wi-Fi and Software Defined Radio (SDR) based LTE network interfaces is considered, focusing on using off-the-shelf, easily customizable, and upgradable wireless communications hardware, when possible. This selection also takes into account the payload weight, size and energy consumption limitations imposed by the current UAV platforms used in ResponDrone.

In order to work as expected, the Communications Payload needs to be permanently connected to the Airborne Network Control on-ground component. For that purpose, the Communications Payload uses an Ethernet interface to connect the *UAV Onboard DataLink*, as described in Section 7.1.1.

A list of hardware and software components that compose the Communications Payload to deploy, both the private Cellular and Wi-Fi Radio Access Network, is presented next.

7.2.1 Cellular Radio Access Network – private LTE/4G

In LTE/4G cellular networks, the Evolved Node B (eNodeB) is the component responsible to deploy the Cellular Radio Access Network, i.e., it provides the radio signal processing and the necessary radio interfaces (connected to the antennas) to establish the radio link with the User Equipment (e.g., mobile phones).

The Cellular Radio Access Network, deployed by the Communications Payload, consists of an SDR-based eNodeB transported on the UAV. Currently, the following components and configurations are considered for the eNodeB implementation:

- **Processing Unit**: Intel NUC8i7BEH (c.f. Figure 10), a small sized computer with high processing power to be able to cope with the SDR software workload.
- **SDR radio**: Nuand bladeRF X40 / Nuand bladeRF 2.0 micro (c.f. Figure 11).
- **SDR software**: srsLTE / OpenAirInterface.
- **Power Amplifier**: Nuand bladeRF specific (for the TX Radio Chain).
- **Low Noise Amplifier**: Nuand bladeRF specific (for the RX Radio Chain).
- **TX and RX LTE Antennas**: directional antennas (directing the radio signal to the ground).
- **LTE Frequency Band**: One of the following three bands will be considered, depending on the available radio spectrum: 800, 1800 or 2600 MHz bands (LTE band 3, 7 or 20).

Note that this hardware and software selection may need to change, depending on the results from the ongoing experiments.

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Figure 17: Intel NUC8i7BEH.

Figure 18: Example of SDR Card: Nuand bladeRF 2.0 micro.

7.2.2 Wi-Fi Radio Access Network

Wi-Fi is a universal wireless network technology, selected to complement the private LTE Cellular Network by offering the following advantages:

- Redundancy of connectivity in case of SDR hardware or software failure.
- Fallback alternative in cases where there is a lack of “free” licensed spectrum in a specific area of operation.
- Offer connectivity to potential victims.

For that purpose, the NUC8i7BEH has an integrated Wi-Fi card that can be configured as a software Access Point connected to an external antenna. A separate USB Wi-Fi interface can also be used, if necessary, to improve the Wi-Fi network performance and range.

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7.3 Camera Payload

The *camera payload* is an imaging system composed by a visible or Electro-Optical (EO) and an infrared (IR) sensor. By spanning both visible and infrared wavelengths, the camera payload allows providing situation awareness not only during the day but also the night and in low light conditions. Within the scope of the ResponDrone project, the infrared camera will also be useful to monitor, analyse or track the evolution of fire disasters and for Search and Rescue (SAR).

The critical features for EO/IR systems are commonly long-range capability and stabilization. For that, both cameras will be mounted on a gyro-stabilized gimbal and the chosen EO camera will feature up to 360x zoom: 30x optical zoom and 12x digital zoom. Due to weight, size and power consumption restrictions, the infrared camera will only feature an 8x digital zoom, the reason why the optics' focal length will have to be carefully chosen.

Figure 19: Sony FCB-EV7520A EO camera (left) and the FLIR Boson 640 IR camera (right)

The camera payload system will be composed by:

- An EO camera: Sony FCB-EV7500/7520A full HD (resolution of 1920x1080) camera with high sensibility capability, down to 0.0008lux, defog, auto Infrared Cut Removal (ICR), noise reduction, slow AE response, private zone masking, visibility enhancer, flicker compensation and Wide Dynamic Range (WDR). (Figure 19, left).
- An IR camera: FLIR Boson with a resolution of 640x512@60Hz with a professional thermal sensitivity down to 50mK. (Figure 19, right).
- An embedded single board computer (SBC): NVIDIA Jetson Tegra X2 with a quad-core ARM Cortex-A57 multi-purpose CPU along with a dual-core NVIDIA Denver 2 64-bit CPU and a GPU with 256-core NVIDIA Pascal architecture.(Figure 20).A compact gyro-stabilized gimbal: Gremsy S1 3-axis gimbal with controlled speed up to 100°/s, angular vibration range down to ±0.02° and internal wiring harness. With a weight of 0.75kg and

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a maximum payload of 0.75kg. The total weight of the whole camera payload system will not exceed 1.5kg. (Figure 21).

Figure 20: NVIDIA Jetson Tegra X2 embedded SBC

The embedded SBC will be the central element of the camera payload architecture. Indeed, it will responsible for:

- The video grabbing from both cameras.
- The connection to the autopilot in order to collect real-time telemetry.
- The on-board video-processing.
- The connection to the payload datalink, for video streaming and metadata transmission on downlink and gimbal/camera control command on uplink.
- The connection to the gimbal (Figure 21) in order to receive its telemetry (roll/pan/tilt angles) and send pan/tilt command to change its orientation.

Figure 21: Gremsy S1 3-axis gimbal

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7.4 Release System

The Release System will be capable of releasing a package to be delivered in the field. The package can be of various kinds: medical supplies, blankets, flotation devices, food and water, etc.

Although the specific mechanism has not been chosen yet, it will most likely consist of a servo (Figure 22) activated via a configurable switch of the autopilot (using a PWM signal). The servo would drive the release mechanism. The release system would potentially use a parachute if needed, depending on the nature of the package (if it is heavy, dangerous or fragile).

Figure 22: Example of release servo mechanism.

8. Relevant Logic Interfaces

In this section, the most relevant interfaces are described. The complete set of interfaces can be consulted in section 4 - Architecture. Some considerations must be made:

- The digital datalinks generate a transparent radio connection, which means that:
  - Serial connections to the datalink on ground will be able to communicate transparently to their peers on air.
  - Ethernet/network connections to the datalink will be able to communicate transparently with the elements on air or ground.
  - UAV serial connections are usually RS-232, but it also offers to RS-485 or RS-422 capabilities.

8.1 TMM - GCS

The interface between the TMM component and the GCS will be implemented using a TCP/IP connection over a network cable. The TMM will take as input the UAV locations (multiple times per second), with their lat/lon/alt locations, and possibly other metadata (callsign, identifier,

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health status, etc.). The TMM will provide to the GCS the UAV mission plans (4D trajectories), and possibly UAV emergency commands (ad-hoc commands such as "return to home").

8.2 TMM - Data Repositories

The interface between the TMM component and the data repositories will be implemented using a web service connection (e.g., HTTP) over the network connection on the site. The TMM will take as input the first responder locations (lat/lon/alt, possibly missions and other metadata), air traffic data (lat/lon/alt, possibly flight plans and metadata), no-fly zones (lat/lon/alt polygons, possibly temporal data and other metadata), meteorological data (wind, precipitation, visibility), maps and GIS data (maps, airspace, critical infrastructure, utility lines, buildings, terrain), UAV and payload availability, and payload drop mission requests (acting as the "use case" component). From these data items, the TMM will create safe and risk-minimizing trajectories based on the risk model. The TMM will, in turn, provide as output to the repositories air traffic data sourced locally (e.g., via ADS-B or FLARM), information on its own UAV (routes, current locations, 4D trajectories) and mission plans.

8.3 TMM - Video Processing

The interface between the TMM component and the video processing will be implemented using a TCP/IP connection over a network. The TMM will take as input the mission plans for video-related use cases, i.e., the mission plans (list of lat/lon/alt waypoints for waypoint-based missions etc.). The TMM component does not provide any output on this interface.

8.4 TMM - Airborne Network Control

The interface between the TMM component and the INESC TEC communications component will be implemented using a TCP/IP connection over a network. The TMM will take as input the mission plans for communication-related use cases, i.e., the UAV target positions (lat/lon/alt position for each UAV).

The ANC component will send the Mission Plan to the TMM component from DLR. The Mission Plan includes the optimal locations for the UAVs to hover with the Communications Payload. Using this Mission Plan, the TMM component is then responsible for calculating the respective low-risk flight routes. The interface between the ANC and TMM components will be implemented using TCP/IP.

This interface will be bidirectional, allowing the ANC component to get an explicit acknowledgement/feedback from the TMM, stating whether the Mission Plan was accepted or not, and if not why.

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8.5 GCS Ground Data Link - Airborne Network Control (ANC)

The interface between the GCS Ground Data Link component and the INESC TEC communication component will be implemented using a TCP/IP connection over a network connection.

The ANC component not only calculates Communications Mission Plans according to the Mission Requests, but also implements the LTE Core. The LTE Core is an important component of an LTE network, which needs to be connected to the Communications Payload in order to provide LTE functionality. The ANC also acts as an On-ground Network Gateway, effectively connecting the First Responders using the UAVs Radio Access Networks (LTE and Wi-Fi) to the ResponDrone platform. On top of this, the ANC also needs to communicate with the Communications Payload to be able to change on demand the configuration of the parameters of the Radio Access Networks (e.g., radio channel, transmission power) and collect possible network statistics. The network traffic between the ANC and the Communications Payload is transported using the *GCS/UAV Ground DataLink* (or an optional dedicated *Payload DataLink*).

8.6 Airborne Network Control - Data Repositories

The ANC component is a consumer of the following Data Repositories:

- **Mission requests** – used to trigger the creation of a new Mission Plan according to the type of Mission Request.
- **Maps/GIS** – used to propose Mission Plans considering UAV locations with the correct altitude above ground level.
- **First Responders locations** – used with two purposes in mind: 1) to avoid suggesting UAV locations directly on-top of First Responders, which would not be authorized by the TMM; 2) to periodically adjust the mission plan accordingly to the First Responders dynamic locations, optimizing the overall quality of service of the network.
- **UAV/Payload availability** – used to validate whether there are enough available resources to implement the requested mission. The Mission Plan will attempt to use the lowest number of UAVs while meeting the coverage requirements.

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8.7 GCS Ground Data Link - Video Processing

Figure 23 details the configuration of the information flow concerning video processing:

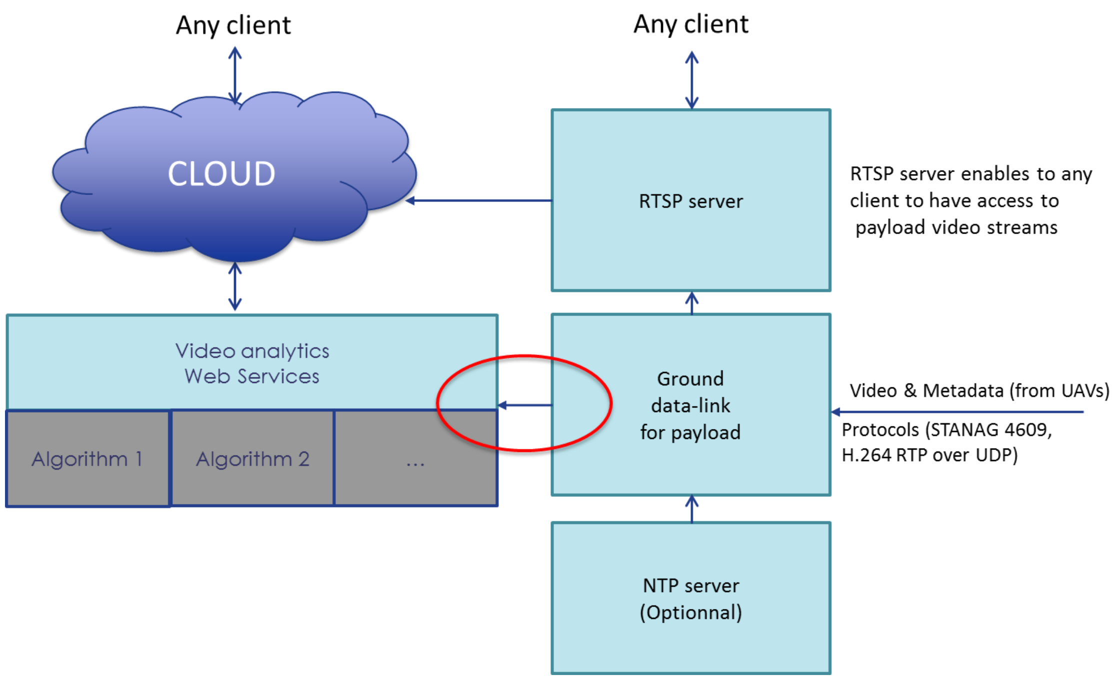

Figure 23: Ground data Link – Video Processing

For live video analysis, Thales video processing module will receive all RTP H.264 over UDP, coming from all UAVs payload.

For a posteriori video analysis, a specific TCP/IP or Web Service protocol will be used to control a video processing service (start, stop, pause a processing task…). It will allow also sending parameters (i.e. video source, processing algorithm selection, framerate, output data format).

8.8 Video Processing - Data Repositories

The interface between the Video Processing component and the data repositories will be based on STANAG 4609 standard. The video processing in the web application interfaces with the video streaming and displays the video from the EO and IR cameras. The video analysis products are also displayed as layers on top of the video display.

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8.9 Decision Support - Data Repositories

The interfaces between the Decision Support component and the data repositories will be implemented using web services connection (e.g., HTTP) over the network connection on the site.

The decision support component is a consumer of the following data repositories:

- **Information about the ongoing crisis** : type of event, start time, fire lines and damage data, vector geographic data. This is distributed in several repositories.
- **Maps and GIS data** : maps, critical infrastructure, roads, buildings, elevations, water resources, power lines, density of population or vegetation if available, etc.
- **Terrain data models** of the area of the crisis.
- **Weather data** : wind, precipitation forecasts.
- **First Responder locations** : lat/lon/alt, possibly missions and other metadata.
- **Video processing results** : timestamped and geolocated active fire area / burnt area, flood lines/area, detected objects or people, etc.

The decision support web-service will produce results that shall be stored in a repository and shown on the graphic interface of the end-user application.

8.10 Web Microservices - Data Repositories

The data repository is accompanied with a micro-service that provides REST API for CRUD (Create / Read / Update / Delete) operations on the data. The data is accessed only through the micro-service which handles permissions and synchronization of the data.

It is the responsibility of the provider/creator of the repository:

- To publish a public REST API, through which all consumers communicate with the data repository.
- To implement a micro-service providing the public REST API.
- To implement the internal layer of the micro-service, implementing the actual translation of API calls to database queries.

9. References

- ResponDrone - D3.2 Preliminary Architecture & Concept.
- ResponDrone - D15.2 Report of Field Studies.
- ResponDrone - D15.4 ResponDrone Concept/Mock-ups.
- ResponDrone - D15.4 ResponDrone Concept/Mock-ups, Annex 1: Summary of the Design Thinking Workshop.
- ResponDrone - D15.5 Functional Design.

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