A Holistic Fire Management Ecosystem for Prevention, Detection and Restoration of Environmental Disasters

# TREEADS D5.1 Live doc. TREEADS SOCIO-TECHNOLOGICAL Solution for Detection and Response. V1

| | |
|---|---|
| Work package | WP5: TREEADS Socio- Technological Solutions for Detection and Response |
| Tasks | All tasks of WP5 (T5.1; T5.2; T5.3; T5.4; T5.5; T5.6; T5.7; T5.8) |
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# Revision and history chart

| Version | Date | Main author | Summary of changes |
|---|---|---|---|
| **0.1** | 30/11/2022 | SIMAVI | Draft outline |
| **0.2** | 01/12/2022 - 15/01/2023 | SIMAVI, CERTH, DH 8 BELLS, NCSRD, USAL, ACCELI, FI | Contributions for Task 5.1, Task 5.2, Task 5.6, Task 5.3, Task 5.4, Task 5.7, Task 5.8 |
| **0.3** | 03/02/2023 | SIMAVI, ECOSAT | Contribution for Task 5.5 |
| **0.4** | 04/02/2023 | ECOSAT | Contribution for Task 5.5 (Updated). Deliverable ready for the first internal review. |
| **0.5** | 07/02/2023 | ACCELI | First review |
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| **1.0** | 27/02/2023 | SIMAVI | Final submitted version |
| **2.0** | 24/11/2023 | SIMAVI, CERTH, FI, BAM, FRN | Revised after EC review, see list of comments and edits below. |

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## GLOSSARY OF TERMS

| Term | Description |
|---|---|
| **Extreme wildfire event** | In TREEADS, the term is used to depict wildfires with exceptional physical characteristics, including size, duration, regime, behaviour, severity, and rapid evolution. |
| **Wildland fire / wildfire** | An occurrence of a wildland fire, wildfire, forest fire, bushfire or rural fire is unplanned and uncontrolled incident, caused by humans or natural phenomena that requires a response to prevent or minimize loss of life or damages to property and/or the environment. |
| **Wildland fire management** | Application of the suitable management response to wildfires to accomplish specific resource management objectives in predefined designated areas. |
| **Wildland firefighting locations** | During the planning, implementation and assessment of wildland firefighting activities, a lot of locations are used for supporting a wide variety of objectives. These locations have a precise destination, serve many purposes and are often critically important in carrying out firefighting actions. |
| **Wildfire risk assessment** | Identify and quantify necessary the risks posed by wildfire and based on the appropriate assessment, to develop cost-effective mitigation strategies and operational scenarios. |
| **Wildland – Urban Interface (WUI)** | Area where wildland vegetation adjoins or mixes with humans and their development, including the houses and infrastructure. |
| **Wildfire Response Engine (WRE)** | In TREEADS, the Wildfire Response Engine is used for applying various analytics methods in order to evaluate data in real-time, anticipate and predict a critical situation, and recommend the optimal response / action. |

## LIST OF ABBREVIATIONS AND ACRONYMS

| Abbreviation | Meaning |
|---|---|
| **2D** | 2 dimensions |
| **3D** | 3 dimensions |
| **AI** | Artificial Intelligence |
| **API** | Application Programming Interface |

| | |
|---|---|
| **AR** | Augmented Reality |
| **BPM** | Business Process Management |
| **CAF** | Compressed Air Foam |
| **CEP** | Complex Event Processing |
| **CNN** | Convolutional neural networks |
| **CO** | Carbon Monoxide |
| **CPP** | Coverage Path Planning |
| **EDSD** | Event Driven Situation Detector |
| **EFFIS** | European Forest Fire Information System |
| **FBB** | Forest Black Box |
| **FIRMS** | Fire Information for Resource Management System |
| **GCS** | Ground Control Station |
| **GPS** | Global Positioning System |
| **GSD** | Ground Sample Distance |
| **GUI** | Graphical User Interface |
| **HTML** | Hypertext Markup Language |
| **IT** | Information and Technology |
| **JSON** | JavaScript Object Notation |
| **LiDAR** | Light Detection and Ranging |
| **MCC** | Mission Control Centre |
| **MODIS** | Moderate Resolution Imaging Spectroradiometer |
| **MWIR** | Mid-Wave InfraRed |
| **OS** | One Seven |
| **PHP** | Hypertext Preprocessor |
| **PM** | Particulate Matter |
| **PNOA** | Spanish National Aerial Orthophoto Program |

| | |
|---|---|
| **PRISMA** | PRecursore IperSpettrale della Missione Applicativa |
| **QA** | Quality Assurance |
| **REST** | Representational State Transfer |
| **ROI** | Region of Interest |
| **RFCN** | Region-based Fully Convolutional Networks |
| **RPN** | Region Proposal Network |
| **SDK** | Software Development Kit |
| **SLSTR** | Sea and Land Surface Temperature Radiometer |
| **SNPP** | Suomi National Polar-orbiting Partnership |
| **SSD** | Single-Shot Detector |
| **SVN** | Subversion |
| **TIR** | Thermal InfraRed |
| **TL** | Team Leader |
| **UAVs** | Unmanned Aerial Vehicles |
| **UI** | User Interface |
| **UX** | Use Experience |
| **VIIRS** | Visible Infrared Imaging Radiometer Suite |
| **VR** | Virtual Reality |
| **WRE** | Wildfire Response Engine |
| **XLT** | Template file created with Microsoft Excel |

# EXECUTIVE SUMMARY

The deliverable presents the joint work of the TREEADS Consortium regarding the development process specific to the detection and response stage, based on a common approach and strategy. The document is the first of the three deliverables corresponding to WP5 and covers the requirements of the proposed solution for detection and response, as described in Tasks 5.1 to 5.8.

The complexity of the proposed solution, both from the technological point of view and the architectural design, structured on well-defined layers, derives from the achievement of the objectives proposed by WP5, namely:

- Enabling an innovative four-layer approach in detection and response dedicated to wildfires and emergency situations, based on state-of-the-art detection sensing systems.
- Providing the necessary optimization of route management and patrolling in the area affected in case of wildfires.
- Providing specific solutions of fire-fighting chemicals that aid in the suppression of fire in wildlands.
- Designing and developing the wearable sensors and gear which will be utilised by the first responders.
- Designing, integrating and testing all hardware, software and communication protocol components on-board and on-ground for a consistent and versatile aerial communication and connectivity infrastructure.
- Utilizing LiDAR point clouds with an ultra-high resolution for characterizing the forest fuels and for further fire prevention and management
- Providing an appropriate Wildhopper platform that offers a distinctive helpful tool to firefighters.
- Providing specific exercises and training simulators to first responders and volunteers in an Enhanced Reality platform.

The deliverable aims to build a detection and response solution by integrating technologies, tools, applications, equipment and devices with detection, monitoring and response capabilities within the project, using a unitary approach with the following structure:

1. General description,
2. Technological approach,
3. Methodological approach,
4. Functional view and
5. Operational view.

# 1. INTRODUCTION

## 1.1 PURPOSE AND SCOPE

The current deliverable is the first report addressing the requirements of WP5 (Tasks 5.1 to 5.8), which presents the most relevant aspects regarding the implementation of detection and response within TREEADS project. It describes the major components of the detection and response solution, capturing both the technical capabilities, the development / implementation methodologies as well as the functional and operational views.

To create a comprehensive and logical presentation, the deliverable is structured in different chapters dedicated to the major components of the detection and response solution, corresponding to the associated Tasks in WP5. Thus, comprehensive sections are dedicated to the technical descriptions of the implemented solutions, both at the level of physical infrastructure and communications, equipment, devices and sensors, as well as at the level of software applications and architectural vision.

Moreover, this deliverable establishes the roadmap for showcasing the TREEADS Technological Solutions for Detection and Response through a demonstrator that will be developed in the second version (D5.1.V2).

## 1.2 OVERVIEW

The common approach adopted for detection and response, as required in WP5, takes into consideration both the technologies of the components described in the tasks as well as their interconnection and integration within the TREEADS platform.

The deliverable is drafted in such a way as to ensure a unitary vision of the detection and response solution, from theoretical, methodological and practical perspectives, highlighting the innovation elements specific to each task.

## 1.3 DOCUMENT STRUCTURE

**Section 1. Introduction**: Presents a summary regarding the scope of the deliverable, an overview, its structure and relation to other tasks and deliverables.

**Sections 2-9. TREEADS solution for detection and response:** Each section describes in detail the theoretical, methodological and practical development of major components of the solution for detection and response corresponding to each task from WP5.

The presentation of each component of the solution for detection and response:

- Task 5.1 - Four Layered enhanced detection, targeting and extinction system,
- Task 5.2 - Route management, patrolling and automation optimisation for teams and incidents,
- Task 5.3 - Fire retardant rapid deployment, Fire Walls, Search and Rescue,
- Task 5.4 - Personal monitoring and protective equipment for emergency responders,
- Task 5.5 - Space and Aerial means,

- Task 5.6 - Enhanced Reality, UX Design, Training, including virtual reality simulators for air fleet and resources,
- Task 5.7 - Resilient Context-aware Detection of Emerging Fire-related Situations,
- Task 5.8 - Decision Support for Wildfire Response Process Management,

comprises *a general description, technological approach (including the innovation), methodological approach, functional view* and *operational view*.

**Section 10. Integration within the TREEADS platform:** Presents the most relevant aspects regarding the integration of each component of detection and response within the TREEADS platform and the appropriate approach towards the initial development of the demonstrator.

**Section 11. Addressing the extreme wildfire events in TREEADS:** Elaborate the approach for extreme wildfires within TREEADS and how it is applied in the deliverable.

**Section 12. Conclusions and implications:** Presents the conclusions about the current stage of implementing the TREEADS solution for detection and response and further steps to follow during the deployment of the project.

**Section 13. References**.

## 1.4 RELATION WITH OTHER DELIVERABLES

The specific work on detection and response presented in WP5 is correlated with the activities and outcomes from WP2, WP3, WP4, WP7 and WP8. The architectural vision depicted in the deliverable is compliant with the architectural solution of TREEADS platform described in deliverable D3.5.

The sections describing the technical solution and the functional perspective for each component rely on the information and findings provided by the deliverable D2.3 V1 - requirements analysis for detection and response from WP2.

The specific work on detection and response presented in WP5 has a similar approach to the organization of information, the same vision on implementation and the roadmap for showcasing the TREEADS Technological Solutions for Detection and Response like in WP4.

The operational view from the description of each component considers the specific requirements and findings presented in the Pilots scenarios from WP8. Moreover, the relevant aspects and outcomes of WP5 will be taken into account when drafting the deliverables D7.1.x from WP7.

# 2. IMPLEMENTING A FOUR LAYER APPROACH IN DETECTION AND RESPONSE, BASED ON THE STATE-OF-THE-ART DETECTION SENSING SYSTEMS

In the Detection and Response phase, the existence of timely, accurate and comprehensive information is crucial in order to enhance situational awareness, minimize reaction time and reduce casualties. TREEADS project, among other sources of information, is building a dense network of sensors and visual sources distributed in a wide and diverse set of aerial and ground means of different operational capabilities, along with advanced detection algorithms able to detect hotspots and objects of interest in very short time. For this reason, a four-layered enhanced detection, targeting and extinction system is being developed by exploiting several types of aerial and ground means, such as: Unmanned Aerial Vehicles (UAVs) which are categorized into **low altitude drones**, used for small area hyperspectral imaging, LIDAR scanning detection of false positive fire ignition alarms and seeding during forest restoration, **medium altitude, heavy payload drones**, acting as fire retardant fluid bombers or sprayers. Additionally, high **altitude airships** (Zeppelin) are used for large area image spectrometry, large area surveillance and detection of new hotspots, and finally very high altitude **Satellite** imaging assists in large area monitoring for day and night hot spot detection. Additionally, the platform integrates data from other supplementary remote sensing systems, such as the Forest Black Box platform, air quality sensors, etc., collecting valuable information from ground level near affected areas. Information generated from all these heterogenous data sources is collectively employed in order to enhance situational awareness during emerging fire incidents and is provided as real-time input to the Holistic Fire Management System that is being developed in WP7 and serves as TREEADS's Digital Twin.

## 2.1. FOUR LAYER DETECTION AND RESPONSE PLATFORM

The following section describes the structure and the functionalities of the Four Layer approach followed in detection and response inside the TREEADS project. Technical and functional details are given regarding the different aerial means and devices used, the integrated sensors, the intercommunication infrastructure and the employed algorithms and models, as have been implemented in the first development phase.

As already mentioned, the TREEADS Four Layer detection and response platform combines information stemming from different sensors and different altitude levels, in order to extract more global and comprehensive information during a fire incident. The structure of the different components of the platform is described below:

### 2.1.1 SATELLITES

Satellite systems play an important role in fire management by providing active fire monitoring throughout the entire European territory and neighbouring countries. Therefore, the TREEADS project has put focus on satellite systems, such as EFFIS and FIRMS, mainly for reasons of active fire monitoring. EFFIS (European Forest Fire Information System) services from Copernicus provided by NASA's Fire Information for Resource Management System (FIRMS) allows for active fire detection by mapping active fires based on MODIS (Moderate Resolution Imaging Spectroradiometer) and VIIRS (Visible Infrared Imaging Radiometer Suite) satellite sensors. The MODIS and VIIRS sensors make it possible to detect hotspots and thus identify active fires. The MODIS sensor on board the TERRA and AQUA satellites identifies areas on the ground that are clearly hotter than their surroundings and marks them as active fires. The difference in temperature between areas that are actively burning compared to neighbouring areas makes it possible to identify and map active fires. The spatial resolution of the MODIS active fire detection pixel is 1 km. Similarly, VIIRS sensor on board the NASA/NOAA Suomi National Polar-orbiting Partnership (SNPP) uses similar algorithms to MODIS to detect active fires. VIIRS active fire products complement MODIS active fire detection and provide improved spatial resolution, around 375 m per pixel. In addition, VIIRS is capable of detecting smaller fires and can help delineate the perimeters of large fires in progress. Further information on the properties of the Terra/ Aqua and NOAA satellites is given in Table 1.

**Table 1 - Satellite systems related to active fire detection**

| Satellite | Instrument | Temporal resolution | Spatial resolution (m) | Swath width (km) | VIS bands (µm) | MIR-TIR bands (µm) |
|---|---|---|---|---|---|---|
| Terra/ Aqua | MODIS | 4 images daily | 250 – 1000 | 2330 | 19 bands | 16 bands (including 3.9, 11.0) |
| NOAA | VIIRS | 2 images daily | 375 – 750 | 3000 | 14 bands | 7 bands (including 3.7, 8.5, 11.45) |

In addition, the Sentinel 3 mission (currently composed of Sentinel 3A and Sentinel 3B platforms) has been recently released for the measurement of sea and land surface temperature, among other objectives. For this purpose, the Sea and Land Surface Temperature Radiometer (SLSTR) incorporates 4 bands measuring in the MWIR (Mid-Wave InfraRed) and TIR (Thermal InfraRed), specifically dedicated to the detection of active fires. The four bands are S7, S8, F1, F2, with the latter ones (F1 and F2) presenting a dynamic range in order to prevent saturation over fires. MWIR band allows measurements even when smoke plume is present, since radiation in this wavelength is not absorbed by smoke, while the measurement in TIR band allows the computation of temperature measurements. More detailed information is provided in Table 2. Additionally, information on how the aforementioned Satellite systems are integrated in the Four Layer Platform is provided in Section 1.1.3 'Hotspot detection'.

**Table 2 - Satellite bands specifications**

| BAND | CENTRAL WAVELENGTH (µm) | SPATIAL RESOLUTION (m) |
|---|---|---|
| S1 | 0.554 | 500 |
| S2 | 0.659 | |
| S3 | 0.868 | |
| S4 | 1.374 | |
| S5 | 1.613 | |
| S6 | 2.255 | |
| S7 | 3.742 | 1000 |
| S8 | 10.854 | |
| S9 | 12.022 | |
| F1 | 3.742 | |
| F2 | 10.854 | |

### 2.1.2 HIGH ALTITUDE PLATFORM SYSTEM (ZEPPELIN)

Another layer of information integrated in the TREEADS four-layer platform is the High Altitude Platform System, which is an unmanned airship provided by ECOSAT. ECOSAT`s infrastructure for detection and response consists of two main components: the AS30 unmanned airship, which is shown in Figure 1, and the Mission Control Centre (MCC), which is shown in Figure 2. The former will provide aerial support through a state-of-the-art hyperspectral camera (still under selection process) assembled in the lower part of the airship, which will capture high-resolution images of the area of interest. The latter will monitor the operation of the airship, giving support to the remote pilot if needed, and will receive and manage the images taken by the hyperspectral camera. For its operation, the airship requires a ground crew to help in the take-off and landing manoeuvres and additional MCC personnel.

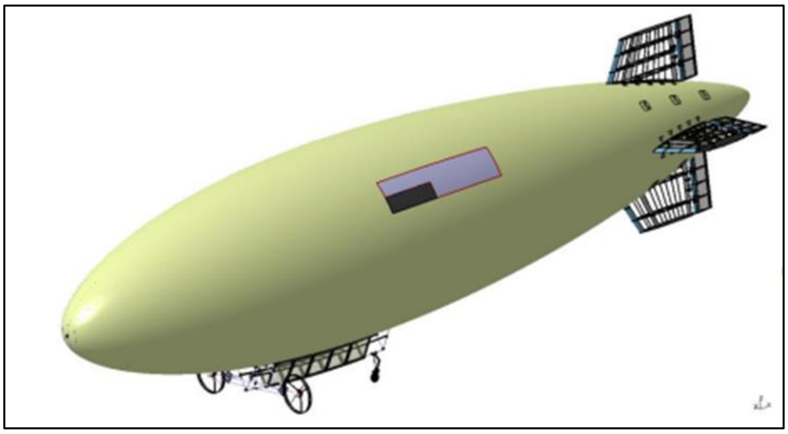

**Figure 1 - AS30 Airship**

A critical aspect of detection and response is that the camera mounted on the airship should cover accurately the area of interest. For this purpose, the software of the MCC contains a Mission Management Tool, where the flight route is defined by adding waypoints along the path. Once the route is loaded, the automatic pilot can command the airship to follow this trajectory. The interface of the mission management software is depicted in Figure 2.

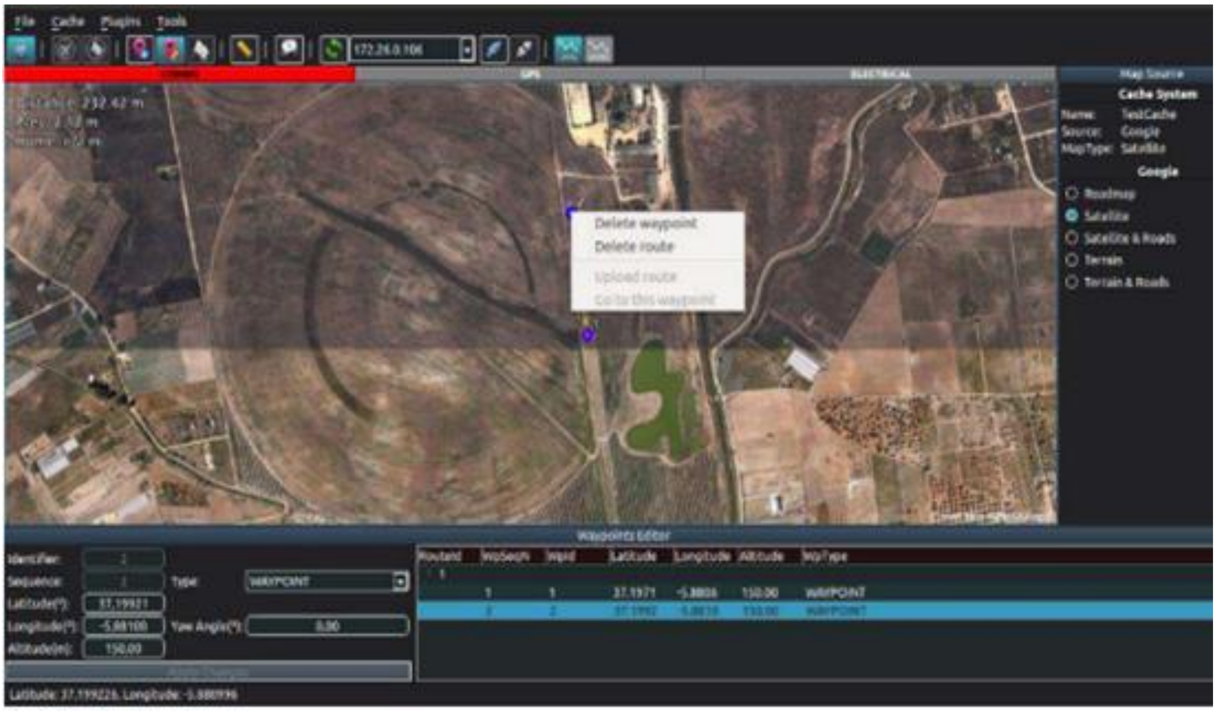


**Figure 2 - MCC mission management software interface**

Another key component is the communications subsystem, which purpose is to provide a direct link between the MCC and the airship. The communications subsystem is a complex system, so only a few characteristics are highlighted here:

- To assure communication safety, the system is redundant, based on two datalinks, the primary datalink and the secondary datalink.
- The link is bidirectional; the airship will send telemetry and video data to the MCC (downlink communication) and the MCC will send telecommands to the airship (uplink communication).
- The LRS system ensure manual control of the aerial platform at all time. This wireless modem will establish communication between the remote console and the main communication equipment at MCC.
- The ADS-B Transponder is used to broadcast the position, barometric altitude and groundspeed of the airship, so that the aircrafts in the surroundings of the airship are able to display this information in order to show a status of the close aerial environment.
- The AS30 is fully electric, thus it can be operated with zero carbon footprint.

#### *2.1.2.1 TECHNICAL DESCRIPTION*

The operation of the airship for wildfire detection and response tasks poses a series of technical challenges. Firstly, even flying the brand-new airship prototype in a low-risk environment is a challenge because of its innovative concepts, its physical characteristics and the personnel needed to operate it. Additionally, it should be noted that during TREEADS's Use Case, the AS30 airship prototype will be used in a real-demo project for the first time, operating simultaneously with other systems, which makes the operation even more challenging.

The payload of the airship in the Spanish Use Case will be a hyperspectral camera, which will be assembled in the keel, located in the lower part of the airship. The camera will take images of the terrain and will send the information to the MCC, which at the same time will send it to the TREEADS cloud system. Therefore, a highly resilient intercommunication infrastructure is needed to guarantee a permanent link between the MCC and the antennas of the airship, and to upload the information to the TREEADS cloud.

Given the complexity of the different systems involved, the methodology to apply for deploying the airship and for its operation, the demo must be meticulous and progressive. It will be necessary to ensure the availability of the logistical requirements that allow the deployment and operation of the aircraft. In parallel, it is possible to work on adapting the interfaces between the ECOSAT MCC and the end users. Image formats, coverage areas, refresh rates, image quality and typology must be clearly specified by the final user. Therefore, the need to implement a progressive and collaborative methodology among all the systems involved in the airship's operation is identified.

The architecture of ECOSAT's detection and response system is briefly presented below (many components and subsystems of the airship and the MCC are omitted here):

- **Airship**: it is the main component of the ECOSAT infrastructure. It is a lighter-than-air vehicle which serves as a high-altitude platform for wildfires detection and response.
    - Hyperspectral camera: it is a high-resolution camera mounted in the lower part of the airship which will take hyperspectral images that will be used to create 3D models and forest fuel characterization maps.
    - Communications subsystem: it sends the telemetry and the hyperspectral images taken by the camera to the MCC and receives telecommands. It is composed of the primary datalink, the secondary datalink, redundant antennas etc.
- **MCC**: the Mission Control Centre is the ground control station that continuously monitor the operation of the airship. Two main components should be mentioned:
    - Communications subsystem: it receives the telemetry and the image data from the airship; and send telecommands. It also uploads the hyperspectral images to the TREEADS cloud.
    - Mission management software: allows to define the route using waypoints that the airship will follow.
- **TREEADS cloud**: it is the repository where all the data supplied by the four layered system will be stored.

The goal is that all the architectural elements will work together properly and thus they will deliver the functionality of the whole system.

#### *2.1.2.2 OPERATIONAL VIEW*

ECOSAT`s AS30 airship will be used in the Spanish use case to capture high-resolution photos using a hyperspectral camera mounted on the lower part of the airship. AS30 is an electric and autonomous aircraft that do not rely on fossil fuels and do not put human lives at risk, which is a great advantage compared to conventional aircrafts such as helicopters and planes. However, despite its advantages, there are some considerations regarding the participation of ECOSAT in the use case that should be taken into account:

- The exceptional logistics requirements (hangar of 50x30x12 m approximately) greatly limit the location of the use case.
- Due to the characteristics of the airship, meteorological conditions shall be under operational limits, with the wind gust in the area being the most restrictive parameter.

- For the operation of the airship, it is necessary to obtain a Permit to Fly emitted by the national air space authorities and to publish a NOTAM (Notice to Airmen) informing about the operation. An example of NOTAM is given in Figure 3.

| |
|---|
| 02199/22<br>Q) LECM/QXXXX/IV/BO.AM/000/033/4235N00539W005<br>A) LELN B) FROM: 22/07/12 04:15 TO: 22/07/15 07:30 |
| E) AS30 AIRSHIP OPERATING WI LELN PERIMETER. (AIR-TO-AIR COORDINATION AVBL ON FREQ 122.100MHZ) |
| LOWER: SFC<br>UPPER: 03230FT AMSL<br>SCHEDULE: 0415-0730 |

**Figure 3 - Example of NOTAM**

- The MCC and the airship cannot be moved at the same time.
- The MCC needs to be deployed in a place that guarantees a direct link with the airship.
- For the take-off and landing, a wide-open area closed to the hangar is needed. The ground should be hard, preferably tarmac or similar, so the landing gear does not get stuck.

### 2.1.3 UNMANNED AERIAL VEHICLES

A third layer of information in the platform is produced from Unmanned Aerial Vehicles (UAVs) used either for area surveillance and detection or as heavy payload drones for fire extinguishing or seed planting. Main drone providers in the framework of TREEADS projects are Drone Hopper and ACCELIGENCE and the following section describe the solutions that they will provide and configure for the needs of the project.

#### *2.1.3.1 WILD HOPPER UAV*

Drone Hopper has developed and provides to the project the WILD HOPPER, a Heavy-Duty UAV for day and night firefighting operations. The following section describes in detail technical and functional aspects of the WILD HOPPER, its ground control station and the onboard processor and sensors that will be integrated into the drone.

The integration and validation of the communication capabilities of the WILD HOPPER system are according to European UAS C2 communication standards. The design of the communication systems of both WILD HOPPER and the ground control station (GCS) are performed in parallel. In both elements, transmitter, receiver, antenna, power supply, and the processor are designed in detail. Also, the frequency of communications should be carefully selected so that both WILD HOPPER and the GCS can operate effectively even in the worst-case scenario.

The WILD HOPPER Communication System consists mainly of two groups of communication equipment, one onboard the WILD HOPPER and one inside the GCS. An important function of the communication system is to provide the data link between the various elements of the system represented respectively as WILD HOPPER-TO-GCS, GCS-TO-WILD HOPPER and WILD HOPPER-TO-WILD HOPPER, as shown in Figure 4. Through the communication system, data from the WILD HOPPER and the GCS are linked together (data link), constituting an uplink and a downlink. Part of the data link is also the telemetry which is a communication process by which WILD HOPPER flight measurement data are collected and automatically transmitted to the receiver of the GCS.

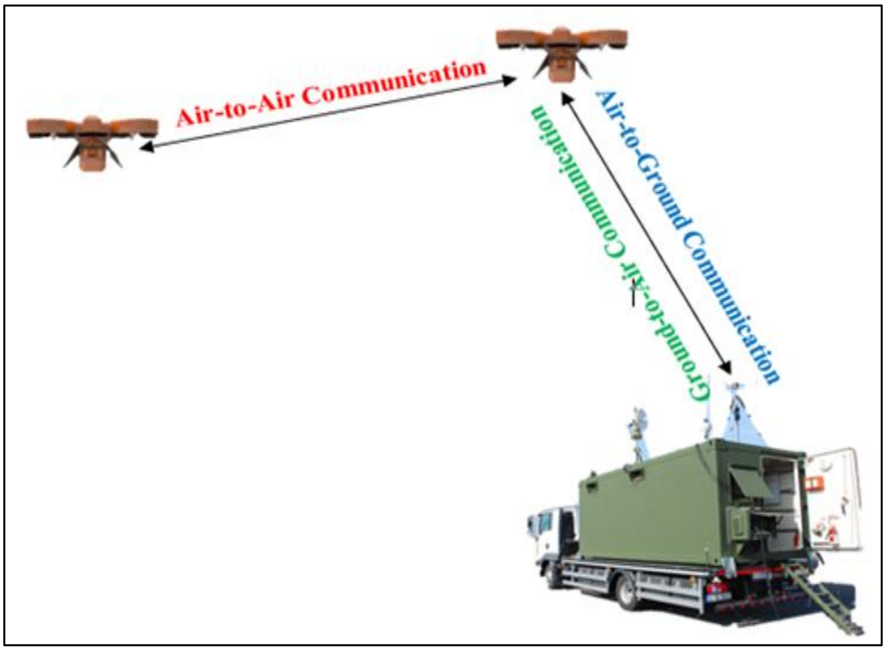


**Figure 4 - WILD HOPPER Communication System**

### 2.1.3.1.1 WILDHOPPER'S GROUND CONTROL STATION (GCS)

Figure 5 depicts an overall view of the GCS configuration, whereas details about the individual components of the GCS are presented in Table 3. Additionally, Figure 6 provides a diagram of the software structure of the GCS.

**Figure 5 - The Ground Control Station**

**Table 3 WILDHOPPER'S Ground Control Station (GCS) equipment**

| GCS EQUIPMENT | |
|---|---|
| **RF Communications** | Omnidirectional antenna<br>RF Module |
| **Network inside the GCS with the following equipment** | PCs<br>Hub/Switch<br>Server<br>Operating System (OS)<br>Control panels<br>Joystick<br>Printer<br>Screens<br>UPSs |
| **Power supply system** | Power generators |
| **Cooling system** | Air Condition |
| **Support equipment that is used on the ground** | Launch System<br>Recovery System<br>Fire recovery system |

Figure 6 provides a diagram of the software structure of the Ground Control Station.

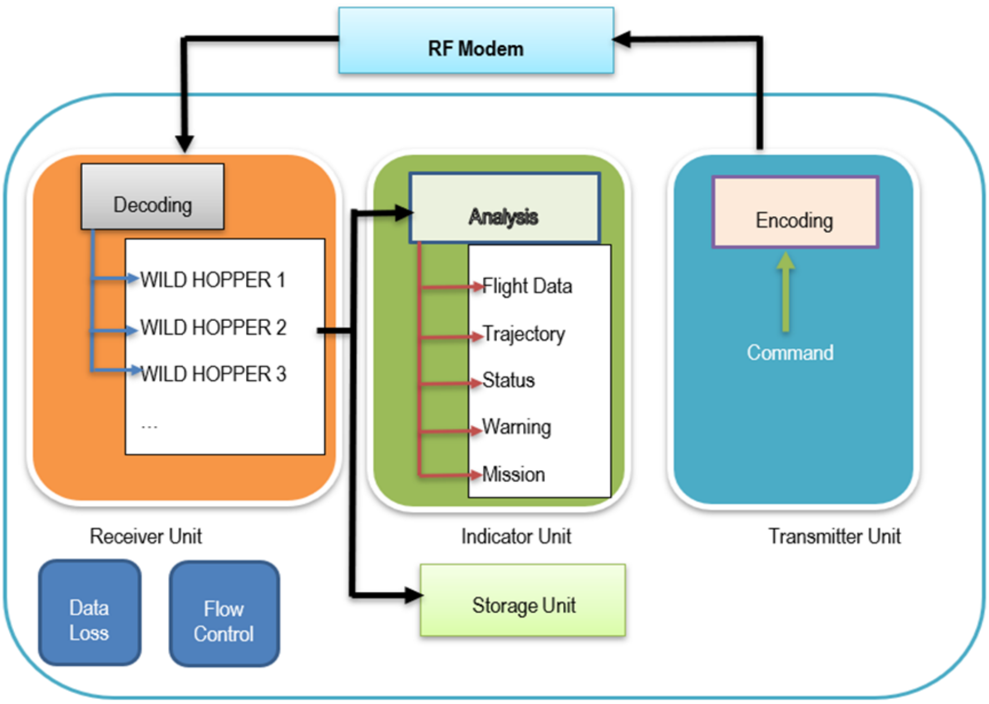


**Figure 6 - Software structure of the Ground Control Station.**

#### 2.1.3.1.2 SKY HOPPER PRO V5 (DATA MODEM)

For communication between the ground station and the aircraft, a SKY HOPPER PRO V Modem system is used, see Figure 7Figure 5. SkyHopper PRO V offers a bi-directional Data Link with video processing & analytics capabilities specifically designed for commercial and industrial drones. By employing leading wireless technologies, the SkyHopper PRO V includes a dual video inputs and outputs, dual built-in video encoders / decoders, three camera interfaces and local recording ability. SkyHopper PRO V delivers long range and Non-Line of Sight (N-LOS) communication that supports multiple transmission modes and supports Point-to-Point communication with multiple viewers.
The key features of this equipment are the following:

- Supports both Analog and HDMI Interfaces,
- Low Latency,
- Local Recording Ability,
- SW and HW decoding (PC, Tablet and/or Monitor),
- Up to 5km Line-of-Sight (LOS) range,
- Broadcast and Unicast Transmission Modes,
- Encrypted & Secured,
- Control, Telemetry and Full HD Real-Time Video,
- Robust N-LOS Operation.


**Figure 7 - Sky Hopper PRO V5**

#### 2.1.3.1.3 FUNCTIONAL VIEW

WILD HOPPER is an innovative system, with a communication network based scalable and distributed hardware architecture, and a service-based software architecture, this system can be defined as an abstraction communication layer, allowing the separation of concerns to facilitate interoperability and platform independence.

WILD HOPPER will be equipped with thermal sensors and thermal camera (on going process) and software for object recognition, which will give highly efficient impact for detection and response, to be used in both day and night operations.

Additionally, WILD HOPPER is equipped with an onboard processor, Jetson Xavier (depicted in Figure 8), which is already programmed to be integrated to the drone. Jetson Xavier will give WILD HOPPER powerful specifications represented in core i6 NVIDIA Carmel ARM®v8.2 64-bit CPU 6 MB L2 + 4 MB L3, vision accelerator with 7-Way VLIW Vision Processor.

**Figure 8 – NVIDIA Jetson Xavier**

WILD HOPPER is also a heavy payload platform with a 600-litre tank of water designed for firefighting. This payload capacity overcomes typical limitations of electrically powered drones that cannot be used for anything more than fire monitoring, as they do not have sufficient lifting power.

The enhanced capabilities of the WILD HOPPER allow to complement existing aerial means and overcome their main limitations, especially the difficulty to cover night operations. This allows reducing the duration of the wildfires by allowing continuous aerial support to the extinguishing activities once the conventional aerial means (hydroplanes and helicopters) are set back to the base at night.

Other advantages of the WILD HOPPER are the precision of the release, derived from multirotor platform dynamic capabilities. This, together with the proprietary water jet nebulization system, yields a very high efficiency compared to traditional means that carry similar (helicopters) or more litres (hydroplanes) that just drop the water at a certain speed from a higher altitude over the target fire, limited by their dynamic operational envelope.

## 2.1.3.1.4 OPERATIONAL VIEW

WILD Hopper will be used for firefighting activities using its high payload capabilities of its 600-litre tank and the water release system, with the high precision of water release, as shown in Figure 9. Being an autonomous vehicle, Drone Hopper's new UAV does not put at risk human lives as the platform's management is done from a safe ground base.

Drone Hopper has developed proprietary water mist jet creation technology to be used specifically for the firefighting operations, improving heavily the water usage. Apart from the patent, registered under patent number ES-2560952 A1, DRONE HOPPER has invested important number of resources on simulation and testing to optimize the complex performance of the water nebulization system. This development and adaptation of the previous patented mechanism also uses the airflow from the engines to convert the water into small water drops (water mist or nebulized water) and mix it with the air flow, creating a wet air flow that is directed to the ground. The capacity of locating and releasing nebulized water directly above the target enables high penetration compared to water reaching the ground only by gravity, like in conventional solutions. This precision and positioning above the target with controlled horizontal speed thanks to the inherent handling qualities of a multirotor platform, is unlike conventional aerial means.

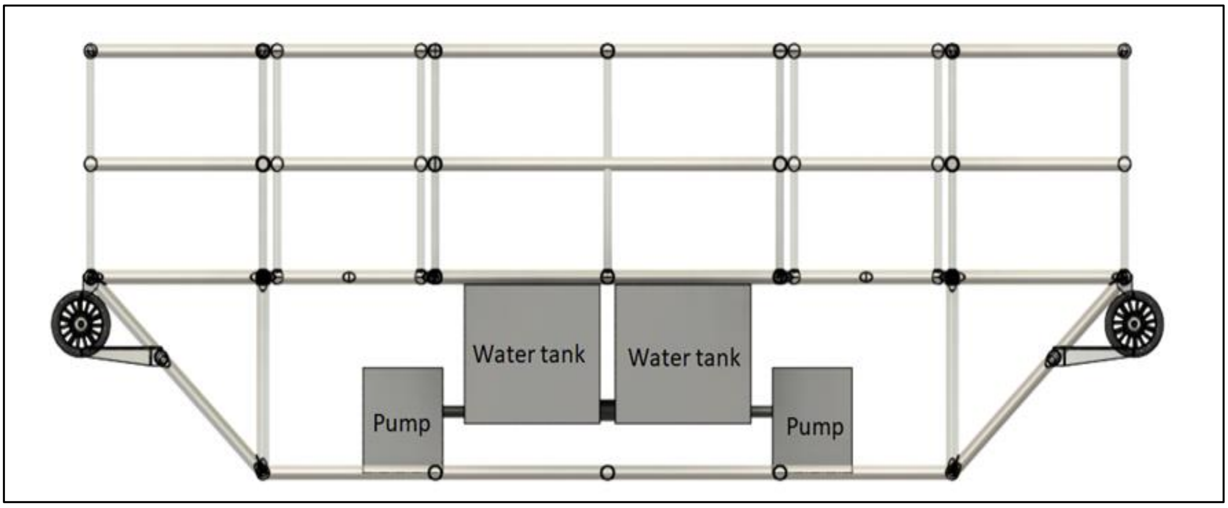


**Figure 9 - The UAV architecture with the enhanced capacity payload of the water tank (600L)**

### *2.1.3.2 OCTA-ROTOR UAV PLATFORM CERBERUS*

The versatile octa-rotor UAV platform CERBERUS developed by ACCELIGENCE can carry out a range of missions. A photo of the Cerberus UAV is shown in Figure 10 and the main specifications are given in Table 4. It has a longer flying length of up to 30 minutes thanks to its optimized design, which is a significant benefit when compared to traditional models currently on the market. It also has a high accuracy localization of 1cm utilizing GPS-RTK2. Its design and build are focused on the powerful NVIDIA Jetson AGX Xavier AI-oriented computer, which allows for limitless on-board computational capability. The High Level Design of ACCELI UAV is illustrated in Figure 11. CERBERUS is the best drone for difficult tasks like event identification, object detection/counting and collision avoidance, since its configuration is ideal for executing complex artificial intelligence algorithms.

The CERBERUS flight controller is based on the open-source ArduPilot software and is wrapped in the ROS standard software, which is fully integrated with the DDS standard. This immediately meets the needs of thousands of applications that need real-time data exchange in sectors like precision agriculture, aerospace and defense, autonomous vehicles, smart grid management, and transportation systems, among many others. Additionally, CERBERUS offers full out-of-the-box integration of ROS with multispectral and high-resolution cameras that work seamlessly with the on-board computer to accomplish the goals of each individual mission and in accordance with customer specifications.

**Table 4- ACCELIGENCE CERBERUS main specifications**

| ACCELIGENCE CERBERUS MAIN SPECIFICATIONS | |
|---|---|
| **Size – max diameter** | 1.25 m (w/o propellers)<br>1.65 m (w/ propellers) |
| **Size – height** | 0.5 m |
| **Weight** | 9.5 kg (w/o GPU and camera)<br>10,5 (with GPU and camera) |

| | |
|---|---|
| **Total Motor Thrust** | 22.8 Kg |
| **Max Flight Radius (w/ radio control)** | 10,000 m (nominal) |
| **Max flight time (no playload)** | 30min |
| **Battery Capacity** | 34 Ah |
| **Avg flight time (typical payload)** | 25min |
| **Max payload weight** | 5Kg |
| **Max take off weight** | 16Kg |
| **Operating Temperature** | -10$^{o}$ to 45$^{o}$C |
| **Precision automated take-off & landing** | Yes |
| **Flight controller** | Pixhawk 4 |
| **Motors** | 8x T-MOTOR U5 KV400 |
| **Electronic Speed Controller (ESC)** | T-MOTOR AIR 40A 6S |
| **RC transmitter** | FrSky Taranis X9D Plus SE V2019 + FrSky R9M + FrSky R9 SX long-range receiver |
| **GNSS module** | Holybro H-RTK F9P GNSS Helical (centimetre-accuracy) |
| **LiDAR Rangefinder** | SF30/D LightWare LiDAR (Altitude above ground level applications) |
| **Basic configurations** | o Flir Duo Pro R HD Dual-Sensor camera<br>o DragonEye2 dual EO-IR stabilized camera Micasense RedEdge-MX multispectral camera<br>o Mag-03MS100 Magnetometer (Bartington Instruments) |
| **Custom configurations** | o Lidar sensor (Phoenix Scout - Ultra recommended)<br>o RGB commercial cameras<br>o Custom solutions per use case |

**Figure 10 – Acceligence Cerberus UAV**

CERBERUS will be fully customized, able to accommodate the various hardware components required to execute smart algorithms (e.g., visual object detection and collision avoidance services, swarming algorithms), and will be easily adaptable to the user's current operation.

It will be able to perform on-board image processing using machine learning-based techniques, specifically Deep Neural Networks (DeepNN) and Convolutional Neural Networks (CNN), on data obtained from the various aforementioned sensory inputs (e.g., 2D/3D images/point clouds). The computations will be carried out on the NVIDIA JETSON on-board supercomputer, which offer enhanced AI performance in a small package, making it suitable for mobile robotic applications, see Figure 12.

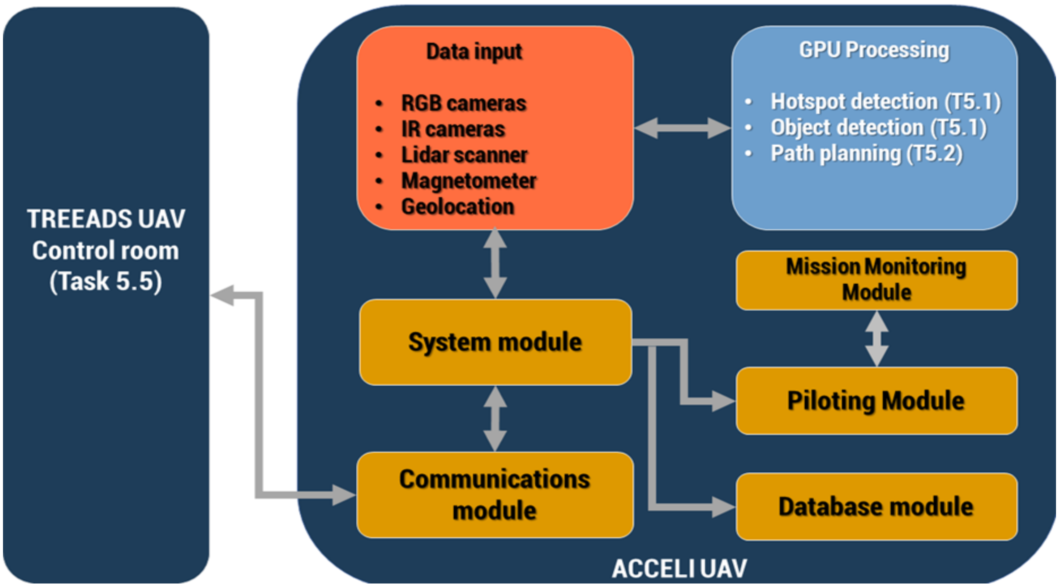


**Figure 11 - High Level Design of ACCELI UAV**

NVIDIA Jetson AGX XAVIER operates on as little as 10 W and can deliver up to 32 TOPS. Further specifications are given in Table 5. NVIDIA Jetson AGX XAVIER is supported by NVIDIA JetPack, which includes a board support package (BSP), Linux OS, NVIDIA CUDA, cuDNN, and TensorRT software libraries for deep learning, computer vision, GPU computing, multimedia processing, and much more.

It is also supported by the NVIDIA DeepStream SDK, which delivers a complete toolkit for real-time situational awareness through intelligent video analytics and NVIDIA Isaac SDK, which delivers a software toolkit for robot development. These aids in improving performance and speeding up software development while lowering costs and effort.

**Table 5- Onboard processor specifications**

| NVIDIA Jetson AGX XAVIER specifications | |
|---|---|
| **AI Perf** | 32 TOPS |
| **GPU** | 512-Core Volta GPU with Tensor Cores |
| **CPU** | 8-Core ARM v8.2 64-Bit CPU, 8 MB L2 + 4 MB L3 |
| **Memory** | 32 GB 256-Bit LPDDR4x \| 137 GB/s |
| **Storage** | 32 GB eMMC 5.1 |
| **VIDEO ENCODER** | 4x 4K @ 60 (HEVC) \| 16x 1080p @ 60 (HEVC) \| 32x 1080p @ 30 (HEVC) |
| **VIDEO DECODER** | 2x 8K @ 30 (HEVC) \| 6x 4K @ 60 (HEVC) \| 26x 1080p @ 60 (HEVC) \| 72x 1080p @ 30 (HEVC) |
| **PCIe** | X8 PCIe Gen4/x8 SLVS-EC |
| **CSI Camera** | Up to 6 cameras (36 via virtual channels) \| 16 lanes MIPI CSI-2 \| 8 lanes SLVS-EC \| D-PHY 1.2 (up to 40 Gbps) \| C-PHY 1.1 (up to 91 Gbps) |
| **DL Accelerator** | 2x NVDLA Engines |
| **VISION ACCELERATOR** | 7-Way VLIW Vision Processor |
| **Networking** | 10/100/1000 BASE-T Ethernet |
| **M2 KEY M** | NVMe |

**Figure 12 - NVIDIA Jetson AGX Xavier**

The block diagram in Figure 13 illustrates a high-level overview of the CERBERUS UAV connectivity architecture, representing the electrical connections between the hardware components:

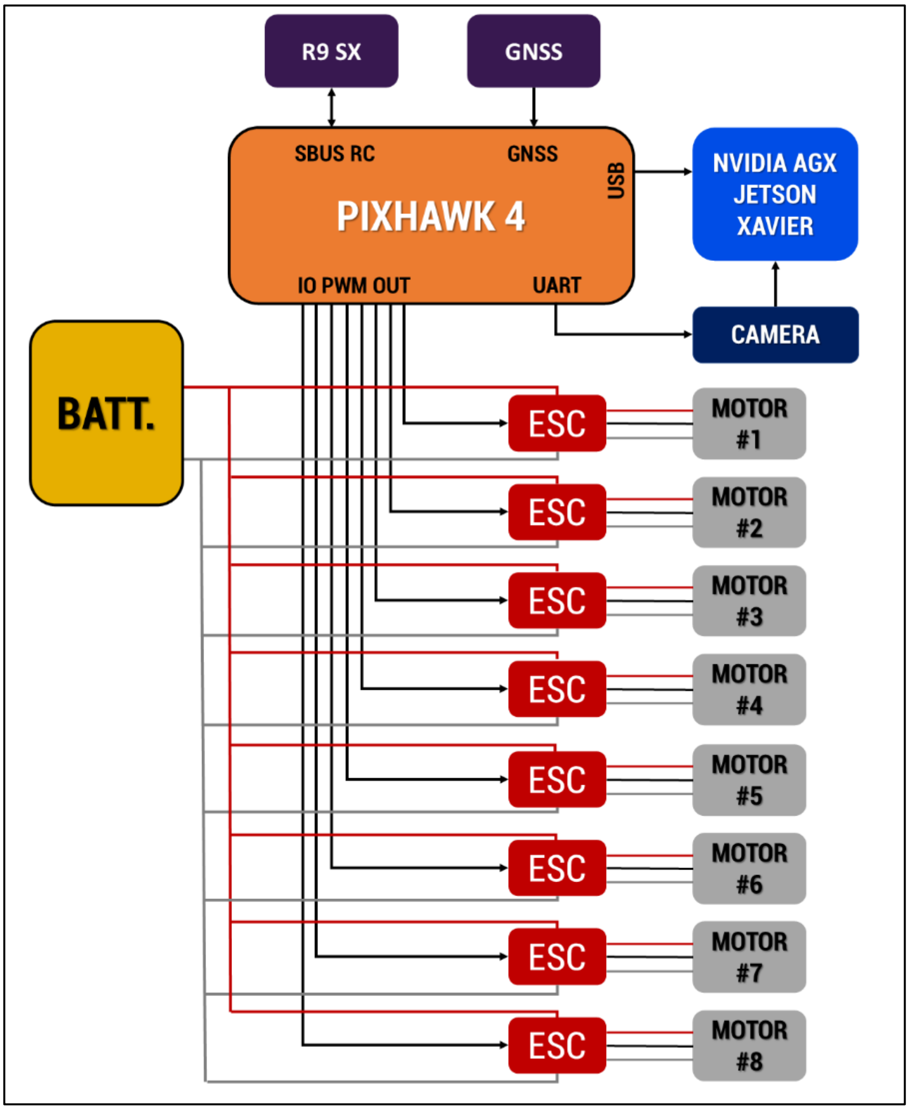


**Figure 13 - CERBERUS UAV: High level connectivity Block Diagram**

##### 2.1.3.2.1 CERBERUS UAV OPERATIONAL CAPABILITIES

**Event detection capabilities:** Data collected from available sensors/cameras will be processed in a hierarchical manner for event detection, both locally at the agents (when possible, cooperatively) and centrally at the command center. The UAV can directly exploit the results of collaborative data processing and fusion tasks, or they can be transmitted to end users for further analysis and processing. Early event detection will generate alerts, prompting the operator to take additional action.

**Advanced navigation capabilities:** The platform will include advanced methodologies for UAV agent cooperative navigation. When a mission is assigned to a specific UAV on the battlefield, the UAV typically operates in a semi-autonomous, distributed, cooperative, and coordinated manner. When direct human control is explicitly required, a manual Remote-Control functionality is provided.

## 2.2 OTHER REMOTE SENSING SYSTEMS

Apart from information coming from all the aerial platforms described in the previous sections, the Four Layer platform will also integrate information from other sensors specifically designed to facilitate First Responder's activities.

### 2.2.1 FOREST BLACK BOX

Forest Black Box (FBB), developed by 8Bells, is a compact sensors platform, specially designed for forest fires detection and response. It comprises a set of various sensors namely temperature, humidity, Carbon Monoxide (CO), Particulate Matter (PM) and a thermal camera, as illustrated in Figure 14. It provides sensor measurements, while also monitor a wide area using thermal imaging technology. CO & PM sensors will be provided by NCSRD and will be integrated in the device, in a joint 8Bells-NCSRD effort.

The FBB platform will be used by the relevant stakeholders in order to get informed on ambient temperature, relative humidity and also air pollutant's concentration levels which is a priority in emergency fire operations. The selected CO sensor has a high sensitivity and fast response time that can detect CO gas concentrations from 10 to 500ppm, while the PM sensor is an optical laser-based PM sensor. Its measurement principle is based on laser scattering. This sensor measures mass concentration and number of particles of 1 $\mu g/m^3$, 2.5 $\mu g/m^3$, 4 $\mu g/m^3$, and 10 $\mu g/m^3$.

In addition, the thermal camera may provide surveillance over wide areas (Field of View: $18^o \times 13^o$, detection vehicle: ~4Km, person: ~2Km) and can be operated during night and day and under adverse atmospheric conditions, such as smoke. The thermal camera will be operated remotely and data will be transferred via the available network. All sensors' outputs will be displayed, integrated in a UI.

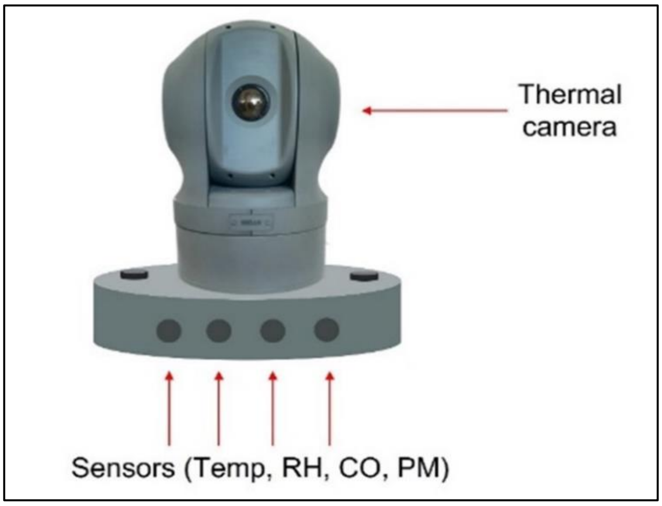


**Figure 14 - Forest Black Box conceptual illustration**

The system consists of the following:

- A thermal camera and can be rotated in order to provide 360o surveillance,
- Sensors of various types,
- A ruggedized housing which hosts the above subparts,
- An UI which is user friendly and contains the following information:

The UI of the Forest Black Box, is conceptually shown in Figure 15:

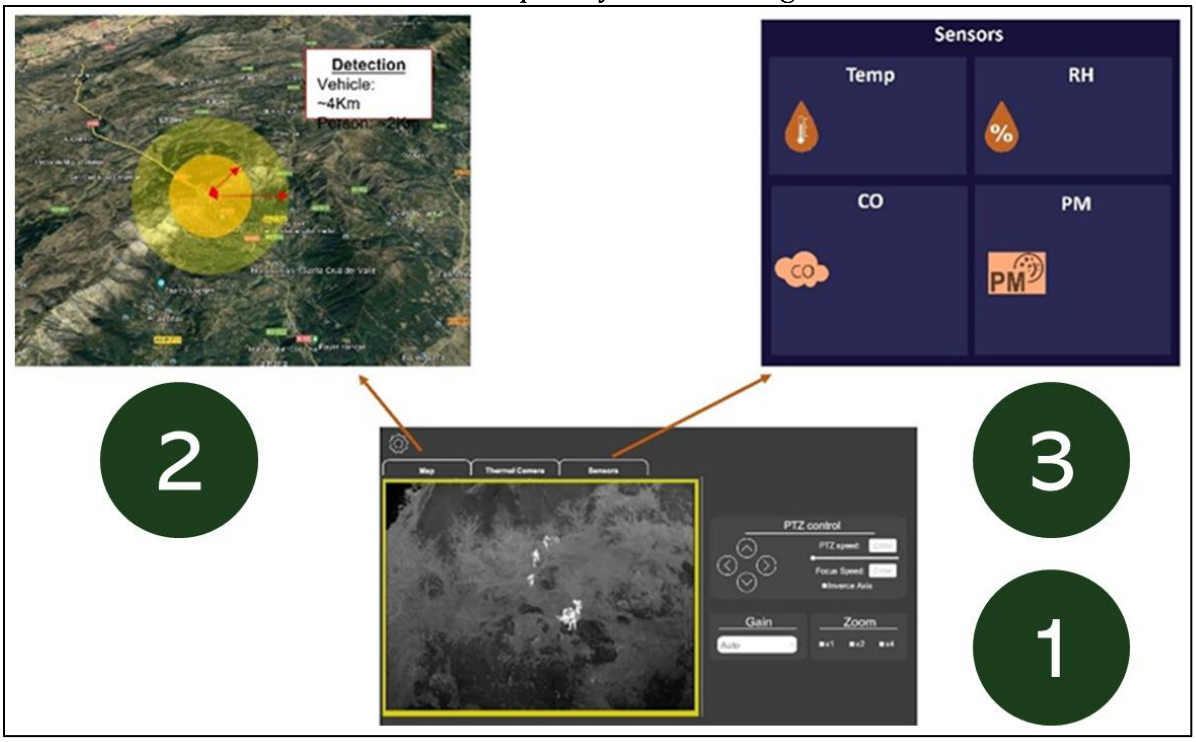


**Figure 15 - Forest Black Box User Interface illustration**

1. Map: Map of the area to be monitored,
2. Thermal Camera: Thermal imaging of the area,
3. Sensors: Sensors values (temperature, humidity, CO, PM).

Data from sensors may be transmitted to the Control Station through cable or by using the available network on the site.

### *2.2.1.2 BLACK BOX - THERMAL CAMERA APPLICATIONS*

The thermal camera can have a dual role, i.e., acting as an early warning system for fire detection, while also it can be used in Search And Rescue (SAR) applications after a fire incident in order to locate people and/or animals for evacuation purposes. Since thermal imaging technology is based on the temperature difference between the target and the background (scene) and fire's temperature is well above the background temperature, the thermal camera is an ideal early warning tool for fire detection purposes. Along these lines, the temperature of living objects (people, animals) differs from the scene temperature. In addition, thermal emissivity of human body is high, thus the thermal contrast is quite high. Both conditions enhance the visibility of living objects with thermal imaging, facilitating their detection.

**Specifications:**

- Provides 360° surveillance of the Area Of Interest,
- Field Of View: 18° x 13° , see Figure 16,

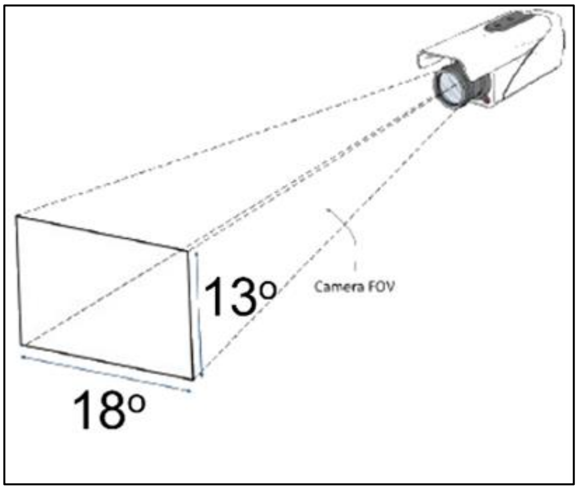


**Figure 16 - Thermal camera's FOV**

- Detection Range: 4 Km vehicle & 2 Km person, see Figure 17,

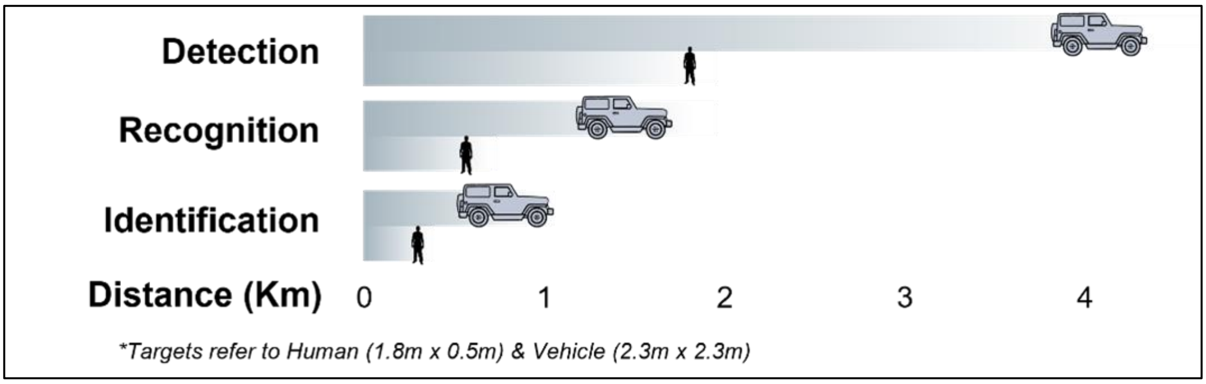


**Figure 17 - Thermal camera's Detection Range**

- Digital zoom (X2, X4),
- Requires no ambient light, effective operation in night and day, under any weather conditions,
- Able to detect living persons/ animal through dense smoke (in case of fire) or foliage,

- Robust housing, designed for outdoor use in adverse conditions,
- Can be operated in extreme temperature conditions, thus throughout the year,
- Uncooled technology that requires minimal maintenance, with a very high MTBF,
- High frequency rate, without image lag, even for moving targets,
- Image and video recording available,
- Search And Rescue (SAR) & early detection of fire applications.

### 2.2.2 AIR QUALITY SENSORS

NCSRD in the frame of WP5 has been designed and it is under development an Air Quality monitoring multi-sensor device for providing in real time information about air pollutants' concentrations levels. The device will be used by the black box (for continuous monitoring of the corresponding area). The priority air pollutants in emergency fire operations correspond to Carbon Monoxide (CO) and Particulate Matter (PM). The integrated device will consist of the AQ sensor sub-components, the central processing unit (CPU), the data communication units (DCUs) and the power management unit (PMU).

NCSRD will also deploy a broker solution providing an interface for NCSRD sensors to communicate seamlessly across the TREEADS platform. The deployment of an MQTT based broker will also be considered since embedded devices are heavily involved and computational cost is of high importance.

#### *2.2.2.1 CO SENSOR SUB-COMPONENT: SEMICONDUCTOR CO SENSOR*

The selected sensor has a high sensitivity and fast response time that can detect CO-gas concentrations from 10 to 500ppm. The sensitive material of the gas sensor is SnO2, with lower conductivity in clean air. It makes detection by method of cycle high and low temperature and detect CO at low temperature (heated by current flow at 1.5V for 90s). The sensor's conductivity gets higher along with the CO gas concentration rising. At high temperature (heated by current flow at 5.0V for 60s), it cleans the other gases adsorbed at low temperature. CO Sensor's standard characteristics:

- Heater Resistance (RH = 29Ω±3Ω),
- Heater consumption (PH ≤ 900mW),
- Sensitivity (S: Rs (in air)/Rs (in 150ppm CO) ≥ 5),
- Output Voltage (Vs: 2.5V 4.3V (in 150ppm CO)),
- Concentration Slope (α ≤ 0.6 (R 300ppm /R 50ppm CO),
- Sensor Output Format (analog voltage output related to PPM – requires additional processing for PPM calculation).

#### *2.2.2.2 PM SENSOR SUB-COMPONENT*

The PM sensor is an optical laser-based PM sensor. Its measurement principle is based on laser scattering. This sensor measures mass concentration and number of particles of 1 $\mu g/m^3$, 2.5 $\mu g/m^3$, 4 $\mu g/m^3$, and 10 $\mu g/m^3$. Optical particle counters (OPCs) guide ambient, suspended particles to a measurement cell inside the device. The measurement cell consists of a light source (e.g., a laser) and a photo-detector. Due to the interaction of particles and light, part of the incoming light is scattered towards the nearby photo-detector. The collected signal is converted into real-time particle count and mass concentration values, respectively given in #/cm3 and in μg/m3. PM Sensor's standard characteristics:

- Operating voltage (3.3V-5V),
- Operating Current (60mA max),
- Mass Concentration Precision (±10 μg/$m^3$ @ 0 to 100 μg/$m^3$, ±10 % @ 100 to 1000 μg/$m^3$),
- Mass Concentration Resolution (1 μg/m3),
- Sensor Output Format (digital communication via I2C or TTL UART through a proprietary protocol for sensor configuration and data acquisition).

#### *2.2.2.3 CENTRAL PROCESSING, DATA COMMUNICATION AND POWER MANAGEMENT UNITS*

The device will use as CPU an ESP32 low-power SoC microcontroller with an embedded Xtensa 32-bit LX6 core microprocessor operating at 160-240 MHz. The central role of CPU is to process the analog signal data from the CO sensor and calculate PPM concentrations, process the digital data of the PM sensor and deliver the processed sensory data (to various data consumers) through the device's embedded DCUs (Bluetooth/Cellular). CPU will send the sensory data in short range (to FR's equipment or Black box) using Bluetooth protocol and remotely (to TREEADS system backend) using MQTT protocol over cellular data connection.

## 2.3 PLATFORM'S FUNCTIONAL VIEW

The integrated information extracted from all the different data sources, described in the previous sections, is a valuable asset towards enhanced situational awareness, by leveraging advantages of all the different layers involved. Among several potential applications of the platform, the most practical functions will be: i) the combination of Satellite services and other aerial means for providing enhanced Hot Spot detection, and ii) the provision of enhanced object recognition functionalities onboard edge devices for the *detection, localization and risk estimation* of people, animals, vehicles etc., for *personnel monitoring, assistance in evacuation missions and other potential activities*. More details on the functional aspects of the platform are provided in the following sub-sections.

### 2.3.1 HOT SPOT DETECTION

TREEADS proposes to perform hotspot detection following a coarse to fine approach that can take advantage of the four layers used. Satellites allow covering active fire monitoring of the entire European territory and neighbouring countries. Data available for specific detailed areas from zeppelin, drones or other sensors will provide an extra factor of reliability and better spatial resolution for hotspot detection and assessment. By employing the Copernicus services and the time series provided, together with zeppelin and drone data, a set of services have been designed. These detection services can be integrated into the webGIS application to provide information related to the detection of hot spots and possible fire factors (e.g., smoke plumes, etc.). The services will provide data input from the four-layer approach.

MODIS, VIIRS, and the Sentinel 3 mission will be used, as already described, especially focusing on the 4 bands specifically dedicated to the detection of active fires from Sentinel 3: bands S7, S8, F1, F2. In all cases, the main drawback of the use of satellite imagery for hotspot detection is the low spatial resolution, of 375 meters in the best case (VIIRS) and 1000 meters in most cases (MODIS and Sentinel 3). This could be solved by the application of unmixing algorithms, that allow the automatic improvement of the spatial resolution of thermal infrared satellite imagery based on the assumption that variations in the land use can be associated with changes in the spectral response of the materials. In this way, using the visible (VIS) or short-wave infrared (SWIR) channels of a satellite image, which usually present a greater spatial resolution than the thermal infrared (TIR) channel (Sentinel 2 imagery, with 10 meters resolution in the SWIR bands, can be used as reference), the image classification can be performed. This image classification is used as reference for the unmixing of the pixels in the TIR image, resulting in a synthetic TIR image with the same spatial resolution as the VIS or SWIR images used for reference.

These services have been planned for several stages of action, with the objective of offering a differentiating and improved functionality in the detection of hotspots in TREEADS, as described below:

##### *2.3.1.1 INTEGRATION OF EFFIS SERVICES INTO TREEADS PLATFORM*

This integration, offers a better active fire warning service based on a specific area (polygon or bounding box) defined by the user, by: 1) Providing a wrapper of additional functionality to the current services, offered by Copernicus, with the aim of targeting points of interest for the user, by monitoring areas (pilot zones, regions, worst areas, etc.); and 2) Offering an automatic alert notification service to the security services (e.g., 112 Service), in order to reduce the response time and avoid constant manual inspection by the end-user.

Hotspot detection is attainable by means of remote multispectral sensors equipped on ground, satellites or other aerial platforms. The sensitivity and frequency of the fire detection will depend on the satellite, its orbit and the specific characteristics of the instrument (Engel, et al., 2021). Active fire detection is based on sensors such as Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), Visible Infrared Imaging Radiometer Spectrometer (VIIRS) or Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR), among other instruments.

Active fires are located on the basis of the so-called thermal anomalies produced by them. The algorithms compare the temperature of a potential fire with the temperature of the land cover around it. If the difference in temperature is above a given threshold, the potential fire is confirmed as an active fire or "hotspot."

The objective set for this section is to cover the European area and neighbouring countries, as well as to monitor and automatically alert the user in areas of interest. To this end, this service will connect with the API offered by EFFIS (based on FIRMS) developing a set of logic that offers the functionality set out in the objective. EFFIS distributes near real-time active fire data (NRT) from the MODIS radiometer spectra on board the Aqua and Terra satellites, and the visible infrared imaging radiometer suite (VIIRS) on board the S-NPP and NOAA 20 (formally known as JPSS-1). Globally, these data are available within 3 hours of satellite observation. The detection service monitors at defined intervals the three WFS services offered by FIRMS; MODIS, VIIRS S-NPP and VIIRS NOAA-20 to obtain active fire/hotspot data in vector format.

A first prototype has been designed, its logic is able to interpret data from EFFIS-FIRMS services and notify the security services when an incident occurs in a defined area. This service has been divided into two main processes.

- The first process is responsible for downloading the active fire data sources. For this purpose, tasks/jobs have been designed where download is automated independently for each of the MODIS and VIIRS sources offered. This task/job can be executed in time intervals (currently every 15 minutes). In this process, new information is downloaded and recorded in the hotspot early warning data model. Among the recorded data, values of interest such as incident coordinates, reliability percentage, brightness temperature, radioactive power, etc., are stored for query filtering. Incidents with a reliability higher than 50% can be considered as real fire alerts in the forest environment. Lower reliability can give false active fires, coming from industrial emissions, urban areas or other sources.
- The second process is executed when the first step is finished. This process is responsible for detecting of incidents occurring in a defined spatial area and notifying the user accordingly. To do this, each area is analysed towards defining whether there has been an active fire/hotspot in the last 24 hours. The incidents are recorded in a database and the user is notified.

#### *2.3.1.2 IDENTIFICATION OF SMOKE PLUMES*

Identification of smoke plumes for a given polygon or bounding box based on satellite images. State-of-the-art computer vision techniques will be used and analysis based on Land Surface Temperature (LST) will be applied in order to provide more accurate detection results. This step will be based on the use of Sentinel 3 and its bands for active fire detection S7, S8, F1 and F2.

#### *2.3.1.3 IMPROVED RESOLUTION HOTSPOT DETECTION FROM SATELLITE IMAGERY*

Remote sensing imagery to detect and monitor forest fires requires the availability of thermal infrared data at high spatial resolution because of the rapid development of fires and the fragmentation of most forest landscapes. Conversely, no single sensor meets these combined requirements. Data fusion approaches offer an alternative to exploit observations from multiple sensors, providing datasets with better properties.

A novel spatial data fusion model based on constrained algorithms denoted as multi-sensor multi-resolution technique (MMT) was developed and applied to generate TIR synthetic image data at high spatial resolution. The procedure consists of unmixing the lower resolution TIR images using the information about their pixel land-cover composition from co-registered images at higher spatial resolution based on the assumption of linearity for thermal radiance. An example would be the unmixing of TIR Landsat 8 data (30 m resolution) to the Sentinel 2 MSI with 10 m resolution (Herrero-Huerta et al., 2019). The constrained unmixing preserves all the available radiometric information of the 30 m images and involves the optimization of the number of land-cover classes and the size of the moving window for spatial unmixing. Figure 18 clarifies the workflow and the data products of this method.

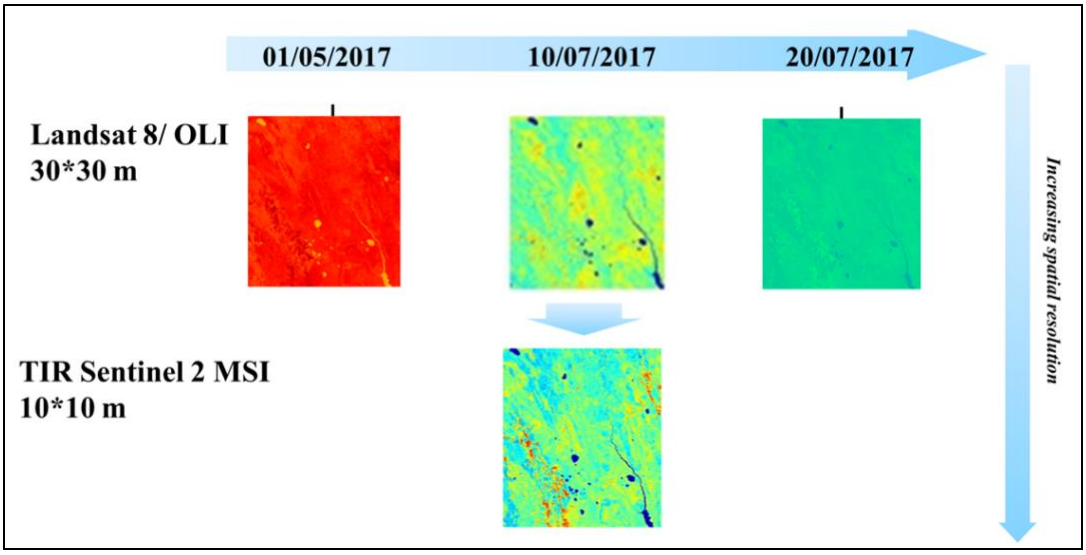


**Figure 18 Workflow to generate high resolution TIR image data at 10 m x 10 m spatial resolution (Sentinel 2 / MSI)**

### *2.3.1.4 HIGH-RESOLUTION HOTSPOT DETECTION FROM AERIAL MEANS*

The TREEADS platform will include high-resolution hotspot detection from drones and zeppelin through thermographic analysis of smoke and fire plumes. A diagram of the Hotspot service for monitoring and analysis of active/hotspot fires is given in Figure 19. The results obtained from the computer vision and artificial vision of the cameras will be provided to the hotspot detection service, for the registration of hotspots when detected. This task will develop the dimensional analysis software of edge elements in vehicles, drones, and fixed cameras in the field.

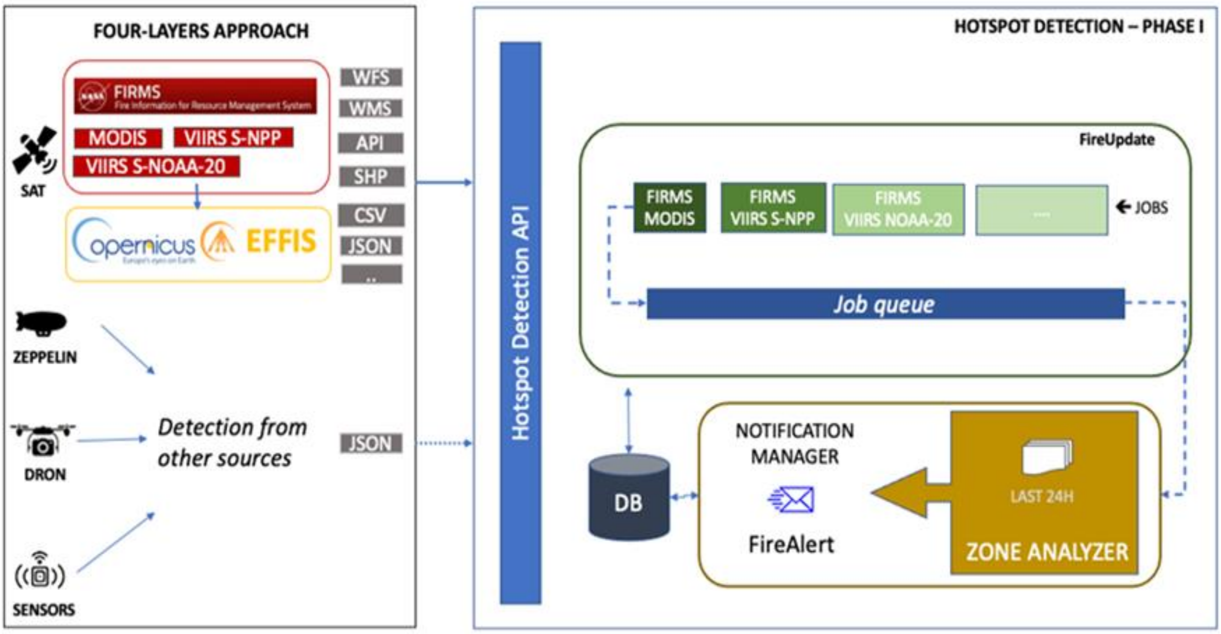


**Figure 19 - Diagram of the Hotspot service for monitoring and analysis of active/hotspot fires in defined areas**

## 2.3.2 OBJECT RECOGNITION FOR EMBEDDED DEVICES

In addition to the identification of forest fires, the detection of impacted targets, such as pedestrians and vehicles, is also an important aspect of crisis management during response phase, especially in Search and Rescue operations. Thus, a separate module was developed, using deep-learning object-detection techniques, in order to detect humans, vehicles and other objects of interest. Examples are given in Figure 20.

The objective is to develop low-computational cost models in order to be able to perform object recognition activities on the fly on edge computers mounted on UAVs. In order to approach our task, we selected YOLO (You Only Look Once) algorithm [1] which is quite efficient and can process images in real-time and specifically version 4. The model creates bounding boxes around detected objects localizing the objects inside an image, along with corresponding scores for each bounding box in the range of 0.0-1.0 (0%-100% accuracy).

#### *2.3.2.1 METHODOLOGICAL APPROACH*

There are several object detection models being developed and with the introduction of convolutional neural networks (CNN) detection accuracy improved significantly. However, one of the problems that emerged with CNN was the relatively large model size and long processing time. Object detection models can be divided into two major categories: the two-stage detectors, such as Fast RCNN and Region-based Fully Convolutional Networks (RFCN) architectures, and the one-stage detectors, such as single-shot detector (SSD) and You Only Look Once (YOLO). The difference is in the use of a separate subnetwork which is responsible for the proposal of bounding boxes named Region Proposal Network (RPN). Two-stage detectors are considered more effective but less efficient in processing time, contrary to one-stage detectors. Therefore, the interest of the community lately has shifted to one-stage architectures because of their benefits in processing time.

For our implementation, we selected the YOLO algorithm, which is time efficient and able to produce relatively accurate results, which makes it a suitable model for object detection in embedded platforms [2]. We have experimented with version 4. The algorithm predicts classes, probabilities and bounding boxes for multiple objects in each input image in one run, unlike models such as Faster RCNN which require an extra step for each image. A CNN is used to predict class probabilities and bounding boxes. The model creates bounding boxes around detected objects, localizing each object inside the image. Alongside the aforementioned bounding box, the model provides a corresponding score for each bounding box in the range 0.0-1.0.

In order to train the model, there was a need to collect a dataset which contains all the predefined classes, suitable for the needs of the project. The main focus was on the position of the capturing camera, to be either UAV perspective (with inclined view) or fixed camera perspective (which for surveillance purposes is usually an elevated camera which captures a wide area). A set of publicly available datasets has been collected, using UAV perspective, and will be updated in the future with more visual material in order to enhance the dataset and increase the model performance. Some of the publicly available datasets used are:

- The VisDrone dataset [3] with 10,209 images collected from UAV perspective.
- UAV123 dataset [4] with objects captured from a low-altitude point of view.

The trained model was tested on a Jetson AGX Xavier to evaluate both its accuracy and its efficiency, by using as an evaluation set, a certain subset of the collected dataset, containing 1800 images. In order to evaluate the accuracy of the model, the mean Average Precision (mAP) metric was calculated, by averaging the Average Precision (AP) over all classes. For the calculation of the AP, the area under the curve of the Precision-Recall curve is computed, where Precision and Recall metrics are defined as:

$$\mathbf{Precision} = \boldsymbol{TP/(TP+FP)} \quad \textbf{and} \quad \boldsymbol{Recall = TP/(TP+FN)},$$

where TP is the number of True Positives, FP is the number of False Positives and FN is the number of False Negatives. The resulting mAP for the classes that have been included until now, i.e., humans and vehicles (car, truck, motorcycle) was 70.02%.

In order to evaluate the efficiency of the model, we estimated the processing time, in terms of number of processed frames per second (fps) on two different hardware setups, a workstation with GPU Nvidia GeForce RTX 3090 and an edge processor Jetson AGX Xavier, since we expect that the module will run on both architectures according to the different project's needs. As expected, results are heavily affected by the hardware available and specifically, the algorithm reached a frame rate of 28 fps on the workstation and 9 fps on the edge device.

To refine the algorithm and better adapt it to the needs of the Use cases, a new round of user requirements was collected through questionnaires that were disseminated to the end user that led the Use Cases, regarding possible uses of the module and additional classes of interest. According to their feedback, the list of object classes has been updated (to include for example wild animals) and the model will be adapted accordingly in the next round of development. Additionally, the main uses of the module will be to detect humans, vehicles or animals in danger and to provide support to evacuation operations by searching for people trapped in an affected area.


**Figure 20 - Object detection examples**

## 2.4 PLATFORM'S DATA REPOSITORY

The data collected from all the heterogeneous data sources in the framework of the Four Layer platform will be archived in a Digital Twin repository based on the open international standard ISO10303. This repository, EDMtruePLM is a scalable solution for archiving, sharing, and exchange of the data from the different sources/ detection layers. A typical framework for PLM repository for capturing sensor data is shown in Figure 21. The ISO 10303 repository can host sensor data, both descriptions of the sensors and the collected sensor measurements, that is, all measurements or a filtered selection for long term storage in a configuration- controlled environment. The repository is currently set up to work with the cloud-based IoT Eclipse Arrowhead Framework, a result of the Horizon/ECSEL project Arrowhead Tools. The main purpose of such a system is to facilitate data interoperability. Pushing and receiving data is easy through REST API. The repository can optionally be used with the Eclipse Arrowhead Framework, which supports Cloud-to-Cloud communication in an IoT setting. Thus, sensor measurements can be streamed to the digital twin and its digital sensor representations in the ISO 10303 repository.

The data model covers, product data management, CAD, FEM, CFD, logistics data and more. For the purpose of the TREEADS project, the most relevant aspect is the sensor data archival. The software runs on Windows and can be accessed through the web-based browser for easy user access. Different users can also be assigned to the same repository with differing data access. Meaning that data can be stored securely.

The PLM repository is enabled through an IoT framework. This generally means that the sensor data must be pushed through a gateway into the repository on the cloud. This is generally done through an industrial PC. The figure below derives a view of the framework to enable data acquisition to the repository. Data can be sent from the sensors through the gateway, streamed or uploaded in batches. The PLM standards make it easy for AI components to access the archived data on the cloud through the REST API or otherwise, the AI can be situated on the edge.

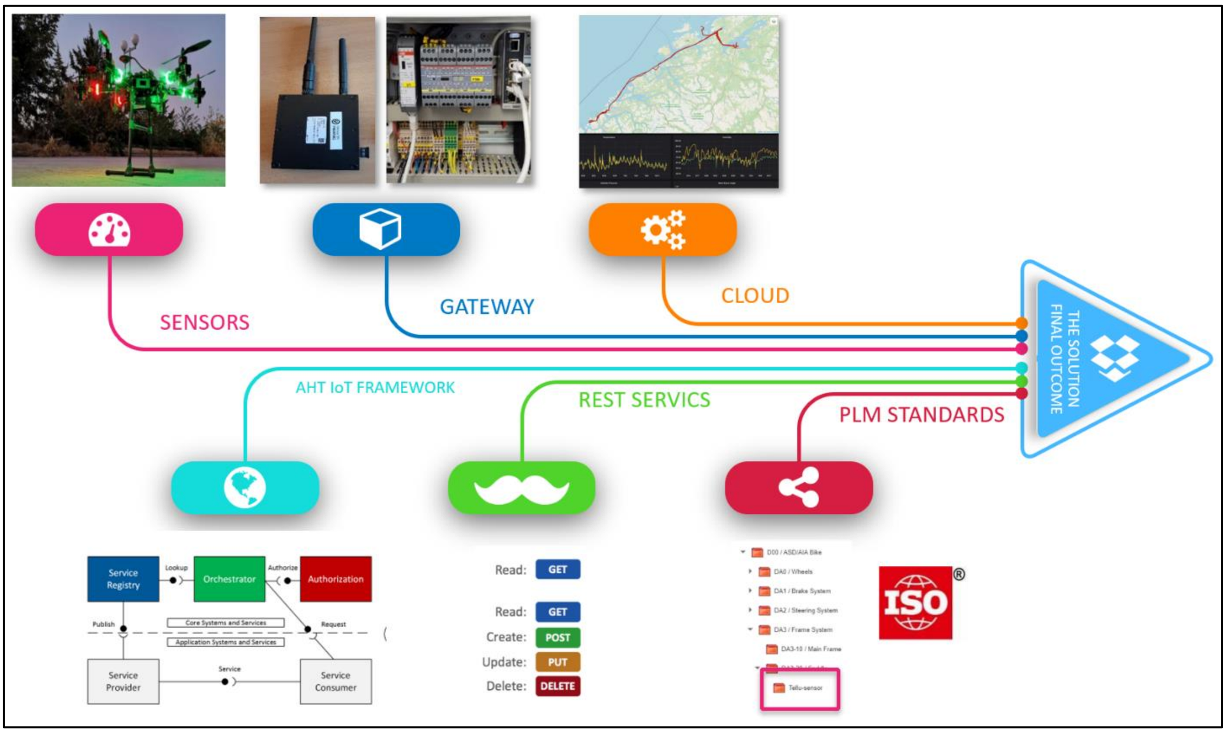


**Figure 21 - Typical framework for PLM repository for capturing sensor data**

# 3. OPTIMIZING OF ROUTE MANAGEMENT AND PATROLLING IN THE MONITORED AREA

The tool presented in this section is developed in the scope of TREEADS project in order to provide high-level guidance for multiple vehicles (more specifically UAVs) participating in the missions and thereby enhance situational awareness during the mission and assist the restoration of forests. The title of the module is *"Optimizing of route management and patrolling in the monitored area"* and in short is referenced as *"Swarm-Optimization"*, since all of the surveying assets (UAVs) form a robotic swarm.

The objective of this module is to provide a tool that will create and manage missions with multiple, heterogeneous assets (UAVs with different technical capabilities), demanding minimum cognitive load from the operator and providing autonomy, safety and increased operational efficiency. Swarm-Opt module receives the high-level operator defined objectives (coordinates of the area, hight from which the images are gathered) and translates them to low-level commands and actions for all the involved assets and modules, participating in a mission. After the definition of a new mission through the User Interface tool that is developed, the back-end algorithm of Swarm-Opt receives and handles the defined, high-level information, in order to coordinate all the participating assets and manage the execution of the mission.

Regarding the path planning functionality, Swarm-Opt is going to support the following modes:

- *Coverage Path Planning (CPP),* gather information (like images) from the operational area with a single pass, ideal for forest restoration missions.
- *Persistent coverage,* constantly provide information over a specific area, ideal for usage during fires.

## 3.1 COVERAGE PATH PLANNING (CPP)

When the description of a mission contains as objective the coverage of a **Region of Interest (ROI)**, Swarm-Opt is responsible to calculate paths for one or more vehicles, inside a polygon ROI, in order to cooperatively, completely cover this ROI. RC expects to receive the following information:

- WGS84 coordinates of the polygon ROI,
- number and names of the vehicles participating,
- scanning density in meters (will be explained later),
- initial positions of the involved assets,
- percentages of the complete ROI that should be assigned to each of the vehicles.

The Coverage Path Planning (CPP) problem deals with the generation of paths inside a given *ROI,* for one, or more vehicles, having in mind *specific coverage capabilities of the sensors* used, with the objective to *completely cover the ROI*, taking into account *constraints that may exist for the vehicles, or the ROI itself*. Most of CPP methods, try to be optimal for specific kind of missions, by trying to minimize turns, operational time, etc.

There are many research works available in the field of CPP. The state of the art on CPP methods is summarized in [5] and [6]. CPP methods can be divided in categories, based on different aspects that are taken into account when trying to solve the problem. Some of these categories are presented below:

- Cellular decomposition/grid-based methods (discretization method for the ROI).
- Single/multi-robot.
- On-line/off-line (depending on the capability to alter missions in real-time).
- Energy-aware or not (depending on the energy-efficiency of the generated paths).
- Categories regarding the patterns of (lawnmower patterns, spiral patterns, Spanning Tree Coverage patterns (STC) [7]).

Having extensively studied the major projects in CPP so far, a new one was developed for the project, incorporating all those features that would make it suitable for this particular use. In the following subsections, the CPP method developed to calculate the paths will be extensively described. This method is based on a previous work from ConvCAO – CERTH's lab, the DARP algorithm [8] that was developed to divide areas for multi-robot CPP, however, a set of optimizations and innovative ideas were used in order to be optimal for real-world use. The provided solution incorporates energy and resource efficient features, supports the definition of obstacles inside the ROI and unlike other methods is able to support both convex and concave polygons, making it ideal for the scenarios that will be faced in the ARESIBO project.

### 3.1.1 ROI REPRESENTATION ON GRID & PATH PLANNING

The user initially provides the boundaries of the ROI (Region Of Interest), along with potential obstacles, in WGS84 coordinate system. Then the *scanning density* in meters, representing the distance between two sequential designed trajectories. Finally, UAV related information if forwarded, regarding the number and position of each asset.

The output produced of the CPP method is a set of paths, one for each UAV, so as to completely cover the ROI.

#### *3.1.1.1 FIELD REPRESENTATION ON GRID*

The CPP method developed for the project is a grid-based method. This means that a physical ROI, selected on a map, has to be represented with the use of a grid, in order to be used as input for the CPP method.

1. **Transformation of Coordinates:** As a first step, all of the coordinates that will be used in the method (ROI, obstacles, initial positions) have to be transformed from the WGS84 system [9] to a local NED system [10] with a common reference point. NED coordinates are used, because of their convenience they offer in the node placement and optimization procedures that take place. The paths are also calculated in NED coordinates and are transformed later, back to the WGS84 coordinate system.
2. **Nodes Placement:** The next step is to represent the polygon ROI with the use of a grid. The grid size should be analogous to the scanning density that user has selected. The centres of the grid's cells are used as nodes for the construction of MSTs, a step that is critical for the generation of the paths.
3. **Grid Representation:** Once the grid is initiated, each node obtains a state to describe it. The possible states are:
   - *Obstacle*, used to represent areas that are outside of polygon, or inside obstacles.
   - *Free Space*, for nodes that will be available for the path generation.

- *UAV*, used to represent the initial UAVs' position.

#### *3.1.1.2 NODE PLACEMENT OPTIMIZATION*

One of the very significant limitations that grid-based methods face when they are applied in complex-shaped ROIs, is that the representation of the ROI ends up being a lot different from the actual region, resulting in incomplete coverage.

In this work, this issue is faced by the implementation of an optimization intending to provide optimal node placement for complete coverage. The key idea is that by *transforming* the polygon ROI over a grid that respects the selected mission constants, there are states that provide better coverage than others. The optimization procedure implemented has a significant effect on both the provided coverage and the qualitative features of the generated paths.

#### *3.1.1.3 TASK ALLOCATION & PATH CALCULATION*

Having an optimal representation of the ROI on grid, DARP algorithm takes over to divide the complete region to sub-regions, exclusive for each UxV, and provides independent paths for all of them utilizing STC. The generated paths have energy efficient characteristics, as they respect UxVs' initial positions, avoiding redundant movements that do not contribute to the coverage process and reduce the number of unnecessary turns.

#### *3.1.1.4 DARP - AREA DIVISION*

DARP algorithm [8] deals with the path planning problem of a team of mobile robots, in order to cover an area of interest, with prior-defined obstacles. This technique transforms the original integer programming problem into several single-robot problems, the solutions of which constitute the optimal mCPP solution, alleviating the original mCPP explosive combinatorial complexity. In the heart of the proposed approach lies the DARP algorithm, which divides the terrain into a number of unique areas, each corresponding to a specific robot, so as to guarantee complete coverage, non-backtracking solution, minimum coverage path, while at the same time does not need any preparatory stage.

DARP's initial implementation provides a fair area division of the region, meaning that all vehicles are assigned with the exact same percentage of the complete ROI. In the context of this work, an extension of the algorithm is implemented, in order to also allow a proportional area division, based on the different energy and operational capabilities of the vehicles.

## 3.2 SIMULATED EVALUATION

The evaluation of the CPP method will be performed through a series of examples shown in Figure 22 - Figure 30 . It should be noted that the efficiency of the generated paths regarding the coverage capability, is independent of the number of UxVs participating. So, a multi-robot coverage example is included just to demonstrate the capability. For all the examples is included an image of the generated paths, a heatmap of coverage showing the percentage of the area that was covered and how many times and a histogram of overlapping coverage. The last figure is helpful to understand if operational resources were wasted in order to provide complete coverage of the region. For all the experiments was selected an overlap percentage of 30-50% for the coverage between two sequential scans, which is usually required in order to have effective operation of the modules utilizing computer vision. Moreover, for all the presented examples is included the number of waypoints, the value of the optimization index J, the actual percentage of coverage and the actual percentage of overlapped coverage. The ROIs presented were selected randomly and were designed for execution with small, coptered, aerial vehicles. However, the mCPP algorithm can provide paths for any type of unmanned vehicles, taking into account the motional constraints and coverage capabilities of them.

### 3.2.1 RECTANGLE ROI

An example of path planning in a rectangular area is shown in Figure 22. The optimization index and percentage of coverage and overlap are given in Table 6, and a histogram of coverage overlap and heat map for the given scenario are given in Figure 23.

**Table 6 – Waypoints: Path planning of a rectangular area**

| # Waypoints | Optimization Index | Percentage of Coverage | Percentage of Overlap |
|---|---|---|---|
| 30 | 0.8982 | 99.998976 % | 34.859423 % |

**Figure 22 - Path planning of a rectangular area**

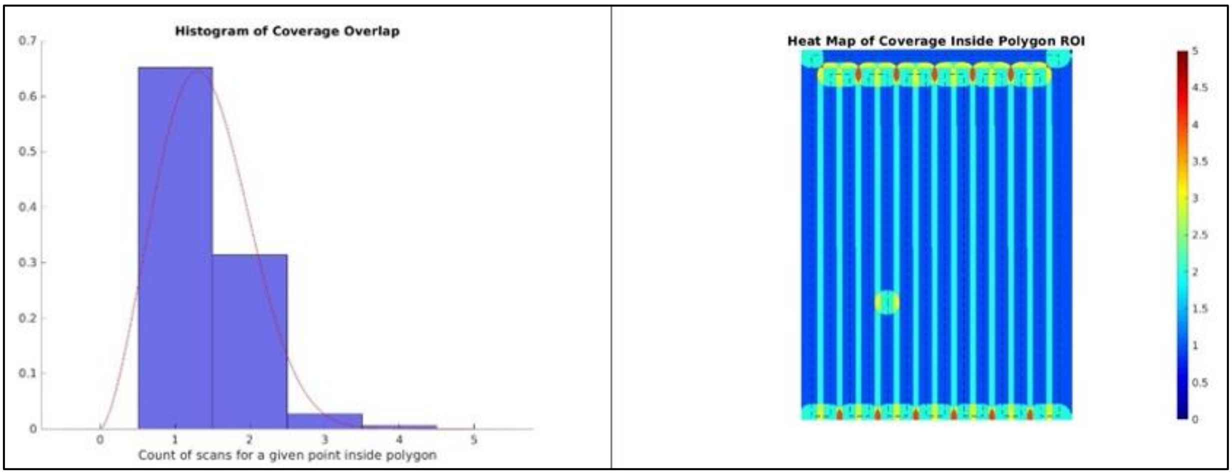


**Figure 23 - Simple example of a rectangular area**

### 3.2.2 CONVEX POLYGON ROI

An example of CPP for a convex ROI is given in Table 7, Figure 24 and Figure 25.

**Table 7 – Waypoints: Path planning of a convex ROI**

| # Waypoints | Optimization Index | Percentage of Coverage | Percentage of Overlap |
|---|---|---|---|
| 59 | 0.770574 | 93.676319 % | 51.022816 % |

**Figure 24 - Path planning of a convex ROI**

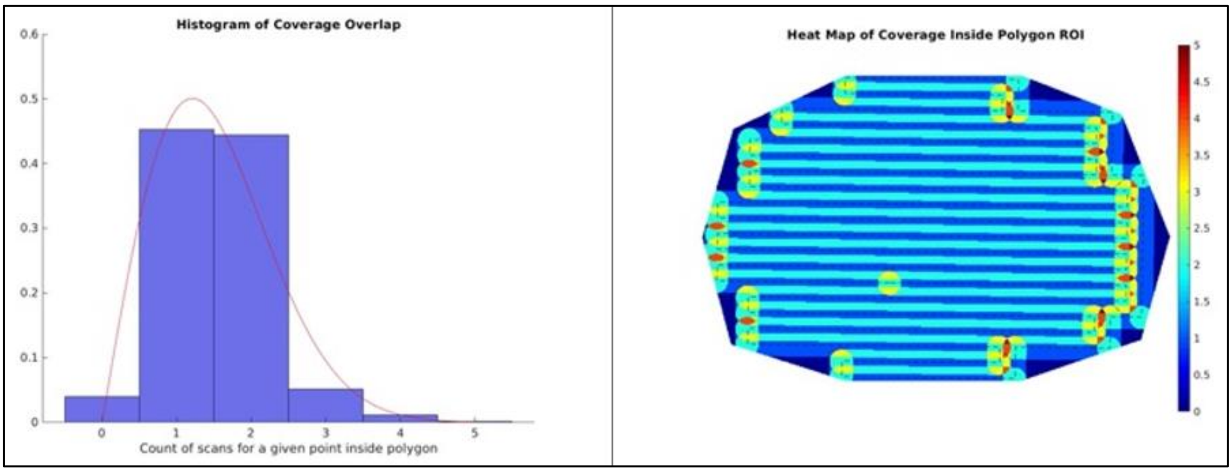


**Figure 25 - Coverage of a convex ROI**

### 3.2.3 CONVEX POLYGON ROI WITH OBSTACLE

An example of CPP for a convex polygon ROI with obstacle is given in Table 8, Figure 26 and Figure 27.

**Table 8 – Waypoints: Path planning of a convex ROI with an obstacle**

| # Waypoints | Optimization Index | Percentage of Coverage | Percentage of Overlap |
|---|---|---|---|
| 70 | 0.775232 | 95.174975 % | 52.911855 % |

**Figure 26 - Path planning of a convex ROI with an obstacle**

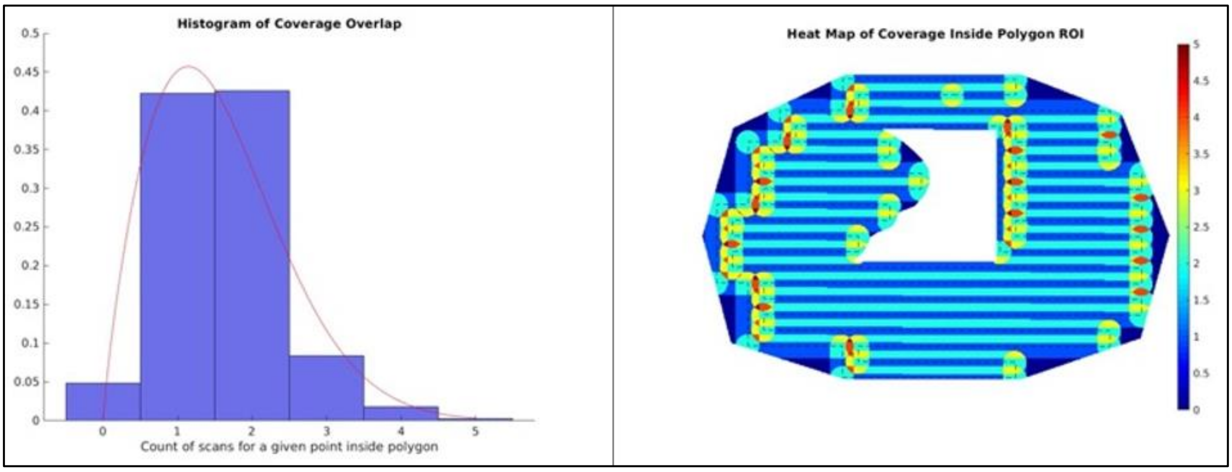


**Figure 27 - Coverage of a convex ROI with an obstacle**

### 3.2.4 CONCAVE POLYGON ROI

An example of CPP for a concave polygon ROI is given in Table 9, Figure 28 and Figure 29.

**Table 9 – Waypoints: Path planning of a concave ROI**

| # Waypoints | Optimization Index | Percentage of Coverage | Percentage of Overlap |
|---|---|---|---|
| 59 | 0.770574 | 93.676319 % | 51.022816 % |

**Figure 28 – Path planning of a concave ROI**

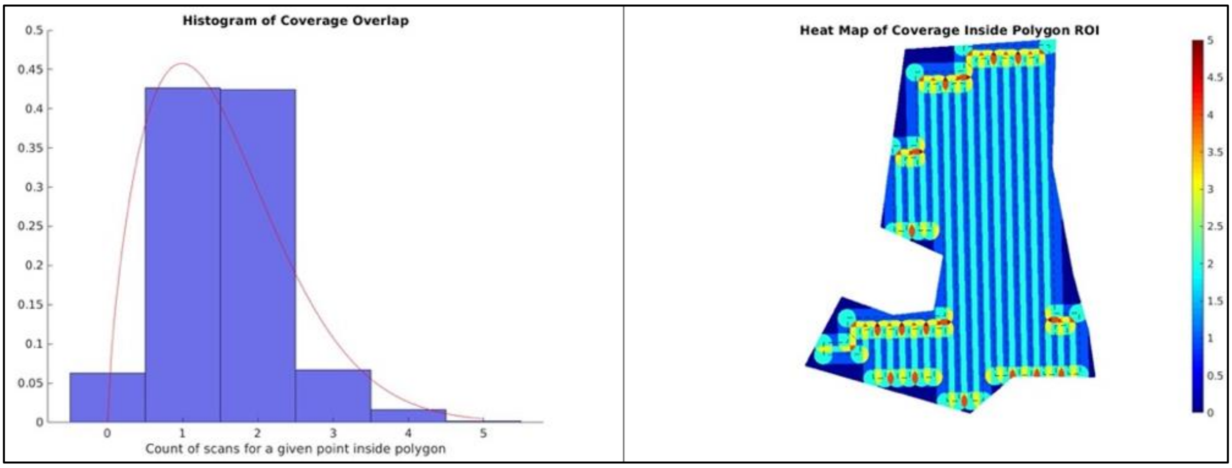


**Figure 29 Coverage of a concave ROI**

### 3.2.5 CONCAVE POLYGON ROI WITH MULTIPLE OBSTACLES AND MULTIPLE UAVS

An example of paths for multiple UAVs in a concave polygon with multiple obstacles is shown in Figure 30.

**Figure 30 - Concave polygon with multiple obstacles and multiple UAVs**

As shown in the previous examples, the CPP method developed for the Swarm-Opt module of the TREEADS platform offers a really high percentage of coverage in the defined ROI, manages wisely the operational resources offering energy and time efficiency and is capable of handling complex concave polygon ROI's with obstacles without any problem. In simple rectangle ROI's the method provides paths that completely cover the ROI, while even in the most unfavourable concave polygons with obstacles, that most of existing CPP methods cannot face at all, this method manages to provide paths with a percentage of coverage larger than 90%. It should be noted that in cases where the complete coverage of the ROI is critical, the method also provides the mode for better coverage that allows the paths to get outside of the polygon. Moreover, smaller scanning density or larger percentage of overlap may be used as well. The features provided by this CPP method makes it ideal for the need of the TREEADS project.

#### *3.2.5.1 PERSISTENT COVERAGE*

In this path planning mode Swarm-Opt will provide paths for one or more vehicles inside a polygon ROI, in order to continuously patrol this ROI. For this path planning mode, the

CPP method described above will be used as a base and a set of optimizations to minimize the time demanded to visit all of region's points again will be used. At the time that this deliverable is writer, the persistent coverage mode of the RC module is at the starting point of development. A detailed description of persistent coverage mode will be provided in the second version of the deliverable.

### *3.2.5.2 OPERATIONAL EXECUTION – USER INTERFACE*

In the aforementioned, we described and presented how the back-end algorithm of Swarm-Opt is used, so as to enhance the capabilities of the end-users during a fire and for the restoration of a forest. In this section we will present how the User Interface of the module is used in order to allow the end-users to provide as input their abstract mission description, in order to forward that information towards the back-end algorithm and output the paths for each surveying asset. An initial version of the user-interface, alongside the back-end algorithm is accessible at: http://choosepath.ddns.net/ (**please note, that this is an early version, thereby many issues may appear**). The intro page of the UI allows the user to either create a new project or work on an already saved one, see Figure 31.


**Figure 31 - Initial image of the User Interface**

When the user creates a project, they have access to specific high-level parameters:

- The operational area, that can be generated by clicking on points on a satellite map, see Figure 32.
- The number of UAVs that will be used.
- The altitude that each will fly.
- The sidelap between sequential images.
- The percentage that each UAV will have to cover, this is of paramount importance when heterogenous assets are enabled. For example, if we have two types of UAVs, the one has a low-resolution light camera that can fly for a longer period and the other UAV has a high-definition camera, which is heavy and limits its time in the air.

Examples of generated paths for three UAVs are given in Figure 33 and Figure 34.

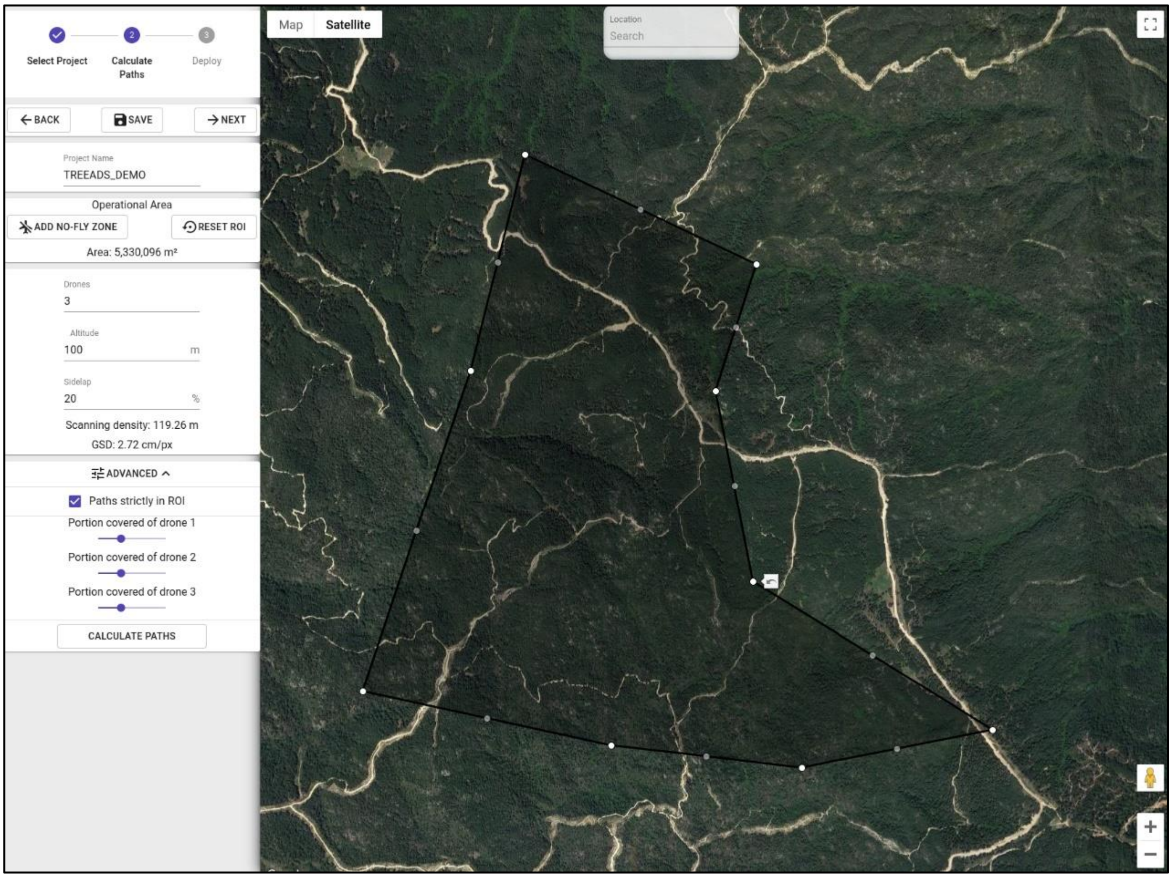


**Figure 32 - Create a ROI based on satellite images**

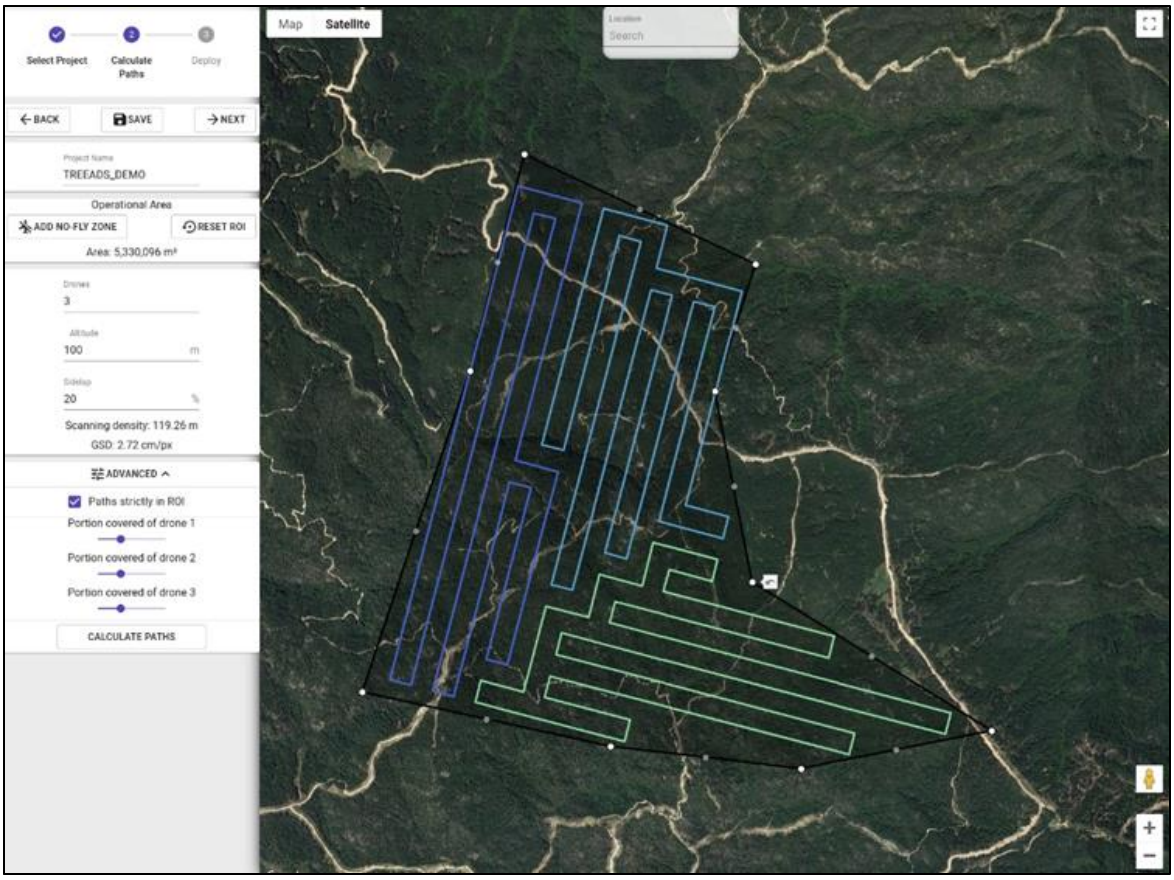


**Figure 33 - Generated path for 3 UAVs with specific parameters**

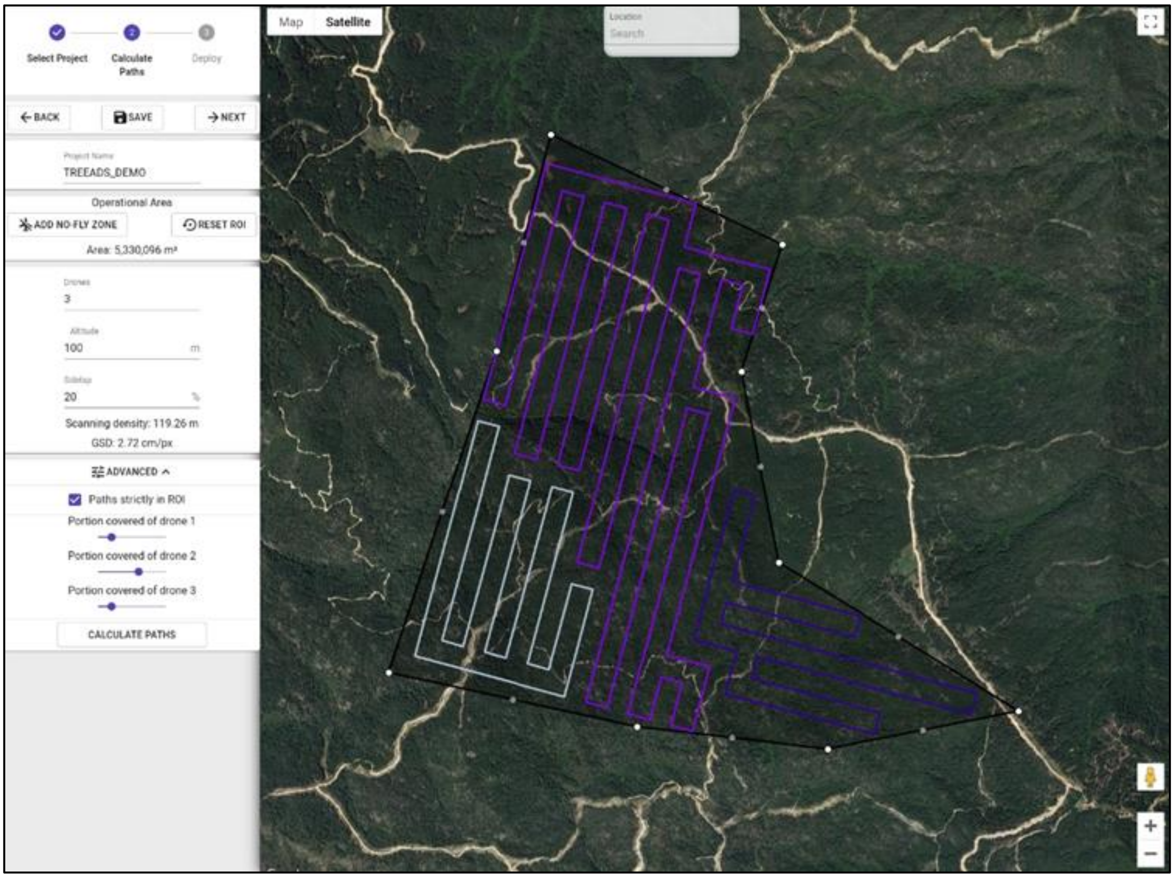


**Figure 34 - Generated path for 3 heterogenous UAVs, on a 20-60-20 split of the area**

## 4. USING FIRE-FIGHTING CHEMICALS FOR SUPPRESSION OF FIRE IN WILD LANDS

Compressed air foam (CAF) is one of the most efficient and eco-friendly approaches in combating wildland fires with high penetration power so that the foam moisturizes soil and ground quickly and deeply. The temperature inside the fire material is reduced, deep-seated pockets of embers are extinguished. OS Class A foaming agents are fluorine-free and quickly biodegradable, thanks to its good adhesion, the soil and vegetation are well moistened and the environment can be protected.

The foam generators developed by OS form an absolutely homogeneous extinguishing foam from water, foam concentrate and compressed air which produces a homogeneous blanket with excellent adhesion and fire smothering properties, with minimal water consumption. In contrast to conventional foam, OS CAF guarantees a reproducible foam consistency with a homogeneous structure of small bubbles even with an extremely low proportioning rate of 0.3% for class A fire (solid fuels) and 0.5% for class B fires (liquid fuels). OS mobile systems consist not only of the foam-generating equipment and foam agents, but are complete solutions with original OS accessories, such as suitable (optimized for OS) nozzles, monitors, hoses and qualified training using optimized tactics when fighting fires with compressed air foam.

The proven unmatched extinguishing performance and efficiency in firefighting in the various fire classes and the universal applicability of the compressed air foam systems have resulted in over 450 mobile OS systems now being in use in France, Germany, Italy, Netherlands, Norway and Sweden together and more than 2 000 worldwide by users ranging from regional fire departments and industrial fire departments to airport fire departments.

The initial workbench exercise within the six fire test laboratories at the OVGU in Magdeburg will be examined in the first phase of the project, following large-scale tests carried out on a 1:1 scale at BAM's test site. The 12 $km^2$ large site located in Horstwalde (Brandenburg, 40 km outside of Berlin), was built for this purpose in the beginning of the 1990s. The following infrastructure will be utilised: Soil humidity sensors; ambient temperature and ambient soil temperature sensors; optical and infrared sensors; airflow and atmospheric composition sensors. The main outcome will be the reduction in fire extinguishing time, reduction in the number of victims trough scenario prediction and response optimisation, reduction of environmental impact.

## 4.1 TECHNOLOGICAL APPROACH

**First approach:** TREEADS will examine firefighting chemicals that help suppress wildland fires. Flame retardants, fire extinguishing agents and other chemicals used for fire suppression can have adverse effects, so this work aims to study the effect of these products on local vegetation. The TREEADS fire retardant and fire wall response study module takes all of the above into account and bringing on board one of the largest organizations in Europe in materials science and fire retardants and will study the use of inorganic and nitrogen free fire retardants considered as fertilizers in comparison with in current heavy chemical retarders.

**Second Approach:** New specialized delivery methods will be developed that allow the use of extinguishing foams as firewalls for ground/peat fires, as well as using new types of silica-based agents in combination with other retardants and extinguishing agents. The output of this task will also provide the necessary fire retardants to be utilised for the fire barrier. The successful outcome of this task also will result on supporting and saving human lives in case of fast reaction.

## 4.2 METHODOLOGICAL APPROACH

The impact of foaming agents on tree growth/health is evaluated for the examination of firefighting chemicals that help suppress wildland fires (first approach in section 4.1). Details are given in section 4.2.1.

New specialized delivery methods (second approach in section 4.1) are investigated by small and medium scale experiments and within the large-scale experiments. Details are given in section 4.2.2.

### 4.2.1 FOAMING AGENT IMPACT ON TREE GROWTH/HEALTH

This approach aims to test whether one-time foaming agent used at 0.3% concentration application impacts tree growth and health.

**Hypothesis:** A one-time application of foaming agent (0.3%) could positively affect the growth and health of trees? Tested parameters:

- **Growth**

- Vegetative growth parameters: seedling height, root length, fresh root biomass, fresh aboveground biomass;
- **Biochemical tests**
  - Total phenol content (TPC), total flavonoid content (TFC), chlorophyll a and b amount, carotenoid content;
  - Antioxidant enzyme content: catalase (CAT) and peroxidase (POX).

#### *4.2.1.1 MATERIALS AND METHODS*

The test will be done in two stages. Stage one will be performed using seeds. Stage two – using ~1 year old samplings. Stage one will take place in a greenhouse, while stage two in outdoor areas:

**Stage I:** As indicators for a mixed forest, four different tree species will be tested – pine (Pinus sylvestris), spruce (Picea abies), aspen (Populus tremula), alder (Alnus glutinosa). Seeds will be planted in SuliFlor SF2 potting mixture in seeding trays, one seeds per pot. There will be two groups per each tree species and at least 20 individuals per each group as to make sure we have statistical validity. One will serve as control, i.e. will not be affected by any outside variables. The other will be affected by the foaming agent. The foaming agent solution will be applied at the same day as seeding, as to imitate how new seeds would be impacted in a forest environment after foaming agent use. Afterwards the seeds and resulting seedlings will be watered as necessary. The test will start in April and finish in September. Samples for biochemical tests will be taken every ~six weeks, while growth will be measured once, at the end of the experiment. Necessary biochemical tests will be made and then the data will be statistically analyzed.

**Stage II:** Two tree species will be used - pine (Pinus sylvestris) and alder (Alnus glutinosa). ~1 year old seedling will be purchased and repotted in SuliFlor SF2 potting mixture. After ~1 month the test will begin. There will be two groups per each tree species and at least 20 individuals per each group as to make sure we have statistical validity. The trees will be watered using foaming agent solution. Afterwards saplings will be watered as necessary. The test will begin in late April and continue up to September. Samples for biochemical tests will be taken every ~six weeks, while growth will be measured once, at the end of the experiment. Necessary biochemical tests will be made and then the data will be statistically analyzed.

### 4.2.2 EVALUATION OF DIFFERENT TACTICS OF FIREFIGHTING WITH WATER AND FOAM

The delivery methods are investigated by small and medium scale experiments and within the large-scale experiments, considering different scenarios which are developed within the German Pilot with the partners BAM, OVGU and OS.

Evaluation of different nozzles and lances with their effectiveness of firefighting on and in the ground, evaluation of the use of spray hoses with foam, evaluation and optimization of foam characteristics (e.g., water-air-ratio) for the use on ground and underground wildland fires. The ground specimens are taken from the local forests of the model regions (see Figure 35). Experiments with use of foam and silica-based suppressants are performed in small scale as preparation for eperiments in medium-scale and large scale in the model regions of Saxony-Anhalt and Brandenburg.

**Figure 35 - Ground specimens from the local forests of the model regions**

One delivery method which is investigated additionally, is the deployment of foam with Drones in collaboration with DH. Drone capacity and suitability of drones for creating foam and supply of foam during flying are investigated at the moment. As the foam is usually created immediately before supply the drone needs to be equipped with the technology for the foam making and storage for water and additive.

WILD HOPPER is a 600-litre platform designed for forest fire firefighting. This payload capacity overcomes typical limitations of electrically powered drones that cannot be used for anything more than fire monitoring, as they do not have sufficient lifting power. It uses all the technologies developed by DRONE HOPPER, yielding a novel tool to counter rush fires worldwide.

The enhanced capabilities of the WILD HOPPER allow to complement existing aerial means and overcome their main limitations, especially the need to cover night operations. This allows reducing heavily the duration of the wild fires by allowing continuous aerial support to the extinguishing activities once the conventional aerial means (hydroplanes and helicopters) are set back to the base at night.

Other advantages of the WILD HOPPER are the precision of the release, derived from multirotor platform dynamic capabilities. This, together with the proprietary water jet nebulization system, yields a very high efficiency compared to traditional means that carry similar (helicopters) or more liters (hydroplanes) that just drop the water at a certain speed a highest altitude over the target fire, limited by their dynamic operational envelope.

## 4.3 FUNCTIONAL VIEW

Response tactics of first responders can be made more efficient with supply of water-saving foam from OS. The development of new supply techniques allows for delivery of foam in regions with low accessibility by other means, e.g., usual fire fighting vehicles.

The silica-based suppressants are tested in small scale experiments as preparation for the large-scale experiments to create fire walls as a fire stop. OS foam is tested for it impact on the environment – regarding the immediate effect on the tested ground specimens as well as the longer-term impact on vegetation and animals.

# 5. SOLUTION FOR PERSONAL MONITORING AND PROTECTIVE EQUIPMENT FOR EMERGENCY RESPONDERS

Personal monitoring (wearable sensors) and protective equipment is critical for emergency responders to ensure their safety while responding to emergencies such as forest fire incidents. These devices may measure various environmental hazards and alert the responders in real-time if they are exposed to levels that pose a threat to their health. This enables them to take immediate action to protect themselves and minimize the risk of injury. In a complementary approach, communication means which are dedicated for First Responders and can provide an undisturbed communication bubble between F.R. team members can play a vital role in emergency situations. Regarding T5.4 the following tools will be developed and deployed within TREEADS project:

## 5.1 AR HELMET

Most people have got familiar with the term of AR through entertainment and the interactive experience of the real-world environment that is provided. Beyond the field of entertainment there are more practical use cases that can be applied to emergency scenarios like natural disasters. AR helmet proposes that AR can make a difference for firefighters and other first responders who are expected to take snap decisions and make tremendous efforts to save lives and minimize damage to the natural environment. Overlaying data such as key points of interest and individual locations, can provide context to emergency responders in critical situations, by improving Situational Awareness which is vital component that can determine a successful First Response scenario or Search And Rescue (SAR) operation.

AR helmet will provide AR solutions both for the Firefighters, but also for the Command operation Centre (CC). The CC operators AR tools will allow them: i) to access and interact with an augmented world in real time, ii) to manipulate and interact multi-modally with sensors and with the firefighters. The AR interfaces for Firefighters are targeting to improve collaboration between different teams involved in a fire emergency, through AR wearable devices where the interactions would be done through gestures or touch. The AR helmet concept is illustrated in Figure 36. Using such an AR system, the field operators would be capable of identifying dangerous locations, areas that were already searched and areas that require immediate attention. More importantly using such system, a control centre could direct field operators to investigate certain areas by targeting locations on a 3D map which would be seen by the operators through the AR component of the system.

AR Helmet provides useful information overlayered on the AR display in a Hands-Free configuration. Information includes map of the area with designated locations of other

First Responders and static stations of interest (e.g., firehoses). In addition, the AR goggles will display the coordinates of the person to wear the AR helmet, temperature, humidity, Carbon Monoxide (CO) and Particulate Matter (PM) values, as well as connectivity details (e.g., WiFi). CO & PM sensors will be provided by NCSRD and will be integrated in the device, in a joint 8Bells-NCSRD effort. The sensors, as described in Forest Black Box (section 2.2.1 – 2.2.2), can be used as portable devices and can be attached on the AR helmet. The sensors' measures are very important for FRs (First Responders) in order to get informed on atmosphere's condition. In case the values are high, thus the area becomes dangerous for first responders' health and they should evacuate the place, while also inform relevant stakeholders to take further actions. Furthermore, having the location of other F.R. displayed on their AR screen, will facilitate their detection, in case of emergency.

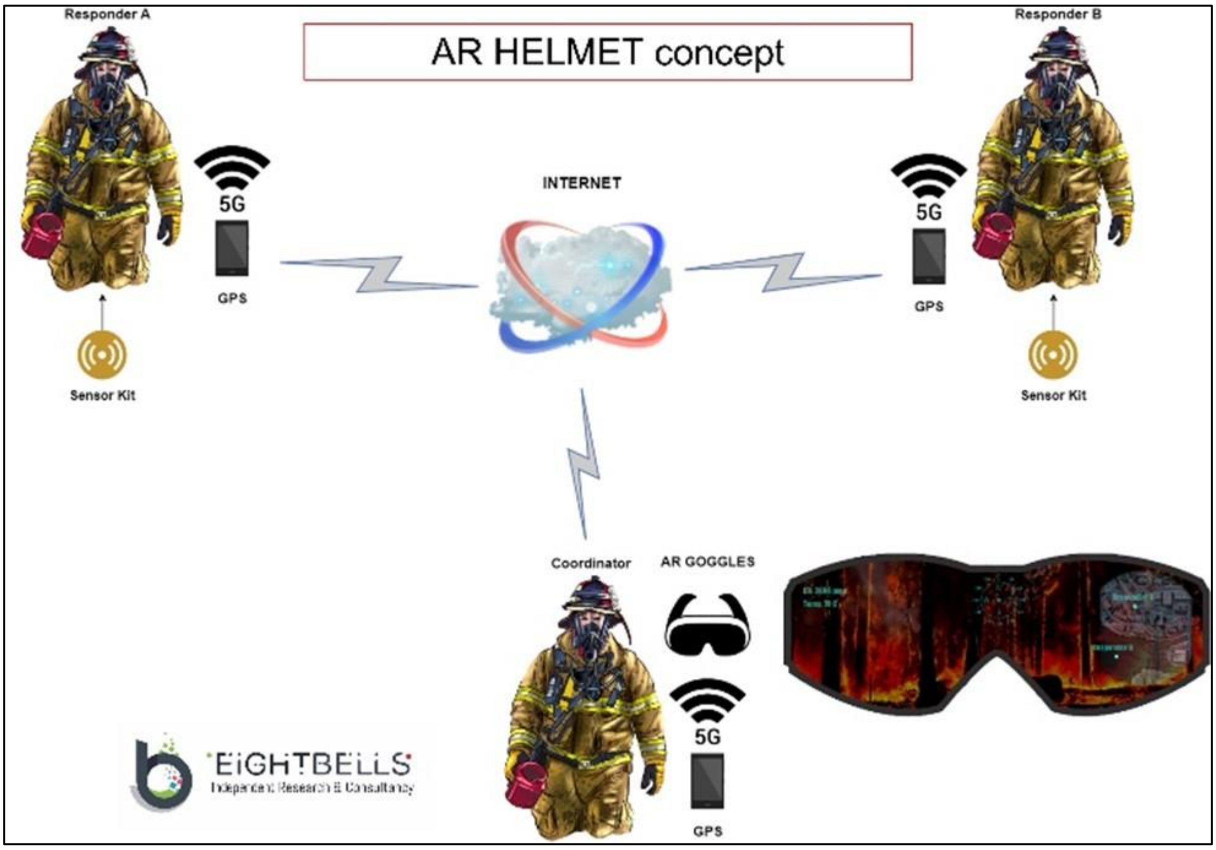


**Figure 36 – AR helmet concept**

### 5.1.1 AR HELMET OPERATIONAL REQUIREMENTS

1. **Device Tracking:** The application will use the GPS capabilities of the AR glasses to detect the user's location and display it, in case of emergency situations such as fire or rescue. Generally, the process involves using the device's sensors to detect and track the environment, and then using that information to determine the device's location and orientation. There is a combination of sensors, including an accelerometer, a gyroscope, and a magnetometer, to detect and track the environment. Additionally, with the use of API's for accessing the sensor data and determining the device's location and orientation.
2. **Gestures**, in order to recognize gestures as input events based on human hands. Gestures are useful in an AR application because they provide a natural and intuitive way for the user to interact with the digital content displayed in the real world. Using

gestures, the user can perform actions such as selecting, moving, and scaling digital objects, without the need for physical controllers or buttons. This allows for a more immersive and engaging experience, and can also increase the accessibility of the application. In order to implement gesture capabilities in the AR application. AR glasses provide their own SDK (software development kit), which provides built- in support for gesture recognition and mapping.

3. **Face tracking**, in order to access face landmarks, a mesh representation of detected faces, and blend shape information, which can feed into a facial animation rig. Face tracking can be used to create more interactive AR experiences. For example, an AR application could use face tracking to allow users who are unable to use traditional input methods, such as a keyboard or mouse, to interact with the AR content. Several SDKs use API's for detecting and tracking facial features, such as the eyes, mouth, and nose, as well as for recognizing specific facial expressions.
4. **Participant tracking**, which is useful in order to track the position and orientation of other devices in a shared AR session. Participant tracking can be done through various ways like through GPS, motion sensor, face detection, facial recognition and many more.

## 5.2 X-BELLO INSTANT MESSAGING

X-BELLO is a self-owned, self-contained and self-operated system. It can be deployed in seconds on smartphones, tablets, desktops, and laptops. The user interface is shown in Figure 37. It provides a secure, powerful, easy to- use collaboration platform to collect and share information and coordinate personnel. It is an instant messaging system for registered closed users & groups. It supports secure exchange of text messages, voice calls, videocalls, group calls, and transfer of multimedia files, through data networks. X-BELLO provides the location, identity, and operational status of the entire team facilitating enhanced decision making and a more effective response. Thus, it gives the opportunity to operate a "tactical communication bubble".

8BELLS brings an operational closed communications tool/application which will assist in FRs activities during a disaster/emergency operation.

**Figure 37 - X-BELLO UI**

There are different groups of FRs active in the field and X-BELLO provides an efficient way for the Head of Operation to manage and communicate with each FR as well as to organize them into a closed group with roles/missions. Each FR has specific credentials (username, password) and user rights which are exclusively assigned by the Administrator/Head of Operation. Enhancing situation awareness, X-BELLO provides functionalities that enable better viewing and management of the operation by monitoring FR's activities. X-BELLO follows a Restful architecture and is responsible for encrypting the users' communication and protecting their data. The X-BELLO main specifications are given in Table 10.

**Mobile Interface**: During the operation FRs can exchange information with the Deployable Platform in the form of instant messages, reports, multimedia files, emergency alerts and notifications under a secure connection. End users can also report back essential information regarding the area of incident such as the location of a FR or victim and the status of equipment directly to the administration panel.

**Administration Interface**: It is a dashboard module where all FRs on the field are displayed along with their location and status. A map of the incident is displayed providing information about FR on the scene allowing the administrators to monitor their activities during the operation and coordinate the different groups.

**Table 10 X-BELLO main specifications**

| # | X-BELLO main specifications: |
|---|---|
| 1 | User & Group Management (create/delete/edit users and assign them to closed groups) (e.g., User: Firefighter, Group Firefighters Team A) |
| 2 | Role Management (create/delete/edit roles and their privileges) (e.g., Role: Responder, Rescuer) |
| 3 | Multimedia (send or view audio/video/image files in a closed group) |
| 4 | Connection to 3G/4G/5G networks or even LEO Satellites (by adding a SATCOM sleeve on smartphone). |
| 5 | Geolocation (identification of the geographic location of a user) |
| 6 | Visualization of end-users activity on an illustrated map of the disaster area |
| 7 | End-to-End encryption |
| 8 | Data encryption in transit |
| 9 | User authentication (verification of user's identity and their access) |
| 10 | Alert notifications |
| 11 | Geofencing (Assign predefined set of geographical boundaries) |
| 12 | Report back selecting predefined Messages |
| 13 | Keeping log files |
| 14 | REST API calls |
| 15 | Emergency Panic Button |

In the context of system architecture, the input from end-users such as multimedia files and their geographical coordinates are reported back to the Administration Interface Panel, which is managed by the Head Operator of the Deployable Platform. Connections between interfaces follow a REST architecture and data are encrypted in transit.

## 5.3 METHODOLOGICAL APPROACH

Regarding AR helmet & X-Bello application tools, the methodology of implementing the solution implies the following stages: i) Requirements collection and definition; ii) State-of-the-art review on current solutions; iii) Taking into consideration specific aspects regarding implementation of proposed solution; iv) Designing the proposed solution; v) Development of subparts, where applicable; vi) Integration of proposed solution; vii) Initial testing and feedback provided for further optimization and viii) Final testing in Pilot Studies. Regarding Forest Black Box & AR helmet, a close collaboration between 8Bells and NCSRD (for CO & PM sensors) is foreseen, in order to define and implement the development of the systems, as a joint effort.

## 5.4 FUNCTIONAL AND OPERATIONAL VIEWS

AR helmet & X-Bello application tools should be user-friendly and easy to operate under extreme conditions by users. In case of emergency, the tools may provide information of crucial importance for people's lives, thus all information should reach the appropriate stakeholder in minimum time and without interventions.

From the operational perspective all tools that will be developed, should be operational in remote locations, thus special considerations must be taken regarding power needs, connectivity (available networks) and robustness for outdoor use under adverse conditions.

# 6. SOLUTION FOR SPACE AND AERIAL MONITORING OF THE AREA

Since we are at very early stage of the project regarding Pilot case specifications, just a very general description is presented here. In future versions of this document, when bilateral meetings between the partners will be allocated and every individual task is perfectly clear, the description will be much more detailed.

The overall objective of this task is to create an intercommunication and connectivity infrastructure for all air means in the *four-layered system*. This means that there will be a bidirectional link between each aerial mean and the Ground Control Station (GCS). Also, there will be a unidirectional link between the GCS and the data repository developed by the partner JOTNE. The general structure is shown in Figure 38.

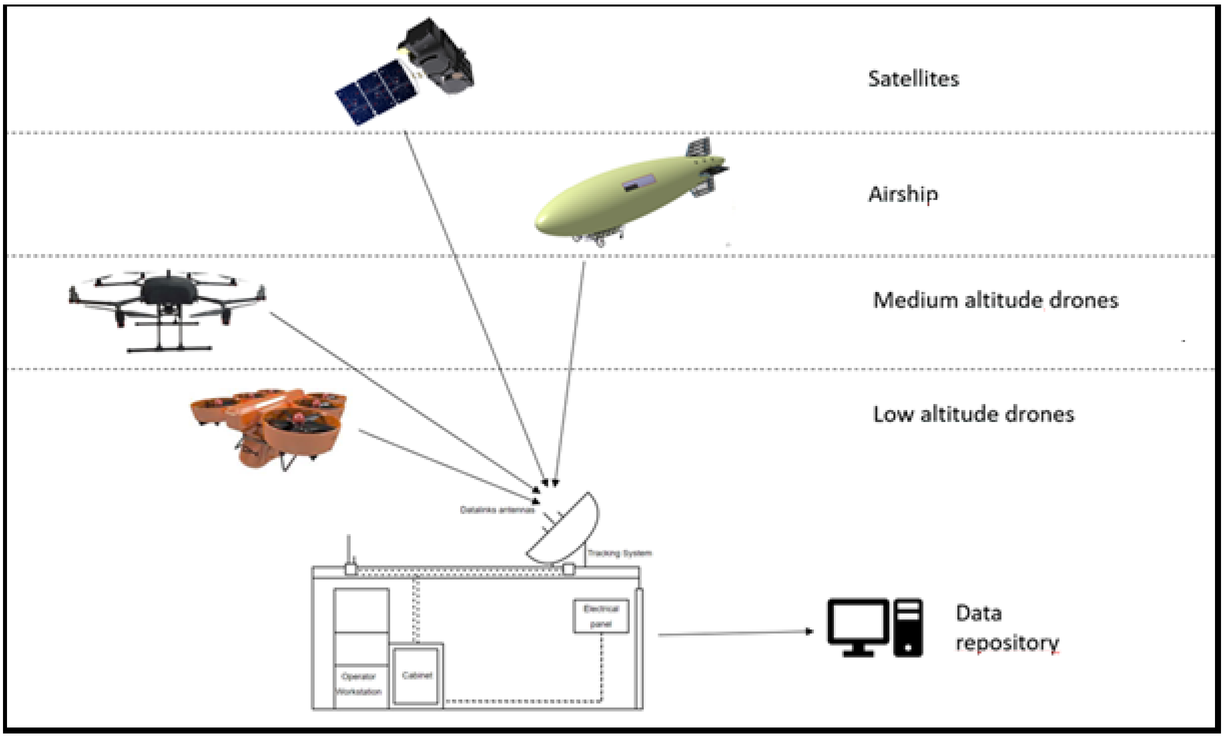


**Figure 38 - Intercommunication infrastructure**

## 6.1 TECHNOLOGICAL APPROACH

The breakdown of the communication structure to ensure the connectivity of all systems should consider the following points:

- Existence of two data links for each platform with its control station, the remote control of the air means must be ensured and, in turn, the telemetry data of each on-board equipment. In this way, it will be ensured that it is possible to command each aerial system and, in turn, obtain download data from the cameras on board.
- The procedure for uploading data from each station to the pilot case repository must be identified and defined, detailing the formats preferred by the end user. Each control station must in this way ensure the correct output of these data with a data rate that must be adjusted as far as possible to the requirements demanded by end users.

## 6.2 METHODOLOGICAL APPROACH

The progressive elaboration of a communications system that provides the necessary viability coverage to the 4 layers of the system and to the whole operation is planned. The methodological approach is specific to the complex projects' implementation, comprising the following stages: a) Definition of requirements (with contributions from the platforms and the end user); b) Identification of needs (with contributions from the platforms and the end user); c) Definition of necessary interfaces; d) Identification of components and software and hardware architectures of the system; e) Draft the model of the proposed communications system; f) Draft the Feasibility study of the system; g) Validation of the proposal communications system; h) Component procurement; i) Assembly and validation tests (bilateral and with all users involved); j) Deployment of the Spanish pilot case.

## 6.3 FUNCTIONAL AND OPERATIONAL VIEWS

Since not all the comms requirements will be the same (high-bandwidth or not) the communications solution for high bandwidth comms, command/control, and telemetry data shall be ensured. In this point the specific requirements and comms from each partner shall be provided to Capgemini.

From the operational point of view, it is important to ensure the compatibility of systems and subsystems, covering the following points that must be correctly defined:

- Areas of coverage in the visual field (Platform & payload).
- Maximum operating altitude of each platform.
- Data link reach range.

All communication systems will comply with the European UAS C2 communication standard. The 4-tier platform must be scalable and optimized for the operating site (this will be defined when the Avila´s final site will be set). In addition, the selection of the communication frequency will be extremely important. This aspect must consider the coexistence of 4 communication channels that must not overlap and must enable the correct functioning of all of them.

# 7. IMPLEMENTING A SOLUTION FOR ENHANCED REALITY, UX DESIGN AND TRAINING, INCLUDING VR SIMULATORS FOR AIR FLEET AND GROUND RESOURCES

Within this task an **Enhanced Reality** platform will be developed for the training of the first responders and volunteers. This platform will enable both single and team-based training of fire related stakeholders with different levels of experience from various organizations by serious games and simulations. This solution will provide an enhanced training of personnel due to the state-of-the-art technologies like **AR/VR tools**, **AR assisted goggles, AI assisted support, 3D authoring tool.**

A continuous development approach will be used providing to the final user the capability to test the scenarios during the development phase and gather its valuable feedback and considerations on their effectiveness as training tools. The training based on the Use Case scenarios will be highly realistic due to the AR/VR interfaces and the AR/VR tools implemented. The AR glasses will also offer live information from the scene and from the involved persons within the environment.

For this task an **Artificial intelligence (AI)** assisted **Decision Support platform** will be developed like a valuable tool to the ones that will act under the pressure of the events and time. This platform will have an authoring tool that allows the manual design of auxiliary information on the map, like first responders trajectories, that can be automatically converted into 3D information and rendered on 3D terrain, thus resulting a more immersive and intuitive design experience.

## 7.1 TECHNOLOGICAL APPROACH

The main development platform for implementing AR/VR applications is the Unity3D engine with C# as programming language. Unity3D is one of the most powerful cross-platform 3D engine that can be used to build high-quality 3D and 2D applications that can be easily deployed for more than 19 different platforms, including mobile, desktop, consoles and AR/VR devices. The Unity editor is supported on Windows, macOS and Linux.

The application programming interface used for the connection with other services within the project is REST API. This API represents a set of architectural constraints and can be implemented in a variety of ways. There are several formats that can be used: JSON, HTML, XLT, Python, PHP or plain text. The AR/VR solution will use JSON format in order to send and receive messages by REST API.

The communication component is one of the most important because it allows direct communication among first responders. Some of the key features of this component are the following:

- They can send and receive audio inputs from the integrated headset microphone and speaker systems. To reduce lag or any kind of delays between headsets, they are linked directly to a secured channel on a cloud server.
- The audio system is designed to send and receive audio signals with minimal distortions in terms of quality.
- All the information sent between headsets is encrypted and secured within the involved systems.

The communication component is developed on Photon cloud-based solution (https://www.photonengine.com/pun) optimized for Unity3D. One of the advantages of using a cloud-based solution is the possibility to port the components on various operating systems and assure cross-platform communication.

## 7.2 METHODOLOGICAL APPROACH

The development of applications for AR/VR can be achieved both natively, using the SDKs made available by two big players in the market, Alphabet and Apple respectively, but also various other third-party frameworks and technologies (React Native, Xamarin, Unity3D), depending on the requirements of the application, correlated with the decisions of the development team and the needs of the beneficiary. The methodological approach for implementing such solutions comprises:

1. Designing the Application Architecture - Definition of a generic skeleton / framework, application design, functionality, navigation flow, data storage, access to data networks and communication with third-party applications, web services or services made available through the operating system, etc.
2. Graphic Design - Creating templates (wireframes) and models (mockups) of application's user interface and user experience (UI & UX)
3. Application development - Writing the application code according to the chosen framework and programming language, implementing the design made by the graphic design team, respecting the lines drawn in the previous stages. Dedicated software (version control software) will be used to manage files created by the development team (Git, Tortoise SVN).
4. Testing and Integration – The phase where the developers ensure that the application does not suffer from functional problems (bugs), is functional with various devices and platforms defined in the initial step, designing the application architecture.
5. Deployment - Creating packages and distributing them (if applicable) in the dedicated stores made available by Alphabet and Apple (Play Store and App Store, respectively) or third-party app stores (Aptoide, Cydida, etc.).
6. Maintenance - Monitoring the application, being responsive to user/beneficiary reviews and feedbacks, releasing updates to fix any reported issues, keeping the application up-to-date by updating the frameworks, tools and libraries used and adding the latest Alphabet and Apple requirements regarding security issues and good-practices in order to run on the latest devices and operating system versions.
7. Continuous improvement - Adding new functionality and features as needed.

### 7.2.1 DESIGNING THE APPLICATION ARCHITECTURE

This is the stage where the overall structure and design of the application are defined. The major components of the application, navigation flow, data storage, required data connections, activities, screens or services served by the application are drawn. The team of architects will ensure that the project requirements and usability are very well understood in the idea of creating a user-friendly architecture. This is also the moment to choose the technologies involved in development, the architectural design-pattern, as well as the roles of the specialists involved in the project. *Agile development methodology* will be used, a flexible methodology that allows testing the application in parallel with its development, as well as good communication and cohesion between people and teams involved in the development (QA, developers, TLs, PMs, etc.). The work method is organized in sprints, the purpose of which is to define what can be delivered during it, as well as how to implement it. The duration of a sprint is usually two to four weeks.

As Agile tool will be used a very popular application - JIRA - who serves more than 180,000 customers in more than 190 countries. It includes complex options related to project management, Agile methodology, issue creation/assignment/editing/tracking and other services.

### 7.2.2 GRAPHICAL DESIGN

This is the stage where wireframes and mockups related to the graphical interface and user experience (UI and UX) are created. Graphic designers will draw a general layout, select proper colors, fonts, as well as other visual elements of the application (logos, animations, etc.). User workflow diagrams will be created to show how to navigate between screens. All of this will help visualize the final product and make it easier to implement the design to the development team. Graphic teams will create several wireframes and mockups, selecting then the version that is considered the most suitable for the project.

Graphical interfaces will be created taking into account the latest recommendations and trends in mobile design. Among the technologies used are **Adobe Photoshop, Adobe Illustrator, After Effects, Adobe InDesign, Adobe Audition, Figma**.

- **Adobe Photoshop** - The most popular and appreciated graphic (photo/video) editing software among digital artists.
- **Adobe Illustrator** - Very popular software used for creating/editing vector graphics that allows the creation of animations, web content or 3D objects.
- **Adobe After Effects** - Editor that allows the creation of animations, digital special effects, as well as video games or video processing.
- **Adobe InDesign** - One of the most complex and popular desktop publishing and layout designing software.
- **Adobe Audition** - Software used in digital audio editing by professionals in the field.
- **Figma** - Interface design application focused on user interface/user experience for creating responsive, intuitive, simple and good-looking graphic interfaces.

### 7.2.3 APPLICATION DEVELOPMENT

the application architecture is based on the effective implementation of the application using the technologies, frameworks and programming languages chosen in the initial stage. A dedicated version control software **(Git, Tortoise SVN)** will be used for an efficient management of the application's code and resource files. This is the stage in which the design made by the team of graphic designers, business logic, data persistence, services are implemented. The development team can be divided into several sub-teams, each led by a Team Leader (TL), for more efficiency and flexibility. Good practices and code writing conventions will be followed to ensure easy maintenance and high scalability in the future. The application can be developed both natively, using the technologies provided by **Alphabet** and **Apple**, **Android SDK** and **iOS SDK** respectively, but also using third-party frameworks such as **Xamarin, Unity3D** or **React Native**.

Native solutions are recommended especially when the low-level resources of the operating system are used. The natively developed applications are responsive, easy to maintain and high scalability possibilities, but it practically requires the development of an application for each separate operating system.

- **Android SDK** - It is based on **Android Studio** as an IDE solution, derived from the popular **Intellij Idea**. It is based on the **Java** programming language, as well as the newer and modern **Kotlin**. It has its own complex system for generating graphic layouts and screens integrated in Android Studio.
- **iOS SDK** - The development bundle for iOS made available by Apple. It uses **Xcode** as IDE and the **Swift** and **Objective-C** programming languages.

Other solutions for the development of mobile applications are represented by third-party frameworks. These are useful for easier code management, mostly common code for all platforms - a single application regardless of the operating system. A disadvantage of them can be the fact that it is possible to write native code for each individual platform:

- **React Native –** An open-source framework used to create applications for Android, iOS, macOS, Windows, Web and more. It uses the **React** framework (based on **JavaScript**) as well as the native capabilities of the above-mentioned platforms for application development.
- **Xamarin** - A cross-platform framework owned by Microsoft used to develop applications for Android, iOS and more. The programming language used is **C#** and **Visual Studio** as IDE.
- **Unity3D -** Another very powerful third-party framework, used for developing applications for Android, iOS, but also many other platforms, including **VR/AR** devices. It is used especially for creating 3D/2D environments, being recognized as one of the most powerful graphic engines, but it can also be used successfully for creating classic applications for mobile devices and more, with the possibility of creating responsive, good-looking graphic interfaces. It is also flexible regarding the IDEs used, being able to opt for both **Visual Studio** and **MonoDeveloper.** Both **C#** and **JavaScript** or **Boo** can be used as programming languages.

### 7.2.4 TESTING AND INTEGRATION

Testing will begin almost immediately with the development process, according to the Agile methodology. Issues will be reported using the JIRA tool, used to create/edit/assign issues reported by the QA team. Various testing methodologies will be used (unit testing, automatic testing, exploring testing) depending on the scenarios that arise.

If the applications will target a wide range of devices, resolutions, operating systems, they will be tested on as many devices as possible, both physical and software emulators, to cover a wide range of scenarios and ensure optimal functionality for them. Testing will continue throughout the life of the project, including the maintenance and improvement phases of the project. Especially dedicated tools will be integrated into the application (Firebase Crashlytics) so that the development team can receive reports related to performance problems or app crashes on users' devices.

#### 7.2.5 Deployment

This step involves preparing the application for making it available to the target users. Deployment can be done both through dedicated application stores (Play Store, App Store) or third-party stores (Aptoide, Cydia, etc.), as well as by providing a link for download and installation directly on the targeted devices. To make the application available in dedicated stores, the application will be sent to them for review and acceptance. Periodically, new versions will be sent to publish, after bug-fixing sessions, maintenance or new functionalities added.

#### 7.2.6 MAINTENANCE

The application will be carefully monitored, and the development team will be responsive to the feedback received from the users or the stakeholders. New releases will be published as performance optimizations appear, issues will be fixed or the application will undergo major updates (new functionalities, library updates, targeting new devices, latest operating system versions, etc.). Security issues will be treated with priority.

#### 7.2.7 CONTINUOUS IMPROVEMENT

Continuous improvement of the application will be maintained by adding new functionalities and options. The step involves careful monitoring of the application, the feedback coming from users or stakeholders with the aim of improving the user experience, but also to optimize the performance of the application. All this may involve updating existing functionalities or adding new ones to keep the application updated and relevant for users.

### 7.3 FUNCTIONAL VIEW

The AR/VR solution will be used both for faster detection and response in case of a fire situation and for training of involved personnel. Fighting wildfires involves a lot of safety measures to be taken care of and a lot of training. To ensure safety, the involved people need periodic training.

A representative schema for describing the main components and the relation between them is presented in Figure 39.

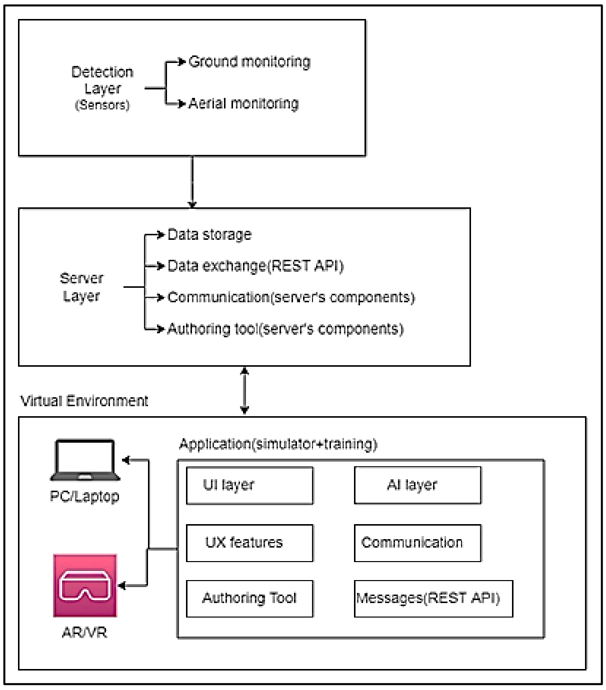


**Figure 39 - Main components of the AR/VR solution**

The major functional components of the solution are presented in the following:

I. **Component's modes:** *3D simulation*, providing the capability to recreate the environment in a 3D world and *AR/VR development,* ensuring that the virtual environment could be accessed by the AR/VR devices.
II. **Component's user types**, each of them will have different roles, rights and restrictions: *firefighter (first responder)*, *ranger*, *coordinator* and *administrator*.
III. **Component's type of view:** *Aerial view,* providing the capability to simulate a view from a drone's perspective and *Ground view,* providing the capability to simulate a view from the ground level perspective.

In order to communicate with the central server, send and receive messages, the component will have a data layer responsible for connecting to the server and reading data, and for parsing the messages and display the information in the UI.

Another important layer is the AI assisted decision support that can read and interpret the data collected from the other components and services and provide as output a certain event or information related to the specific situation. When any kind of information that might be relevant is detected, the application will show it in the corresponding areas of the UI in a **display mode,** such as: i) Received/status information area (for the upcoming events); ii) Environment area (for the enhanced UX device-specific environment); iii) Output area (for the messages generated by the application); iv) Communication area (for the communication with other users).

The application can be used as single player or multiplayer. The communication between the users is also a very important functionality because is a fast way for taking decisions. It will have a dedicated module responsible for the communication between users in both 3D environments and AR/VR environments. The application will use a simulated environment, offering the possibility to create a realistic use case, with an authoring tool. This tool will allow users to create a virtual environment by using:

- Ground resources: terrain, vegetation, etc.
- Firefighters' resources: fire truck, fire extinguisher, etc.

- Interactions: grab an object, drop an object, action for something, etc.

Other specific features will be developed according to the evolution of the project, feedback from stakeholders and technical issues.

## 7.4 OPERATIONAL VIEW

The application will act both as a simulator and as an authoring tool. The simulator will allow different types of users (firefighter, ranger, coordinator) to act in a virtual environment as in a real environment, to receive information from other services involved and, according to the decisions taken or new events that might occur, to have a representation of the feedback resulting from their decisions.

For example, all Pilot Use Cases have a critical factor, time. By using the enhanced reality platform all the users will have a better perspective on the procedures specific to a fire hazard situation, will have the chance to test different scenarios for different environments that maybe are not yet known and will be able to test different approaches in single mode or acting as a team.

**Figure 40 - Terrain variations**

In Figure 40 it is represented how a real-world terrain is simulated into a 3D environment. This kind of transformation will be available for the training, simulation and authoring tool.

**Figure 41 - Modelling the vegetation**

Similar to the terrain variations there will also be vegetation variations on the field. In Figure 41, a sample of such 3D modelling of existing vegetation is represented. The major objectives for the AR/VR component related to the Pilot Use Cases are:

- To reduce the incidence of forest wildfires.

This objective will be achieved by constant monitoring of the environment by different sensors that will send fast the collected data to the AR/VR component.

- To reduce the response time of firefighters in case of fire hazards.

This objective will be achieved by proactive and preventive approach from the sensors and also from the training sessions that will improve the ability to take faster and better decisions.

- Set the prerequisites for improved procedures in case of fire hazard intervention.

The simulated environment for different scenarios will have a significant impact on improving the operational procedures on the field.

- Develop a pilot version with updated preventive measures, based on input from partners.

The AR/VR component with the authoring tool capability will be able to create all kind of scenarios based on the feedback received from partners.

The collected data will be transmitted to the application in a standardized form of a *.json file. For example, there are information received from: Geo-database, statistical data, GPS device, drones equipped with cameras and infrared sensors, fire trucks, etc. The AR/VR component will validate some of the services specific to the Pilot Use Cases: alert service, prevention and preparedness system, training solution for first responders. There will also be a validation form from the stakeholders regarding the AR/VR devices.

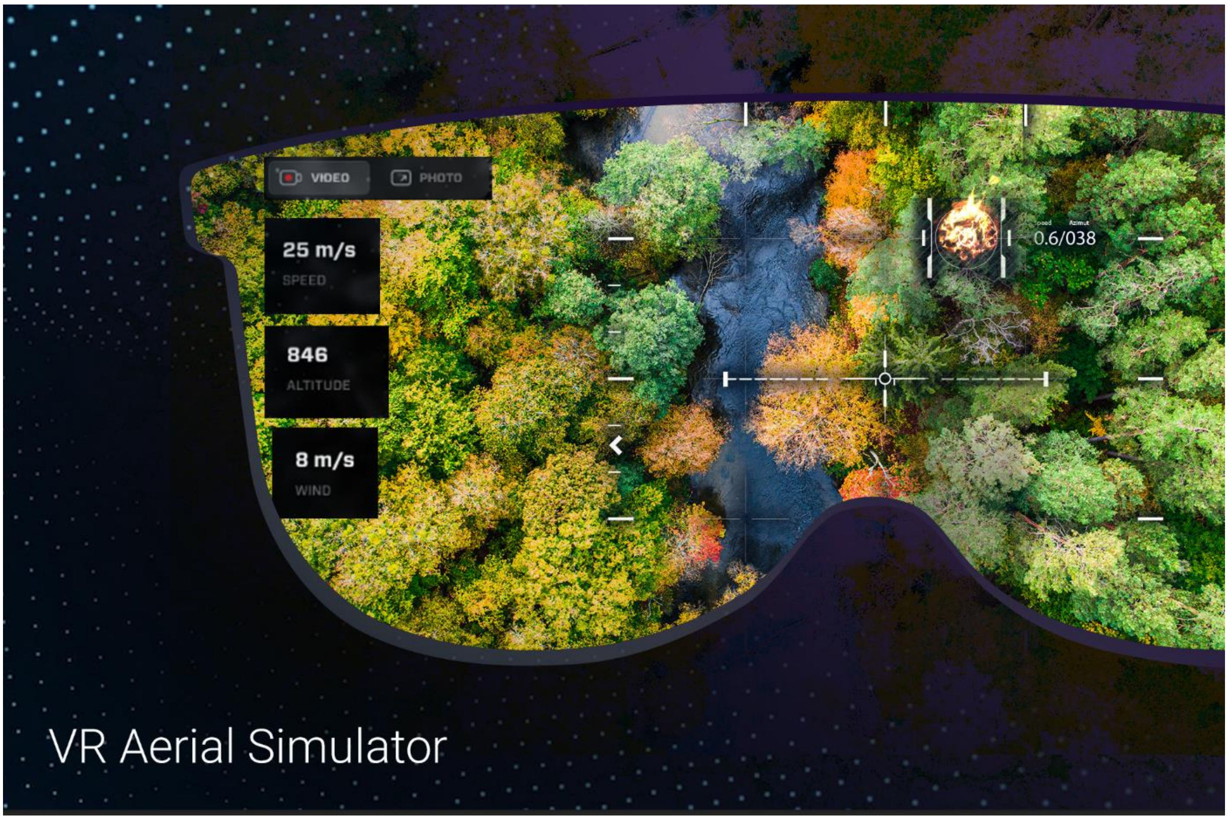


**Figure 42 - VR aerial simulator**

In Figure 42 - VR aerial simulator, there is a type of view specific to the aerial simulator, more specifically the view from a drone. In the left side are displayed various relevant information related to the involved sensors.


**Figure 43 - VR ground unit simulator**

In Figure 43 the VR ground unit simulator is represented, with a view specific to VR but from a ground unit perspective. Helpful information is displayed to the left or to the right but alerts or useful information could be displayed in any place where is needed. This image shows how a VR perspective can help and guide a first responder in a wildfire mission. Moreover, the AR/VR component will help to control faster any extreme and potentially harmful wildfire, will have impact on reducing the occurrence of wildfires and will decrease the firefighter reaction time.

# 8. SOLUTION FOR RESILIENT CONTEXT-AWARE DETECTION OF EMERGING FIRE-RELATED SITUATIONS

The **Context-aware Detection of Emerging Fire-related Situations** lies on a **Complex Event Processing system** (CEP - TREEADS Event Driven Situation Detector) which is able to digest real-time and heterogenous sensor data and outputs of other modules to detect (crisis) situations that require specific response actions. Thus, rules in the form of complex event patterns for modelling and detecting critical situations that represent knowledge elicited from the main crisis management actors is feasible.

The **TREEADS Event Driven Situation Detector (EDSD)** assists in aggregating lots of different information from IoT sensors and other devices. After identifying and analysing cause-and-effect relationships among these events nearly real time, it is feasible to deduct insights that are then fed (via Kafka event middleware) to the **Wildfire Response Engine (WRE)** explained later in the next chapter. This engine matches continuously incoming events against a pattern and provides insights into what is the current status in possible burning areas.

## 8.1 TECHNOLOGICAL APPROACH

Figure 44 depicts the technical architecture of the TREEADS EDSD which is implemented to support detection of fire-related emergencies. The IoT sensors (indicative examples include smoke detectors, UAV health status, temperature and humidity sensors, etc.) outputs are fed into the EDSD system and corresponding data are the input of the CEP engine. The input reaches the engine through the event middleware and based on rules defined by admin users (using a rule editor), the relative risk of a fire-related situation is calculated. If the risk is high, then an alarm is triggered, warning that an emerging fire is possible. The rule processing engine of EDSD stores or updates the data of the context repository. This process produces data that are used by the WRE in order to give guidance to first responders, citizens, authorities, etc. (response plans).

The technologies that are used for the development of the EDSD system are as follows:

- JDK 17 (www.oracle.com/java) as a programming language.
- Spring Framework (spring.io) as a framework to reduce lines of code.
- Spring Boot (spring.io/projects/spring-boot) used for creating stand-alone Spring applications.
- Apache Kafka (kafka.apache.org) as an open-source distributed event streaming platform and suited appropriately for implementing the Event Middleware.
- Esper (www.espertech.com) was customized and extended for implementing the CEP engine.

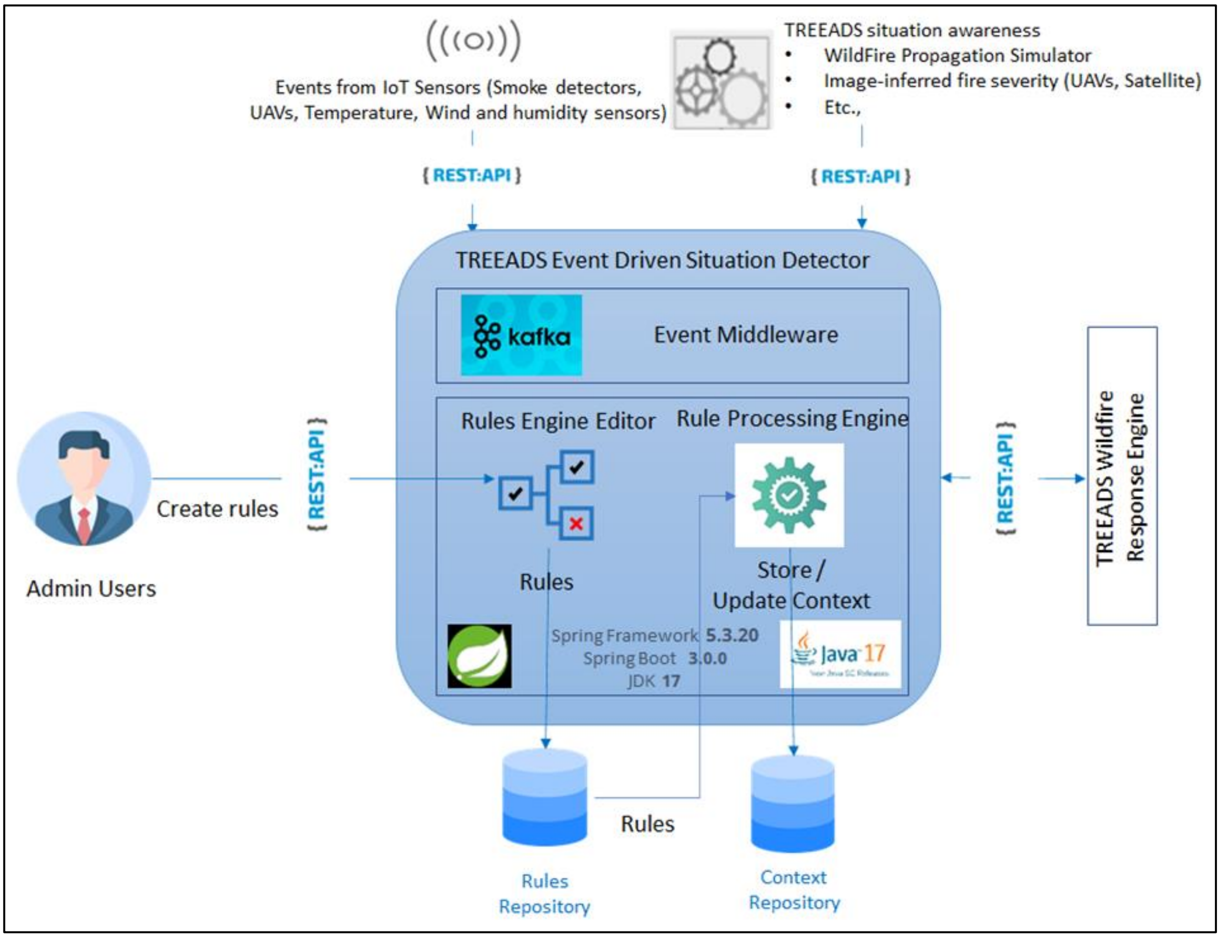


**Figure 44 - Technical architecture of the TREEADS Event Driven Situation Detector (EDSD)**

The data model used for defining the burned areas in case of fire is ESRI's ASCII grid. The first six lines of such a file indicate the reference of the grid as follows:

- ncols and nrows are the numbers of columns and rows, respectively (represented as integers).
- xllcorner and yllcorner are the western (left) x-coordinate and southern (bottom) y-coordinates, such as easting and northing (represented as real numbers with an optional decimal point).
- when the data points are cell-centered xllcenter and yllcenter are used to indicate such registration.
- cellsize is the length of one side of a square cell (a real number).
- nodata_value is the value that is regarded as "missing" or "not applicable" – this line is optional, but highly recommended as some programs expect this line to be declared (a real number).

The remainder of the file lists the raster values for each cell, starting at the upper-left corner. An example map is shown in Figure 45.

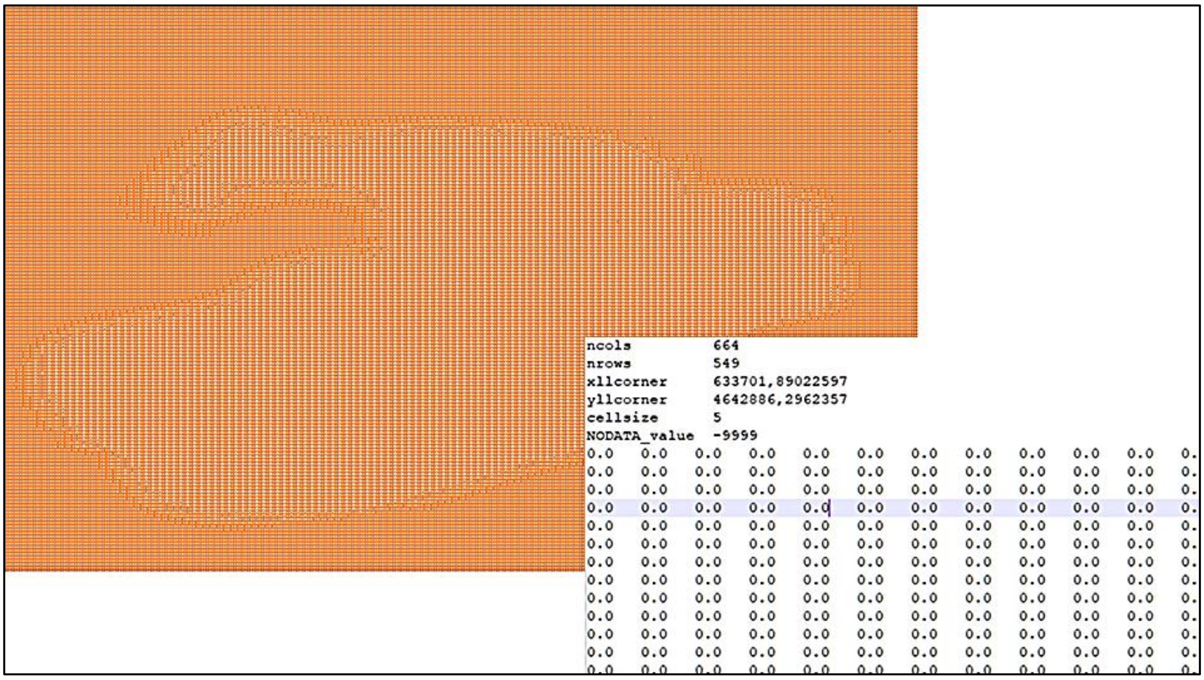


**Figure 45 - Example map of a burned area in ESRI's ASCII grid format**

## 8.2 METHODOLOGICAL APPROACH

The development of the EDSD system was performed by using an agile development methodology. As such the development of the software was based on an iterative and incremental process. Thus, the EDSD was developed in an adaptable, fast, flexible and effective manner. The development started from a general idea of what was needed to be built, elaborating a list of characteristics ordered by priority (product backlog).

***Concept:*** The first step was the concept phase. Here, the scope of the project was determined. Key requirements were discussed and documentation to outline them, including what features are supported and the proposed end results. In the concept stage, time estimation took place.

***Inception:*** Once the concept was outlined, the software development team was built. The necessary tools and resources were given to the team. The design process started, and the team built the project architecture. The inception stage involved further input from stakeholders to fully flesh out the requirements on a diagram and determine the EDSD functionality. Regular check-ins assisted in ensuring that all requirements were built into the design process.

***Iteration:*** Next up was the iteration phase. The developers worked for turning the design into code. The goal was to build the bare functionality of EDSD by the end of the first iteration. Additional features and tweaks can be added in the second iteration.

***Release:*** The quality assurance team performed some tests to ensure the software is fully functional. These Agile team members tested the system to ensure the code is clean — if bugs or defects were detected, the developers addressed them swiftly.

***Maintenance:*** The software was fully deployed and made available. This action moved it into the maintenance phase. During this phase, the software development team provided ongoing support to keep the system running smoothly and resolve any new bugs. Over time, the second iteration will take place to refresh the existing EDSD system with upgrades and additional features.

Simulated data (virtual sensors) were used to feed the EDSD in order to validate the appropriate functionality of the engine.

## 8.3 FUNCTIONAL VIEW

In Table 11, three example rules for detecting fire-related emergency situations are presented. When smoke detector is on fire is evolving and an alarm is triggered after detection by EDSD.

**Table 11 - Example rules that pose risk to safety**

| Smoke detector | UAV Status | Temperature greater than (Celsius) | Humidity lower than (%) | Wind greater than (km/h) | Status reported by Satellite |
|---|---|---|---|---|---|
| Off | Moderate | 35 | 20 | 55 | Moderate |
| Off | Unhealthy | 40 | 25 | 65 | Unhealthy |
| On | All values | All values | All values | All values | All values |

An admin user is able to see the current status of all triggered events or alerts. Thus, the admin user is always aware of the situation and whether an emergency is imminent at the region of interest. Furthermore, he/she able to filter out the different events, in a specific area, for being able to know what the situation is in this area. Finally, he/she has an overview of the events occurred and thus, can easily distinguish between minor/major severity fire-related emergency situations.

An incident verifier, on the other hand is able to verify an event and escalate it to incident, in order to notify immediately the corresponding operators and respective authorities.

## 8.4 OPERATIONAL VIEW

In Figure 46 the EDSD Rule Editor is shown. Admin users can insert rules in this editor that when satisfied a warning is triggered which in turn is given as input to the WRE (via Kafka middleware, as the WRE gets events by being subscribed to the event stream published by the EDSD).

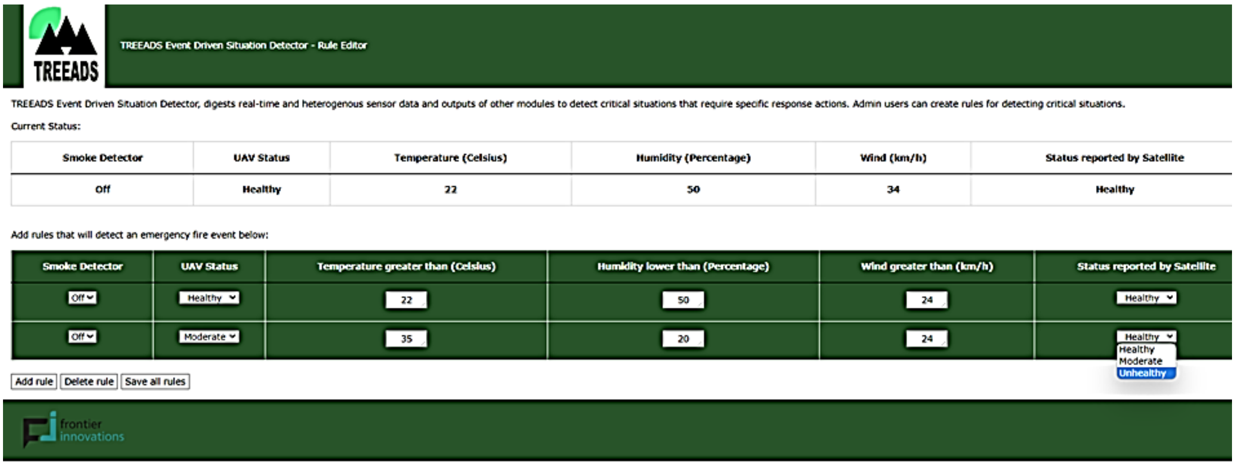


**Figure 46 - EDSD Rule Editor**

The incident verifier uses notifications generated by EDSD as per Figure 47. In this case, the smoke detector triggered an emergency event and an alarm was fired.

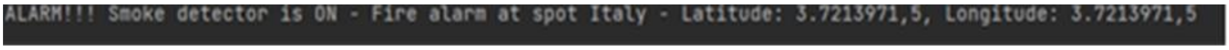


**Figure 47 - Notification generated by EDSD when an alarm is fired**

When EDSD detects a possible emergency and after events are processed by the latter, a warning is given by the backend as shown in Figure 48.

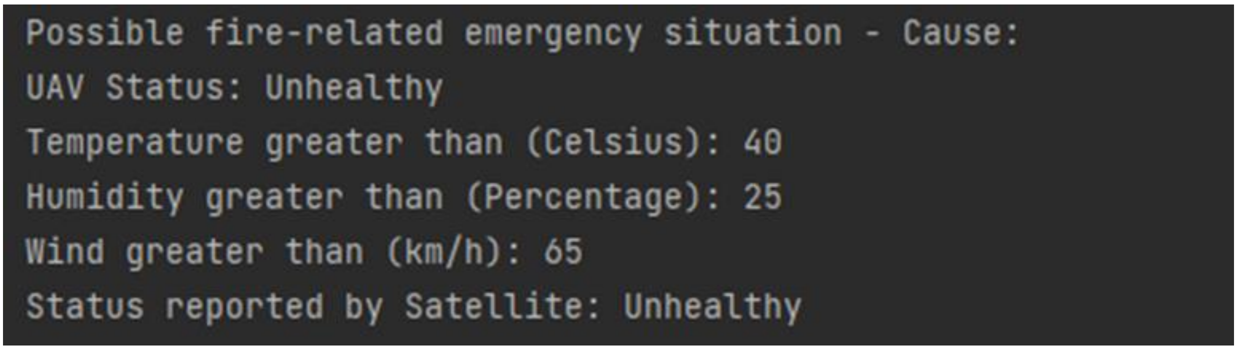


**Figure 48 - Example response given when an emergency is detected by the EDSD**

Figure 49 depicts an example of how the Sensor's simulated data are fed into EDSD. There is a REST endpoint that represents the smoke detector. When fire is detected the sensor sends the coordinates of the respective area to EDSD and then CEP comes into action in order to publish the event to Kafka. The WRE gets this event and provides the appropriate response plan to first responders, authorities, citizens, etc. The endpoints of all sensors are further described in the integration chapter.

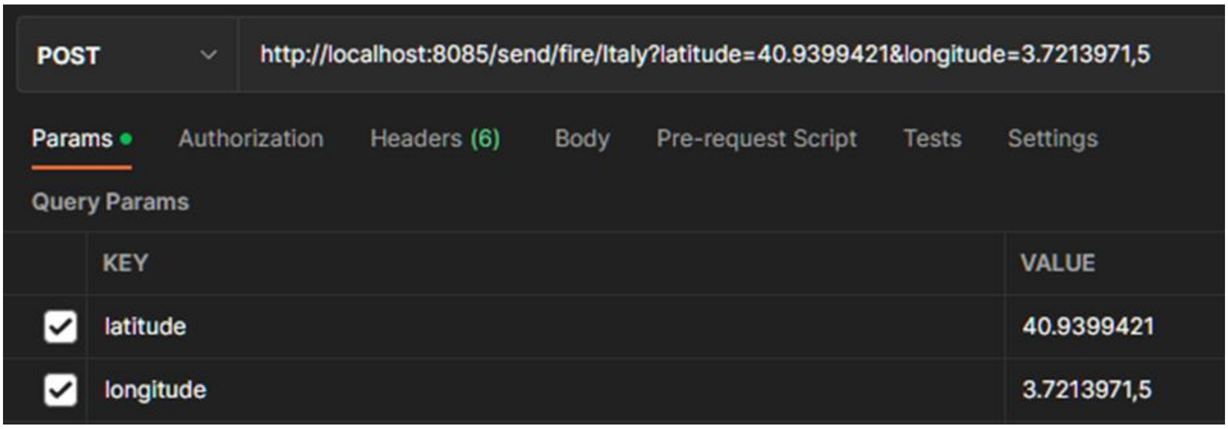


**Figure 49 - Example EDSD input from Smoke Detector Sensor's simulated data**

# 9. IMPLEMENTING A DECISION SUPPORT SOLUTION FOR WILDFIRE RESPONSE MANAGEMENT (WRE)

The WildFire Response Engine (WRE) is developed for handling the execution of fire response workflows (business process management – BPM engine). Domain experts have created the models and goals driving reactions and real-time enactment of business processes adaptations. The WRE exploits analytics methods in order to provide the ability to analyse data in real-time, anticipate and predict a critical situation, and recommend mitigating courses of action. It is designed and developed in such a way to support timely decisions and handle the execution of appropriate fire response workflows to interested stakeholders.

The innovation of this engine lies in the adaptation manager which exploits analytics methods and a BPM engine, in order to provide to the stakeholders, the efficient response plans when a fire-related emergency is detected by the EDSD.

## 9.1 TECHNOLOGICAL APPROACH

Figure 50 depicts the technical architecture of the TREEADS Wildfire Response Engine which is implemented to provide response plans to the appropriate stakeholders after the EDSD system detects emergencies that require specific actions (e.g., evacuation of an area). Events after they are processed by the EDSD, are used by the WRE in order to give guidance to first responders, citizens, authorities, etc. The technologies that are used for the development of the WRE system are as follows:

- JDK 17 (www.oracle.com/java) as a programming language.
- Spring Framework (spring.io) as a framework to reduce lines of code.
- Spring Boot (spring.io/projects/spring-boot) used for creating stand-alone Spring applications.
- Apache Kafka (kafka.apache.org) as an open-source distributed event streaming platform and suited appropriately for implementing the Event Middleware.
- Bonita (www.bonitasoft.com) was customized and extended for implementing the BPM engine.

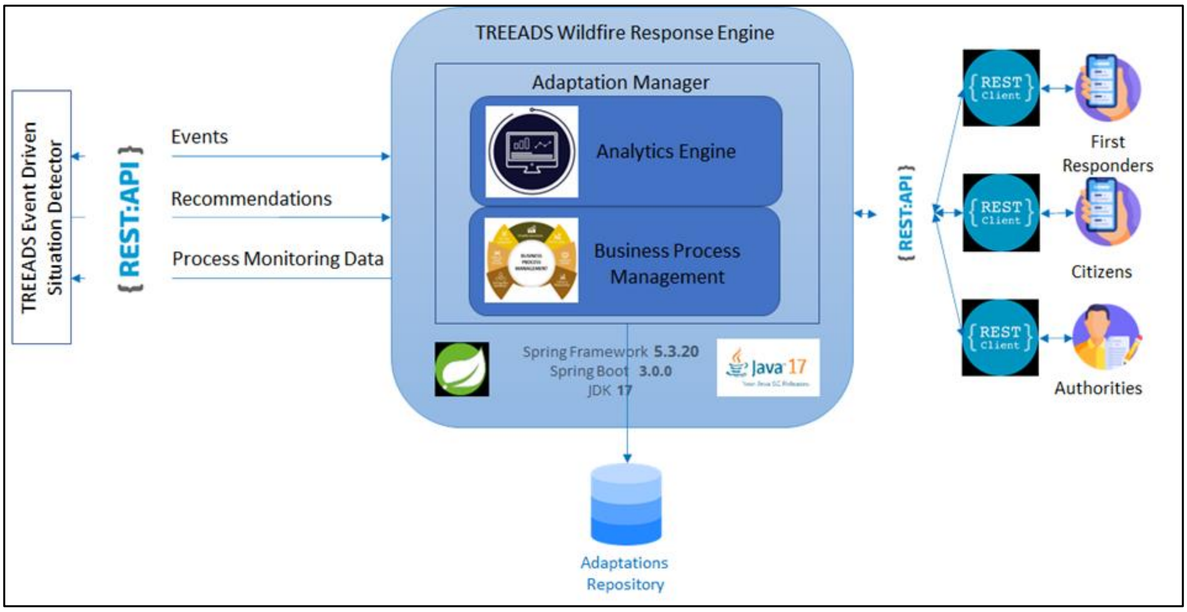


**Figure 50 - Technical architecture of the TREEADS WildFire Response Engine (WRE)**

## 9.2 METHODOLOGICAL APPROACH

The development of the WRE was performed by using an agile development methodology. As such the development of the software was based on an iterative and incremental process. Thus, the WRE was developed in an adaptable, fast, flexible and effective manner. The development started from a general idea of what was needed to be built, elaborating a list of characteristics ordered by priority.

- ***Concept***: The first step was the concept phase. Here, the scope of the project was determined. Key requirements were discussed and documentation to outline them, including what features are supported and the proposed end results. In the concept stage, time estimation took place.
- ***Inception:*** Once the concept was outlined, the software development team was built. The necessary tools and resources were given to the team. The design process started, and the team built the project architecture. The inception stage involved further input from stakeholders to fully flesh out the requirements on a diagram and determine the WRE functionality. Regular check-ins assisted in ensuring that all requirements were built into the design process.
- ***Iteration:*** Next up was the iteration phase. The developers worked for turning the design into code. The goal was to build the bare functionality of WRE by the end of the first iteration. Additional features and tweaks can be added in the second iteration.
- ***Release:*** The quality assurance team performed some tests to ensure the software is fully functional. These Agile team members tested the system to ensure the code is clean — if bugs or defects were detected, the developers addressed them swiftly.
- ***Maintenance:*** The software was fully deployed and made available. This action moved it into the maintenance phase. During this phase, the software development team provided ongoing support to keep the system running smoothly and resolve any new bugs. Over time, the second iteration will take place to refresh the existing EDSD system with upgrades and additional features.

## 9.3 FUNCTIONAL VIEW

A list of user stories that describe the needs of the different types of users were created. Fire responders need to be alerted when an incident occurs so that they are immediately aware of the severity and location in order to activate a proper response plan. Furthermore, they are able to easily communicate with other users/operators in order to share information directly and subsequently decide upon the best response plan together. Finally, they need to verify an event and escalate it to incident so that they can go directly to the burning area in order to extinguish the fire.

Citizens and authorities should be notified as early as possible. Citizens can quickly then evacuate the area and the authorities can coordinate forces of civil protection and assist in fire extinguishing.

## 9.4 OPERATIONAL VIEW

In case of fire, the WRE responds with an evacuation plan, by giving output to first responders, citizens, authorities, etc. As an example, at Samaria Gorge, Figure 51 depicts the escape route in such a case. Moreover, ambulances are notified to approach spots where there could be injured people. Simultaneously, fire trucks are engaged in order for the fire fighters to extinguish the fire at the corresponding spots. The WRE, considers the time dimension, in order to coordinate all of these actions in an appropriate manner.

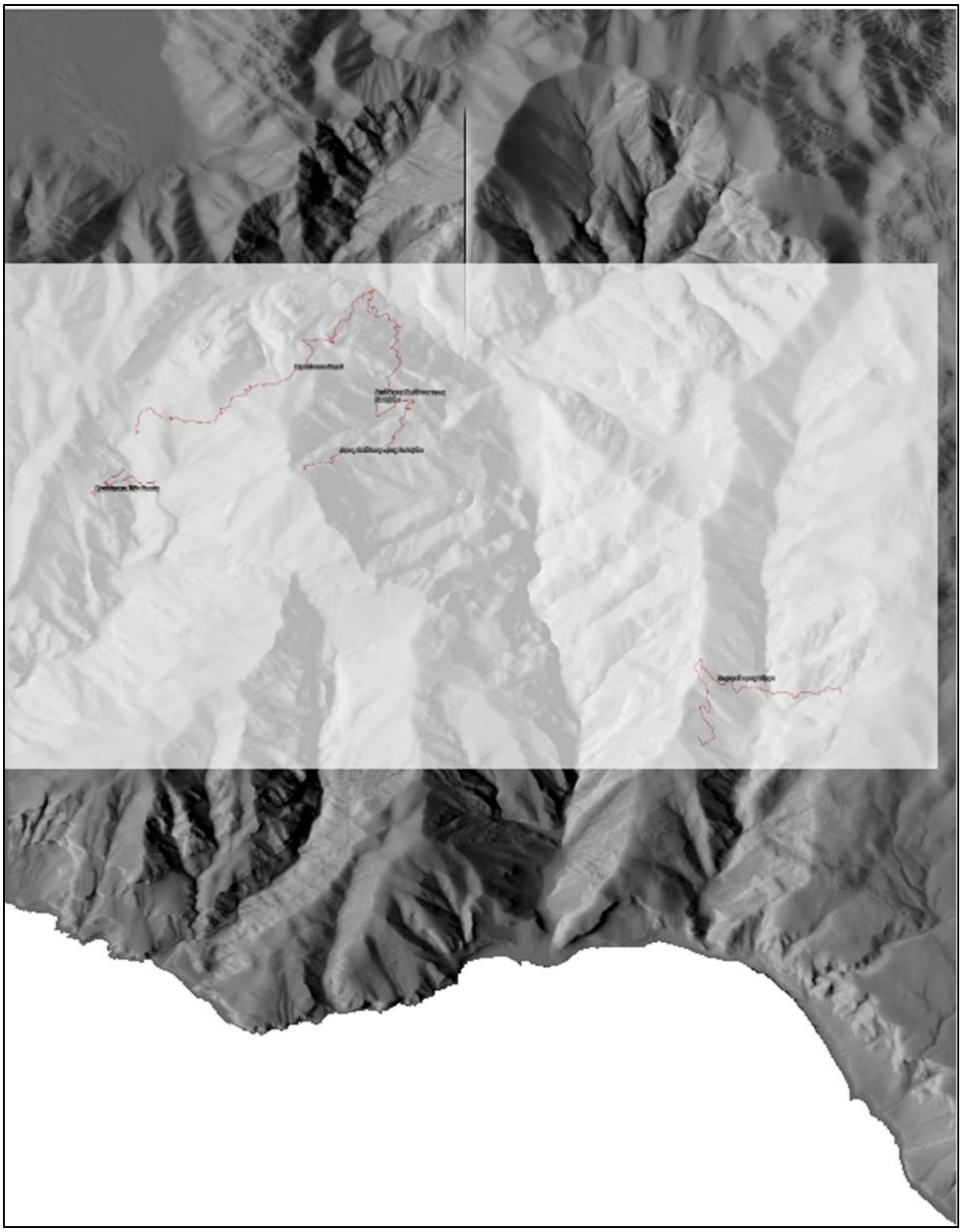

**Figure 51 - Example escape route in Samaria Gorge provided by the WRE**

# 10. INTEGRATION WITHIN THE TREEADS PLATFORM

This chapter presents the most relevant aspects regarding the integration of each component of detection and response within the TREEADS platform. The description of the architectural vision meets the specifications and integration principles of the TREEADS platform, as a whole, as they are presented in deliverable D3.5, using an approach compliant with the descriptions of the components in the previous chapters, namely the "4+1" architectural model.

The international standard ISO/IEC/IEEE/42010 provides different architectural models such as "4+1" view of architectural design which organizes a description of the software architecture based on five concurrent perspectives addressing a specific set of components and concerns. An overview of each "4+1" architectural view, the proposed approach for the detection and response solution, is detailed as follows:

- *Development* view is focused on software components, modules / subsystems in the development environment (related to the Technological approach from the previous descriptions of major components within the document).
- *Deployment* view describes the physical environment, where the system is planned to run (related to the Technological approach from the previous descriptions of major components within the document).
- *Information* view describes the relevant flows of information in parallel or sequential execution of tasks (related to the Technological and Methodological approaches from the previous descriptions of major components within the document).
- *Function* view describes the functional elements of the system, major features, their responsibilities, interfaces and interactions (related to the Functional view from the previous descriptions of major components within the document).
- *Use cases'* view serves two main purposes: as a manner to discover the architectural elements during the architectural solution design and as a validation / assessment role after this architecture design is complete (related to the Operational view from the previous descriptions of major components within the document).

In the following section the major components of the detection and response solution are positioned within the integrated platform based on their features and functionalities and mapped on the views depicted above. Moreover, the generic integration tools and orchestration of specific services are described.

## 10.1 EDSD - EVENT DRIVEN SITUATION DETECTOR

The source code of the EDSD system is in Gitlab – git@gitlab.com:dpanagiotou/treads-cep-bpm-engine.git (EDSD branch). EDSD uses simulated data, in order for its functionality to be tested in the use cases of the pilots. Table 12 summarizes the endpoints that are used by the simulated (virtual) sensors to feed the EDSD system with data:

**Table 12 - *REST endpoints of virtual sensors that feed EDSD***

| HTTP Method | Endpoint | Description |
|---|---|---|
| POST | http://localhost:8085/send/fire/fire?longitude=35.2401 &latitude=23.9612 | Smoke detector status |

| | | |
|---|---|---|
| POST | http://localhost:8085/send/wind/24 | Wind in km/h |
| POST | http://localhost:8085/send/uav/healthy | UAV status |
| POST | http://localhost:8085/send/temperature/22 | Temperature in Celsius degrees |
| POST | http://localhost:8085/send/satellite/moderate | Satellite status |

## 10.2 WRE - WILDFIRE RESPONSE ENGINE

The source code of the WRE system is in Gitlab: git@gitlab.com:dpanagiotou/treads-cep-bpm-engine.git (BPMEngine branch). An example response plan includes the provision of notifications and instructions to different stakeholders including to citizens to follow a specific evacuation path, to first responders to extinguish the fire and to ambulances to pick up injured people as shown in Table 13:

**Table 13 - Example response plan provided by the WRE**

| Response Plan |
|---|
| {"response": "FIRE ALARM!!! - Please follow the evacuation path "PathName" at 16:04 whose entrance is located at Latitude: 23.9612, Longitude: 35.2401} |
| {"response": "FIRE ALARM!!! - Please proceed for extinguishing to spot Samaria Gorge at 16:06 - Latitude: 23.9612, Longitude: 35.2401."} |
| {"response": "INJURED PEOPLE!!! - Please proceed to spot Samaria Gorge at 16:37 - Latitude: 23.9612, Longitude: 34.2305"} |

## 10.3 INTEGRATION TOOLS

The TREEADS platform consists of a large number of systems ranging from web-based services and platforms to various small sensor devices. One of the challenges faced during the design is the integration between components in the TREEADS platform. In light of this challenge a number of integration tools will be deployed allowing for the integration of heterogeneous components in an agnostic manner. The following sections will describe and analyze two different platforms that will be deployed as part of the TREEADS platform.

### 10.3.1 APACHE KAFKA

The first solution is based on the well-known message-based broker Apache Kafka enabling components to integrate in a uniform and consistent manner. Apache Kafka is a stream processing platform that follows the publish and subscribe paradigm. Information in Apache Kafka is structured in various topics. These topics are contextual abstractions for modelling data exchange. The platform allows Publishers to push information into various topics and Apache Kafka is responsible for distributing information to Consumers for the topics they are subscribed. Furthermore, Apache Kafka provides advanced functionality to ensure “exactly once” delivery of messages to all parties. In Figure 52 it is shown the standard architecture for an Apache Kafka cluster consisting of various Producers and Consumers and the Apache Kafka broker in the middle of the architectural solution.

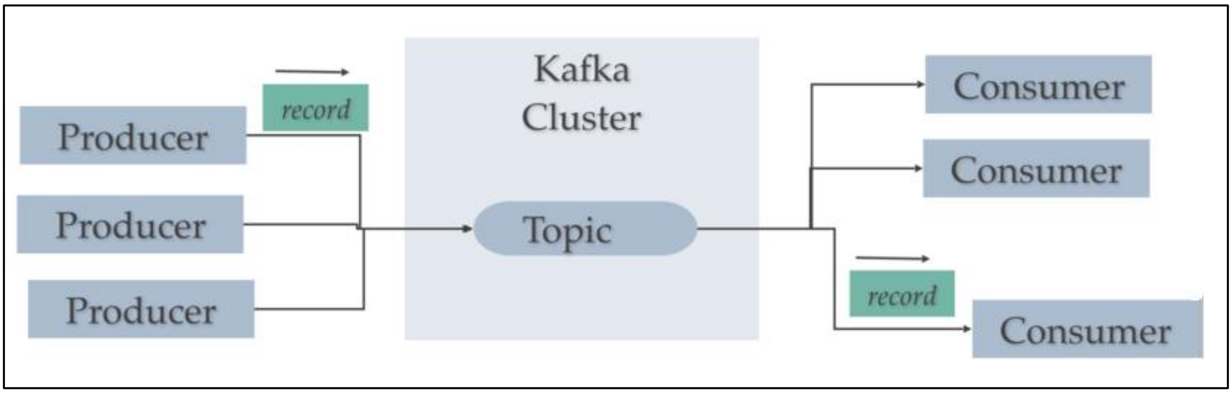


**Figure 52 - Kafka Architecture: Topics, Producers and Consumers - Image Reference: http://cloudurable.com/blog/kafka-architecture/index.html**

Apache Kafka will provide many benefits to the TREEADS platform with regards to integration. More specifically some of the main advantages relevant to the TREEADS architecture include:

- Low Latency and High Throughput capabilities.
- Reducing the need for multiple integrations among tools in the TREEADS platform.
- Libraries for all well-known programming languages.
- Fault Tolerance in node failure scenarios avoiding potential loss of information.
- Scalability.

During the course of the project the platform will be deployed using industry best practices with regards to security and authentication. Technical partners that would like to use the platform will obtain thorough documentation as well as the necessary credentials. The platform will be demonstrated in a live session to all technical partners.

### 10.3.2 MQTT PROTOCOL

While Apache Kafka is a good solution for intercommunication between components such as services, it is not such a great solution for low powered devices and sensors. The TREEADS will include an extensive number of low powered devices and sensors which will play a big role in enabling the overall solution. MQTT (MQ Telemetry Transport) is a standard messaging protocol for Internet of Things (IoT). Its design goals are exclusively focused in providing a lightweight solution for information exchange between low powered devices. Similarly to Apache Kafka the MQTT protocol is also based on the publish and subscribe paradigm allowing heterogenous devices and sensors to communicate in an agnostic and uniform manner. In Figure 53 it is represented a typical MQTT deployment involving information exchange between various devices.

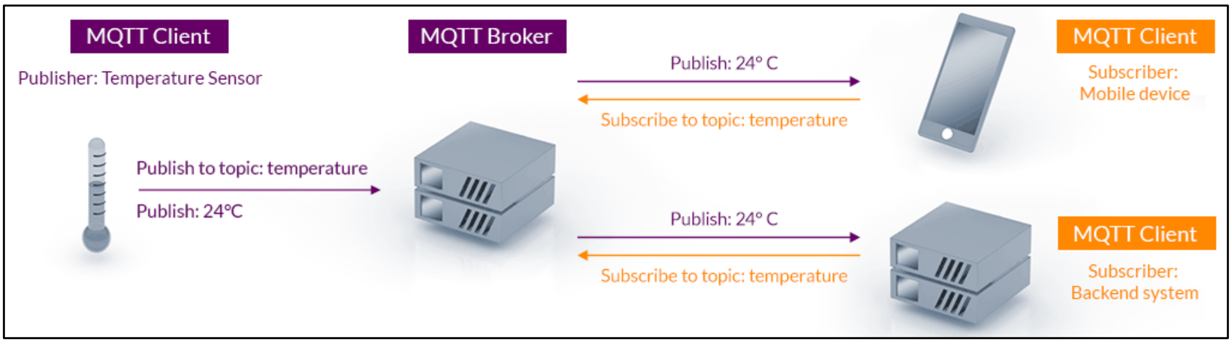


**Figure 53 - MQTT Publish / Subscribe Architecture - Image Reference: https://mqtt.org/**

Since MQTT itself is only concerned with the specification of the protocol, a specific implementation needs to be selected for the deployment of a broker. In the TREEADS platform Eclipse Mosquitto (https://mosquitto.org/) will be thee MQTT broker of choice. Eclipse Mosquitto will be deployed securely with the necessary authentication mechanisms and be accessible to all technical partners. Similarly, to Apache Kafka documentation and a relevant joint workshop demonstrating the platform to partners will be organized.

# 11. ADDRESSING EXTREME WILDFIRE EVENTS IN TREEADS

The socio-technological solutions united in the TREEADS platform aim at preventing and fighting extreme wildfires. There are various definitions of extreme wildfire events. The adjective extreme is commonly used in wildfire sciences to highlight various representations of fire danger, fire risk, fire behavior, fire regime and fire severity [11]. Definition criteria can include physical properties of the fire, such as size and duration, wind speed and fuel load, radiative power, but also impacts. Extreme wildfires typically have rapid spread, often driven by strong winds, low humidity, and dry conditions [12]. Here, the term extreme wildfire is used to depict wildfires with exceptional physical characteristics, including size, duration, regime, behavior, severity, and rapid evolution.

Two important aspects are addressed within the socio-technological solutions for detection and response in TREEADS:

- the way in which the technical solution, as an integrated platform, has the ability to detect the evolution of a wildfire in the optimal time, so that it does not become a major catastrophe (extreme wildfire)
- the technological capability of the detection and response solution to effectively respond to an extreme wildfire event through specific optimization, prediction and intervention functionalities (smart algorithms, rules engine, alerts, decision support)

TREEADS envisions contributing significantly to wildfire management across all incident phases, particularly during extreme wildfire events. Extreme wildfires often occur during periods of elevated fire danger, which may result from a combination of factors such as drought, high temperatures, low humidity, and strong winds. For these reasons, early and accurate weather forecasting is crucial for implementing precautionary measures, such as targeted drone patrols. TREEADS addresses this need through an early warning system that integrates meteorological data with vegetation indices derived from point clouds, satellite images, fuel and ground models, forming a real-time fire prevention system. A critical issue during the handling of an extreme wildfire event is the efficient management of information and suppression units, which encounter challenges arising from their rapid spread, unpredictable behavior, and potential large-scale impact. To overcome these challenges, TREEADS adopts an integrated approach, leveraging diverse advanced monitoring technologies to enhance situational awareness.

The project incorporates fire event detection via social media platforms and hotspot detection through a four-layer architecture that integrates different altitude levels. Social media analysis, with automatic geolocation, complements traditional fire reporting, facilitating real-time mapping, particularly in the case of extensive or abrupt fires. Simultaneously, TREEADS's four-layer architecture significantly contributes to fire mapping, proving especially advantageous in high-intensity, large-scale wildfires by capitalizing on the strengths of different layers. For instance, hotspot detection from satellite imagery benefits from the extensive area coverage of satellite systems, a crucial aspect of large-scale fire monitoring. Additionally, the difficulty in monitoring high-intensity wildfires, characterized by increased heat load and pyroconvective behavior, is effectively addressed through the remote sensing capabilities of satellites and the autonomous navigation of drones, which averts injuries that could evoke during close-range inspection. Consequently, this collaborative approach ensures effective fire monitoring, by leveraging the strengths of low or medium altitude drones and satellite sensors to handle the high intensity and size of extreme wildfires.

An additional constraint is that such fires can occur in challenging terrains, such as mountainous regions or areas with limited accessibility. This can impede firefighting efforts and evacuation procedures. For this reason, TREEADS project aims to assist ground firefighting units by automatically identifying routes with optimal possible access through the coupling use of Hillshade models, that provide information on the terrain, and real-time information about the course of the fire. Moreover, in the case of an extreme wildfire, the EDSD ingests available real-time, diverse data and combines them with weather status, sensor and drone data, which can compose a detailed picture of the current situation to estimate the propagation of the fire. An additional safeguard mechanism is the integration of domain knowledge in the form of rules, which during extreme conditions, will be triggered to invite human intervention as soon as possible. Furthermore, as the situation evolves, the system will continuously adapt, updating its predictions and notifying the decision support system.

To produce an appropriate response plan under extreme conditions, TREEADS WRE is integrating heterogeneous data, combining the estimations of fire propagation with real-time information like the locations of people, vessels, and firefighting resources. Experts and authorities can provide specific information on extreme conditions and compose tailored response plans to address them in the best way possible, for example promoting the preventive early notification of citizens for evacuation and urgent coordination of authorities for effective civil protection and firefighting. As extreme wildfires can surpass the firefighting capabilities of the region, TREEADS incorporates timely human oversight at every stage, providing all information in a transparent way, allowing each response decision to be reviewed and modified before it is dispatched. Additionally, TREEADS advances fire extinguishing through the use of heavy payload fire extinguishing drones, acting complementarily to firefighters, enhancing their capabilities, especially in terrains with low access or where the unpredictable behavior and high intensity of an extreme wildfire would hinder human access to the area.

Likewise, extreme wildfire events can have major social impacts, due to their interaction with conditions of exposure, vulnerability, and capacity to cope, leading to human, material, economic and environmental losses, and impacts [13]. In order to foresee and mitigate these risks, the TREEADS project, apart from fire detection and fire extinguishing capabilities, also concentrates efforts on the protection of human and animal lives through extensive autonomous drone patrolling in the vicinity of affected areas and automatic detection of trapped or injured individuals or animals, via computer vision algorithms embedded on drones. Additionally, automatically generated evacuation routes assist on their evacuation, whereas heavy payload drones can provide them with first aid or can suppress fire in a targeted area.

Extreme wildfires may also have a significant impact on air quality, since the smoke generated by extreme wildfires can degrade air quality over a broad area, affecting the health of both human and animal populations. For this reason, TREEADS develops sensors (black boxes), able to detect air pollutants, that could be valuable both for the detection of toxic gases during fire extinguishing operations and for air quality assessment in general. Additionally, TREEADS develops simulation models in order to estimate the dispersion of smoke and air pollutants that affect air quality and human and animal health.

Moreover, extreme wildfires often result in severe environmental consequences and ecosystem degradation, such as irreversible soil losses, losses of dominant or keystone species, loss of biodiversity, etc. [14]. TREEADS aims to contribute to environmental relief by accelerating restoration activities, such as reforestation through drone seeding technology.

In the context previously presented, within the project, detection solutions are made available with the ability to prevent the expansion of wildfires to extreme wildfires, and in case the evolution of wildfires would be extreme, the proposed integrated detection and response solution has the ability to react in real time at all levels: resources, location management, evacuation and intervention tools, extinguishing solutions and coordination and control at the level of the Command Center. In other words, the detection and response solution is designed from the start to prevent an extreme wildfire and the technologies integrated on the TREEADS platform are prepared to respond to a catastrophe.

# 12. CONCLUSIONS AND IMPLICATIONS

The current deliverable is the first report addressing the requirements of WP5 (T5.1toT5.8) which depicts the most relevant aspects concerning the implementation of the detection and response solution within TREEADS project.

A unified methodological approach was applied for collecting detailed information about the major components of the detection and response solution in this stage of development, capturing both the technical specifications, the development methodologies as well as the functional and practical views.

Significant effort has been put on structuring the large amount of information about each component to have a comprehensive and unified way of presenting the solution complexity. Thus, for creating a coherent and logical presentation, the deliverable has been structured in different chapters dedicated to the major components of the detection and response solution, corresponding to the associated Tasks in WP5.

The deliverable provides a unitary vision of the components and their particularities, from technological, methodological, functional and operational perspectives, using specific methods, technical specifications and common terminology applicable in IT projects implementation. Therefore, comprehensive sections have been dedicated to the technical descriptions of the implemented solutions, both at the level of physical infrastructure and communications, equipment, devices and sensors, as well as at the level of software applications and architectural vision.

The specific terminology used within the document, as well as the presentation of technologies, tools, equipment and services, provide a common understanding for all the partners with regards to each technology, tool, equipment and service scope. Furthermore, the deliverable sets the roadmap for showcasing the TREEADS Technological Solution for Detection and Response through a demonstrator that will be developed in the second version (D5.1.V2).

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A Holistic Fire Management Ecosystem for Prevention, Detection and Restoration of Environmental Disasters

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|---|---|---|---|---|---|
| **FRN** | NO | **INNOV** | CY | **DCNA** | AT |
| **Jotne** | NO | **FI** | EL | **IFR** | AT |
| **BAM** | DE | **GBD** | BE | **FGK** | AT |
| **Altran** | ES | **EFB** | EL | **BFG** | AT |
| **DH** | ES | **LAMMC** | LT | **STRESS** | IT |
| **USAL** | ES | **OneSeven** | DE | **ACaMIR** | IT |
| **SQD** | BE | **VIPO** | NO | **Sorrento** | IT |
| **CARTIF** | ES | **WAS** | NO | **PUI** | FR |
| **UdG** | ES | **CBS** | DK | **FAFCYLE** | ES |
| **NCSRD** | EL | **K3Y** | BG | **DdA** | ES |
| **SIMAVI** | RO | **MAGG** | IT | **TUC** | EL |
| **OvGU** | DE | **NOA** | EL | **MAICh** | EL |
| **ADR** | EL | **MEWF** | RO | **DAAC** | EL |
| **CERTH** | EL | **ASFOR** | RO | **NTUST** | TW |
| **8bells** | CY | **SMURD** | RO | **DTU** | DK |
| **ACCELI** | CY | **JOAFG** | AT | | |

**Contact:**


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