A Technological Framework For Leveraging First Responders' Efficiency and Safety

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***Abstract*—In an event of emergency, first responders are usually the first on the scene, called to act fast and accurate. Multiple units of firefighters, paramedics, volunteers and police officers face challenging, dangerous and draining situations in order to locate and rescue victims, ensuring the safety both of the civilians and themselves. However, the coordination and communication, as well as the effectiveness of all these units is not always guaranteed, especially in harsh conditions and rough environments (e.g. forest fires). This paper presents the platform proposed by the RESPOND-A European project. Its aim is to leverage First Responders' efficiency and safety, by introducing a joint technological and conceptual framework for maximal Situational Awareness in terms of boosting Early Assessment, Safety Assessment and Risk Mitigation capabilities, together with the clear Common Operational Picture and the optimal management of operations. It associates modern telecommunication technology, network enabled tools and advanced equipment with novel practices for First Responders saving lives, while safeguarding themselves effectively and constantly.**

Keywords—first responders, 5G network, situational awareness, common operational picture, emergency units, mission safety

I. Introduction

The European Environment Agency (EEA) [1] has classified three main types of hazards considering their impact on society, economy and ecosystem. Hydro meteorological or weather related hazards (i.e. storms, extreme temperature events, forest fires, droughts, floods), geophysical hazards (i.e. snow avalanches, landslides, earthquakes, volcanoes) and technological hazards (i.e. oil spills, industrial accidents, toxic spills from mining activities, etc.). Evidently, these hazards are becoming more and more frequent across Europe, while their potential to grow further [2] have triggered formidable concerns to scientists and citizens about whether the European Union (EU) can push Research and Development (R&D) innovation towards supporting First Responders (FRs) for acting more efficiently and protecting more effectively the public safety before, during and after such disasters.

Multiple research projects funded by the European Union (EU) are active, mainly under H2020 umbrella [3], offering tools and solutions for enhancing FRs missions. RESPOND-A [4], as an ongoing H2020 project, proposes a holistic approach for multiple emergency units operating in remote areas and under harsh environmental conditions (e.g. public communications failures, operations in distant sites etc.). It offers a joint technological and conceptual framework for maximizing the efficiency of FRs and enhancing their safety, before, during and after disasters, utilizing state-of-the-art technologies and novel practices.

In this paper the work is organized as follows: chapter II discusses the FR's requirements and mission needs, chapter III presents the proposed system architecture, chapter IV presents the early trial of the system and finally chapter V concludes the paper discussing challenges and future improvements of the platform.

II. First Responders' Requirements

RESPOND-A develops technologies optimized for supporting the missions and safety of emergency units. Therefore, the first and most important step for the project consortium was to identify and analyze the FRs needs and translate them into system and tools specifications. The requirements are categorized as:

A. Operational Requirements

A common classification of requirements groups them into three primary categories, namely operational, functional and performance [5]. According to the same classification, operational requirements are related to the use case of the technology, covering aspects such as the mission profiles, infrastructural needs and other contextual aspects of the operational environment. Functional requirements refer to the physical characteristics of the technology and the situations within which it will reside, including elements like technology interfaces and its physical, mechanical and technical properties. Finally, performance requirements refer to the metrics and parameters describing the capabilities of the technology, like data throughput, dependability, power consumption, etc.

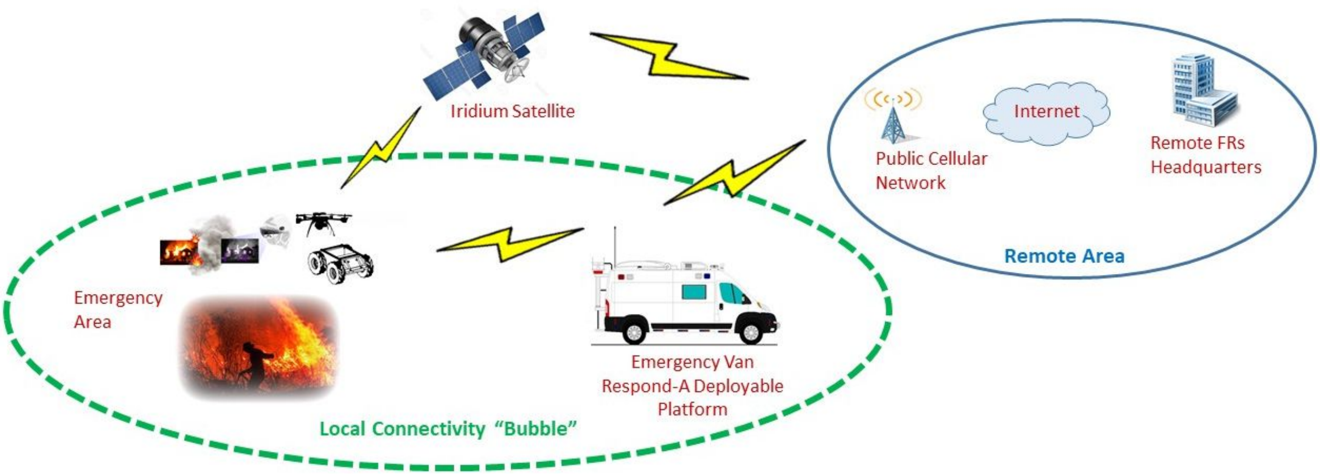

Fig. 1. Conceptual diagram of RESPOND-A project

B. Privacy Requirements

The Privacy-by-Design [6] paradigm is a modern framework that puts privacy and data compliance at the forefront of business priorities and initiatives. This framework aims to achieve these objectives from the start, to safeguard strategies from data violations and to protect the EU from data breaches.

C. Safety Requirements

Safety requirements refer to the reduction of risk towards the safety of FRs during operations. Different types of emergency units are involved during a crisis management like firefighters, police, rescue workers, emergency staff and volunteers. Each of these groups has a specific role in managing the crisis and can be exposed to various health and safety hazards. Safety policies, which shall be in place for the protection of FRs, shall take into consideration three factors: the organization, the technology and the human factor. Using these three factors as the main framework, international organizations have developed guidelines for improving the occupational safety and health of emergency response workers. For instance, the manual developed by Worldwide Health Organization (WHO) [7] focuses on three main parts, equally important to reinforce the safety and protection of workers:

1. Reduce occupational exposures, injury, illness and death among response workers.

2. Decrease stress and reduce fears.

3. Promote the health and well-being of healthcare and other response workers.

D. Requirements elicitation method and analysis

The main source of FRs requirements was the team of end users participating in the project. A combination of structured and unstructured techniques have been employed for feedback acquisition, consisting of interviews, surveys and workshops. Moreover technology providers collected feedback and experience working together and interacting with the FRs for the setup of pilot scenarios. The FRs requirements were then categorized according to the MoSCoW method [8], leading to "Must have", a "Should have", "Could have" and "Won't have" classification.

Implementing the aforementioned methods, over 130 FRs requirements have been elicited, analyzed and prioritized, resulting to 74 high-priority (i.e., must have), 42 medium-priority (i.e., should have) and 16 low-priority (i.e., could have) user needs. Among the most important and emphasized asked requirements from the FRs were the guaranteed communications, the efficient units coordination and the safety maximization. During a mission, where multiple emergency units operate, under complicated and extreme conditions, at remote areas or when the public communications are out of service, the need for reliable communications is the key for a successful mission and, according to the FRs feedback, this is one of the most significant weaknesses of the rescue operations.

III. PROPOSED SYSTEM

Based on the analysis of FRs requirements and the intense need for reliable communications and units' coordination, continuously and everywhere, RESPOND-A proposes a deployable platform along with field tools for leveraging FRs mission and answer their needs. The critical asset that the project offers is that it creates a mobile operational center, equipped with all the necessary tools for approaching the incident area and coordinating and supporting the operating units. Moreover, the proposed system accommodates even more specifications (that are not directly extracted from the FRs requirements) in order to ensure smooth and complete technology integration and mission effectiveness.

A. System Architecture

Fig. 1 shows the architectural concept of RESPOND-A platform. The multiple emergency units (e.g. Firefighters, paramedics, police, etc.) operate in the incident area, not only using new technologies and wearable equipment for enhancing their capabilities, but also fully supported by a deployable platform, installed in a van for approaching fast and easy the incident scene. This platform acts both as an autonomous mobile Command & Control (C&C) center and a communication system, organizing FRs mission, offering guaranteed communication (even if the public network is out of service/reach) and sending them critical information for completing their mission secure and effectively. The mobile unit also serves as a gateway to the remote FRs headquarters and the internet.

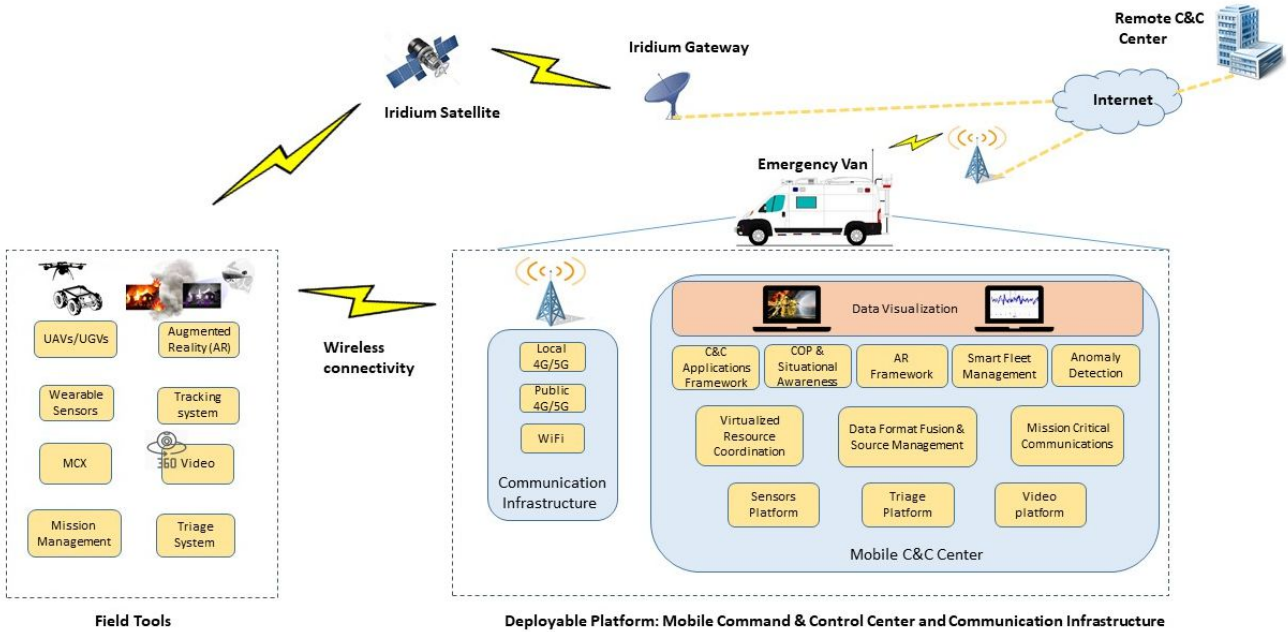

Fig. 2. High level architecture of RESPOND-A platform

Fig. 2 shows the high-level architecture of the system. The core of RESPOND-A ecosystem is the Deployable Platform, hosted by a moving van, embedding all the required components for offering reliable communications (communications infrastructure component) and mission coordination (Mobile C&C Center component). On the operating field, the FRs use tools for enhancing their effectiveness and safety, while being able to communicate and send/receive data through terrestrial communications. The latter is consisted of the local network created by the van or the public network if it exists, while the autonomous vehicles have also the option of satellite communications (Iridium), reaching the internet and the remote headquarters.

B. *Components Analysis*

The Mobile C&C center processes, analyzes and stores all the received mission data towards Situational Awareness, Common Operational Picture (COP), FRs safety and mission enhancement. It is consisted of three layers:

The lower one includes all the platforms for receiving and analyzing data coming directly from the field. **Sensors platform** receives and analyzes data coming from the FRs wearable sensors, **triage platform** [9] analyzes health data, while the **video platform** stores and analyzes the video stream from cameras (e.g. 360 camera, thermal camera etc.).

The middle layer is the intermediate architectural element that connects the low layer components with the higher ones. The heart of this layer is the **Data Format Fusion (DFF)**, where the universal data conversion is taking place, towards homogenized information for the higher level applications. In addition, the **Mission Critical Communication (MCX)** [10] and the v**irtualized resource allocation** platforms are utilized, offering group communication management and reliable cloud resource coordination (for the higher level applications that run in the cloud) respectively.

The higher layer is the interface between the officers and the available data. It is consisted of all the applications that offer situational awareness, COP and mission management as follows:

C&C Applications Framework: This component includes all the required applications for the officers to communicate with multiple emergency units on the field, and send the appropriate commands and feedback to the FRs, either to individual units/rescuers or to groups of them (e.g. firefighters only, paramedics only etc.). The input of this element is the data produced by the corresponding clients of these tools, running on FRs smartphones on the field, after being processed by the DFF. The data are then analyzed/evaluated and information is sent back to the FRs.

COP & Situational Awareness: While a lot of the technologies (e.g. AR devices, wearable sensors, infrared cameras etc.) implemented in the project are towards direction of providing situational awareness, this element of architecture includes all the functions that will optimize the provision of situational awareness and COP, bringing enhanced intelligence to the extraction procedure. It provides the officers with all the centralized necessary information for the mission, properly retrieved and layered in order to facilitate its efficient presentation. It minimizes false alarms and misuse of multiple resources, so to effectively off-load the officers from multi-data processing. This element gets its input from the DFF, collecting data from the field, and the outcome is either visualized on screens or is used as an input to the C&C center system element.

AR Framework: This architecture component provides human augmentation by enhancing experiences of real-world situations and offering advanced Situational Awareness and Early Warnings to FRs and officers. It includes all the mechanisms to ensure modularity, interoperability and seamless integration of different AR related modules towards a unified AR experience. It receives data from the corresponding clients software that run on FRs smartphones, through the DFF (for data homogenization) and sends output to the C&C applications, COP and Situational Awareness architecture elements.

Smart Fleet Management: This architecture element applies the required mechanisms to successfully fulfill autonomous drone fleet operations, either in Visual-Line-of-Sight (VLoS) or Beyond-Visual-Line-of-Sight (BVLoS). It is based on Machine learning/AI-based techniques for semi-autonomous UAV/UGV missions, including path planning, fleet navigation coordination, fleet crash avoidance, even mission security and deviations alert. It takes input directly from the unmanned vehicles on the field, without any data processing in the DFF, in order to keep the latency and the error probability as low as possible. The output is the autopilot of the unmanned vehicles for direct and real time navigation, while the telemetry data (e.g. drones position, altitude, speed etc.) are also sent to the DFF in order to be available to other elements of the system, like the COP, the C&C applications or the AR platform.

Anomaly Detection: This architecture entity implements the mechanisms for security monitoring and analysis of the network, in order to prevent attacks form exterior hackers. It is a human-interactive visual-based anomaly detection system that is capable of monitoring and promptly detecting several devastating forms of security attacks.

Data Visualization: Not only COP, but other functions require data visualization, like smart fleet management, AR technologies or the video platform. So, on top of the three layers, is placed the visualization component that includes all the screens for either combined and generic or specified visualization of the received information from the field and the output of the mobile C&C tools functions.

Fast and reliable communications are essential requirements for the RESPOND-A ecosystem, not only as means of emergency personnel communications, but also for devices interconnection and data exchange. The **communications infrastructure** uses cellular technology (4G/5G) for creating a connectivity "bubble" in the wider incident area, offering local broadband network coverage, even if the public communication infrastructure is out of service. While alternative connectivity solutions are also offered (e.g. WiFi, dedicated microwave links etc.), the main implemented technology is the 5G network, for enabling all the complex and demanding, in terms of bandwidth, reliability and latency, operations of the RESPOND-A ecosystem. Besides establishing a local 5G network, this architecture element offers connectivity to the public network, acting as a gateway to the internet and the FRs remote headquarters, when it is possible.

While the core of the RESPOND-A system is the deployable platform, which offers the connectivity and the mechanisms for effective mission enhancement, management and unit coordination, the technologies that are implemented on the field are responsible for the generation of the data that enable the safety and situational awareness of the operating FRs. Specifically the field tools are:

Wearable sensors: FRs wear a specialized vest, embedding multiple sensors (e.g. health, environmental, etc.) monitoring the health, the status and the environmental condition, sending continuously data to the mobile C&C center through the 5G network.

Tracking system: Utilizing UWB technology [11] and UAVs as anchors (or fixed points when UAV flight is not feasible), the tracking system extracts the human position, especially indoors, where the GPS signal is not available.

Triage system: It collects victims' health data and related info from the field and passes them further to the RESPOND-A ecosystem, wirelessly, utilizing cellular or LAN connectivity.

Augmented Reality (AR): FRs use AR applications like AR goggles, thermal cameras or smartphones running AR client applications, for enhancing their operational effectiveness. The client applications communicate with the mobile C&C center in the van, contributing to situational awareness and COP.

Mission Critical Communications (MCX): These are the client applications of the C&C applications, for direct group communications and teams' management. It runs on the FRs smartphones, exchanging data with the corresponding mobile C&C center using the local (or public) 5G network.

Autonomous Unmanned Vehicles (UAVs/UGVs): UAVs and UGVs operate at the emergency area, embedding specialized equipment, like thermal or 360 cameras and software, like autopilot and mission security for supporting the operations. Telemetry and control is realized through the 4G/5G cellular network (local or commercial), or Iridium satellite if the cellular coverage does not exist. Collected data are received by the C&C center, which runs algorithms and offers situational awareness to officers and FRs.

Each architecture component (e.g. AR framework, C&C applications framework etc.) is consisted of multiple technologies and tools, either working all together or acting as individual, according to the use case scenario. While the work is still in progress, some of the tools are on the final development stage, allowing the consortium to organize an early trial, presented in the next chapter, for testing the technologies and earn feedback from the end users.

IV. Field Trials

In June of 2021, an early trial (using tools not fully developed yet) was held in Athens, Greece, simulating the rescue of a trapped person, in a damaged building, after a severe earthquake. The scenario involved fire and heavy smoke inside the building.

In such a real life scenario, various emergency units (e.g. firefighters, police, paramedics etc.) would need to first detect the damaged building, then to enter in it and under very bad visibility conditions (because of the heavy smoke) and safety danger (fire, collapsed building) to detect the trapped person, to evaluate his condition and rescue him. Critical mission elements like units communication and coordination, interior visibility, safe pathway, health evaluation and rescue time are the challenges that the FRs face and, according to the

Fig. 3. Respond-A mobile Command & Control center

operational requirements research (chapter II), are the ones that suffer most.

RESPOND-A tested how its platform answers the above challenges. According to the trial scenario, after the earthquake and the calls for damaged building and trapped victims a UAV takes off, scanning the wider area and detecting the Region of Interest (ROI). A mobile van, equipped with the RESPOND-A platform, approaches as much as it cans to the ROI and deploys the platform. The action runs as follows:

- The van deploys the 5G base station and covers the operation area with communication network.
- A UAV takes off and transmits real time video of the operation area to the command center, in the van. Officers have aerial picture of the operation.
- The FRs are equipped with a smartphone, running a communication platform for being able to communicate directly with the officers and send/receive data. The command center, utilizing the same communication platform, creates groups of emergency units and coordinates them.
- The FRs are equipped with a sensorized vest. The wearable sensors continuously monitor the vital signs of the FR as well the environmental conditions and sends data to the van. If something goes wrong, an alarm goes off and the officers act accordingly.
- The FRs are equipped with a thermal camera, attached to their smartphone. They can see the image for the camera on the mobile screen, while the picture is also sent to the officers in the van, through the local 5G network.
- The FRs are now ready to enter the building. Having enhanced vision (using the thermal camera) and being guided by the officers in the van, navigate into the damaged building, under heavy smoke and detect the victim.
- The command center coordinates the rest of the operating units towards the rescue of the victim and the transportation to the hospital.

Fig. 3 shows the emergency van, hosting the 5G base station and the mobile C&C center. A panel antenna on a mast offers network coverage, with a radius of about 300-500 meters (depending on the environment and the signal amplification [12]).

After the trial action, a separate session was held for discussing the tools implementation and operation with the FRs. The feedback that they provided was that the tools of RESPOND-A platform offered them significant help to their mission, enhanced their capabilities and maximized their safety. The most critical assets were the uninterrupted fast communications and direct mission management from the mobile C&C center, located close to the incident area. Their main concern was the feasibility of using sensitive devices (e.g. smartphones, AR-glasses etc.) during operations in harsh conditions, like fires, especially when they need to wear gloves or hold other equipment.

V. Challenges and Future Work

Situational Awareness in terms of boosting Early Assessment, Safety Assessment, and Risk Mitigation capabilities, together with the clear COP and the optimal management of operations at any scaling and complexity of disasters are the key factors for advanced and modern rescue missions. In this paper, after discussing about the methodology of extracting the FRs mission needs, the system architecture of the RESPOND-A project was presented along with an early trial of some of the project technologies.

The need to coordinate multiple and heterogeneous operation teams on the field, answering their requirements in different use cases, demands a multilayer system approach involving multiple technologies that must work together, towards a unified platform suitable and friendly to the end-user. The large scale and complexity of the overall system and the diversity of technologies and requirements involved is the main challenge of the RESPOND-A project.

Although the proposed system successfully assisted the FRs during the early trial, the project tools and technologies integration should further be developed for being ready to effectively support real rescue missions (the project technologies are still under development).

But even when the proposed system will be fully developed, there will be still cases where it will not be so efficient. For example, during a forest fire extending to a lot of kilometers or a severe earthquake in a city, multiple and different emergency units (e.g. paramedics, police, fire fighters etc.) need to operate, not only in a defined small area, but across the whole length of the incident. In such cases, a

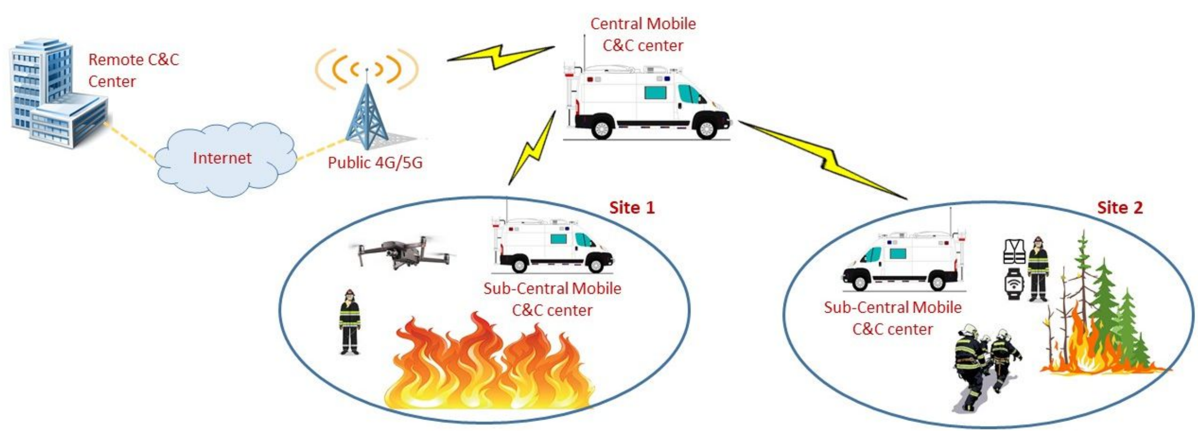

Fig. 4. Cooperated multiple mobile Command & Control centers concept

mobile van is not capable of efficiently handling the whole operation. Not only the range of 5G coverage created by the van base station is not adequate, but also the big numbers and variety of operational units and the amount of data, may cause difficulties to the mobile operational center in only one van. Moreover, if the van faces an unexpected malfunction, then the whole operation management collapses.

As an answer to such circumstances, a solution with multiple mobile coordination centers, interacting and coordinating with each other, could be studied and implemented. Fig. 4 shows a ubiquitous FRs operations management concept, with multiple vans, all connected to each other, acting as sub-centers, all coordinated by a central one, which either can be located close to the incident area or further to a remote site.

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