The 5G-supported Unmanned Aerial Vehicles for Emergency Cases Response

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Abstract – **In this paper, it is analyzed the general UAVs development and their advancement with the Fifth-generation technology standard for broadband cellular networks (5G network), as well as real-time video streaming and other tools deployed for UAV use cases in the context of EU project RESPOND-A. Practically, the paper provides the case study with simulated risk realization events in which were used UAVs supported by 5G network modems, communication terminals, and 4K 360º video cameras with social viewing tools. Especially for advancing operational and surveillance capacities for SAR missions and environment protection, UAV assets are supported by the recent introduction of the 5G network, which enables a continual flow of information between them and shore-based rescue coordination centers. Such a manner would comprehend the integrated UAV data collecting capabilities, their transmission via the next generation of wireless communications, and seamless video and audio data provision, aiming to raise the level of situational awareness.**

Keywords - UAV; 5G; emergency; SAR; real-time video streaming, social video viewing, immersive video;

I. Introduction

In extending situational awareness to provide efficient and cost-effective responses to various maritime and land emergency cases, are used versatile Unmanned Aerial Vehicles (UAVs), UxVs applications, and different autonomous assets. Their key importance is reflected in obtaining timely information and persistently monitoring the current situation at the incident area. As an important support asset to maritime and land surveillance, especially when dealing with emergency cases that require persistent monitoring of water areas where an incident occurred, the UAVs are more often used for safety, security, environmental, recognition, surveying, disaster response, and other missions. Therefore, the UAVs are continuously developed in compliance with the latest advancement in mobile networks such as 4G and 5G, which is of crucial importance for mission-critical communications, increased situational awareness, and consequently the efficiency of maritime actions in the required area. The 4G/5G cells support UAV devices and together with satellite communication provide detailed real-time situational pictures which facilitate the decision-making process for responsible maritime and land authorities and first responders on the scene. In such a way, the advanced UAVs operate over 5G networks, as a cost-effective solution for surveillance and real-time actions, bringing significant benefits to national maritime authorities in terms of image accuracy, video streaming, crisis management, damage assessment and evaluation, instant, and timely information flows, as well as support for the decision-making process. The UAVs are also used for visual inspection because of their increasing availability and outstanding camera guiding capabilities, but the primary goal of their applications in Search and Rescue (SAR) operations is to detect, recognize and retrieve subjects in the lowest amount of time feasible [1].

The UAVs used in safety and critical missions for rescuing or surveillance of sea-polluted areas, wildfires, inspection, surveillance, natural disasters, or other security purposes, are mostly designed for long ranges, with a significant number of sensors, and certain payload capacities, depending on the purpose type and conditions at sea or land. Therefore, they are able to fly at great heights and over long distances [2]. Also, the range of capabilities and operations depends on the level of autonomy of UAVs, so there are 4 main types of classification: a remotely controlled system, an automated system (preprogrammed), an autonomous non-learning system (fixed built-in functionalities), and autonomous learning system (able to modify rules of behavior).

The aim of this paper is to provide a review of recent developments of UAVs in the context of their performance and functionalities using 5G network communication. Therefore, the paper unfolds as follows: after introductory considerations, paragraph II provides an analysis of the current development of the 5G network applied in maritime mission communications; paragraph III reviews 5G-based UAVs and their contribution to maritime SAR purposes. Finally, paragraph IV gives a case study of a SAR pilot with testing of UAVs capabilities deployed under the EU RESPOND-A project, while the Conclusion gives overall remarks on the topic.

II. Recent UAVs developments in the context of surveillance and search and rescue actions

Related to various maritime and land SAR and other emergency missions both at sea and land, in the recent project trials the three models of UAVs proved to be very efficient for required levels of operation, whether it is surveillance from higher layers of the atmosphere or tactical operation and monitoring in close vicinity from the accident location. These three models are:

(1) the AR3 Net Ray Unmanned Aerial Vehicle (UAV), a fully autonomous UAS with 10 hours of flying capacity and a communications span of up to 80 km, recovered by parachute and airbags or with a net system that is specifically designed for maritime operations;

(2) the AR5 Life Ray Evolution, a medium-altitude, and medium-endurance, fixed-wing UAS conceived and constructed for supporting SAR tasks and long-range intelligence observations (up to 16 hours of flight duration and a communications span of 100 km using Radio Line-of Sight (RLoS) means, or unlimited using satellite communications (SATCOM));

(3) the Zephyr UAS, a High Altitude Pseudo-Satellite (HAPS) that co-operates among satellites, manned aircraft and UASs with an operating altitude of about 21 km [3].

The main strengths of these UAVs are lightness and high seeing, sensing, and communication capacities, as well as the ability to provide better information quality and sharing. The complexity of the UAVs makes them more vulnerable. The significant operational feature is the possibility to approach the areas of high risk for humans, while one of the threats is the collapsing of the UAVs due to severe weather conditions/harsh environments [4]. Another important aspect of UAV development is its improvement in terms of integration with embedded AI modules for detecting, recognizing, and tracing the objects at sea with the ability to instantly transmit the information to ground stations and related data lakes for further processing [5].

In a harsh weather environment, as assumed, the wind can be a big challenge to run the UAV appropriately in SAR and surveillance missions, since it can reach more than half of the UAV's airspeed causing the mission to stop. In order to consider the influence of wind on UAV's kinematics, the Coordinated Turn model has been set up and analyzed in reference [6] complying with IAMSAR manual requirements. This method also involves the probability of containment distribution function over the searching area, with the aim that all SAR facilities be equally and precisely identified.

III. 5G NETWORKS' CURRENT DEVELOPMENT APPLIED IN UAV MISSION-CRITICAL PURPOSES

The 5G New Radio (NR), as a current global generation of advanced mobile network communication, is able to facilitate the following features [7]:

- eMBB (enhanced Mobile Broadband), with a peak data rate from 10 to 20 Gbps, 100 Mbps whenever needed, 10000 times greater traffic, Macro and small cells support, High mobility up to 500 km/h, and network energy savings by 100 times.
- mMTC (massive Machine Type Communications) enables the functioning of a high density of devices (about 2 x 105 - 106/km^2), supports a long-range, has a lower data rate (about 1 to 100 Kbps), leverages the benefits of the ultra-low-cost of machine-to-machine (M2M), offers 10 years of battery life and provides asynchronous access.
- URLLC (Ultra-Reliable Low Latency Communications) provides ultra-responsive connections, 1 ms air interface latency, and 5 ms end-to-end latency between UE (i.e. mobile) and base station, it is ultra-reliable and available 99.9999% of the time, ensures low to medium data rates (about 50 Kbps to 10 Mbps), high-speed mobility.

Considering that 5G also allows usage of non-terrestrial networks, like satellite networks, and device-to-device (D2D) communications without network coverage, i.e. using sidelinks, many other maritime services can be based on 5G networks. To mention a few, these are:

- Search and Rescue missions (getting information from different Internet of Things (IoT) sensors in real time, communication, and accurate localization of ships or people in distress),
- Ship-Shore communications (within Vessel Traffic Monitoring and Information System – VTMIS and for assistance to navigation operations),
- autonomous vessels (5G low latency connectivity is essential for remote operation and management),
- predictive operations/maintenance enabled by artificial intelligence (AI),
- digital twin fed by real-time Big Data coming from heterogeneous sources,
- smart UAVs/drones with high-definition (HD) video streaming and monitoring of the situation in real-time, supported by System Intelligence (SI) and Edge Intelligence (EI) concepts ([3],[4],[8],[9]).

Also, related to network advancements, the 4G Long Term Evolution (LTE) significantly supports all kinds of surveillance aerial users and UAV applications. Its most important performance is latency with a round trip time of 127 ms and a standard deviation of 48 ms for the most negative case scenario. This showed the capability of UAV running in operations using the LTE network with a low altitude of up to 100m.

Furthermore, existing LTE networks used for support of UAV deployment with low density and low altitude are confirmed by Third Generation Partnership Project (3GPP) investigations [10]. In the complex environments, under which maritime, coastal, land operations or any other rescue mission can be considered, the growing number of UAVs deployed in on-site actions, requires the development of new technologies to enable cellular-connected UAVs with air-ground interference avoidance and comprehensive 3D aerial coverage.

Also, the mission-critical requirements in maritime and land SAR actions could be fulfilled using the UAVs together with high-capacity mobile cellular communication systems, based on LTE networks, which enable low latency for all command-and-control devices and ground platforms. In the analysis made by [11], the LTE link is used for critical and high-volume traffic with higher power usage and wide availability of high-quality modems, which enable heterogeneous traffic of data and information with varying requirements. This approach resulted in a resource-guaranteed channel access scheme that provides low latency down to a value of 6 ms, with high reliability.

Furthermore, every UAV integrates several sensors, which provide many functionalities. The most important ones are exact position and height (using a GPS), the ability to find a home and to return (managed by remote control by a human pilot), the transmission of data and information collected via sensors, mostly from HD, infrared or thermal cameras, which require an appropriate storing capacity, connectivity with the ground station and immediate streaming of the video and information to land operational pilot. The mentioned functionalities as a prerequisite have the interconnection enabled by 4G Long Term Evolution (LTE), 5G (as an advancement of 4G LTE), and Very High Frequency (VHF). In this way, data and information are instantaneously transmitted and represented over pilot command and control interfaces with visualization and management of surveilled situations, providing First Person View (FPV), as it is in real-time [2].

An interesting use case for UAVs in maritime and any other emergency environment is its utilization as support for providing wireless network coverage during a crisis by acting as a flying wireless base station in the case when the ground station is not working. In such a way, many UAVs' use cases can assist the 5G NR to focus on the minimization of path loss, atmospheric attenuation, and enhancement of the data rate.

Especially, the UAV can be of significant support for providing the communication link between the vessel in the deep sea being far away from the coast. Thus, the UAVs can be incorporated into the operational framework for establishing wireless networking communication links between distant base stations and also extending the 5G cellular network. Also, this type of UAV base station can be deployed using an intelligent machine-learning system like the generalized regression neural networks model, evidencing the improvement of quality of Service (QoS) and energy efficiency ([7],[12]).

IV. Case study: UAV capabilities deployed within pilots of EU project RESPOND-A

1. UAVs and terminals covered by 5G

Technologies such as UAVs and reliable connectivity amid a disaster scenario are crucial for First Responders to ensure a timely reaction. In the RESPOND-A project, technical partner *Atmosphere* GmbH participated as a technology provider bringing in UAVs, including a connectivity solution called PLANET, to demonstrate the effectiveness of UAVs and 5G connectivity in rescue missions (Fig. 1). *Atmosphere* took part in two pilots of the RESPOND-A project, where one was a simulation of a forest fire, which took place in Cyprus and the other was a simulation of an oil spill caused by the crash of two trucks demonstrated at the port of Valencia, Spain.

PLANET is a connectivity terminal that is flown on the drone and shares onboard data to the ground via a 5G link, which was used for the demonstrations. PLANET provides connectivity from the ground to the UAVs in the air. It is capable of providing both cellular and satellite network services. *Atmosphere*'s drones are a fleet of two octocopters ATMO1 and ATMO2 (Fig. 2), one used as a replacement. ATMO1 is a 92-cm wide, 4.7kg octocopter, that has the capacity to carry a payload of 2-3kg, with a total flight time of 8 minutes. ATMO2 is a 130cm wide, 9 kg octocopter, which has the capacity to carry a higher payload of about 4-5 kg.

The octocopters are self-built, allowing for more flexibility for the integration of the payload on the drone during the integration phases of the project. Customizable drones proved to be of great value as they ease mounting various types of payloads such as cameras and sensors, by making modifications to the dimensions and weight of the drones. Additionally, both octocopters can be flown in manual mode or autonomously with the presence of a licensed pilot.

Figure 1: PLANET connectivity solution flown onboard the UAV (Source: own)

In preparation for the pilot demonstrations for the RESPOND-A project, several flight tests were carried out to test the calibration, and wind speed and to determine the total flight time by increasing the payload gradually.

The UAV and its payload are powered by two batteries. ATMO1 was the choice of UAV that was flown in the Spanish pilot for the demonstration of the rescue mission and an oil spill at the Valencia port. *Atmosphere* has a 5G base station that is capable of providing a 5G network as a stand-alone device, additionally, it is capable of integrating with external 5G cores to set up a 5G network.

In the case of the RESPOND-A project, the 5G base station, which is an Amarisoft callbox mini (Fig. 3) functioned as a 5G radio access network and integrated with a partner's 5G core device.

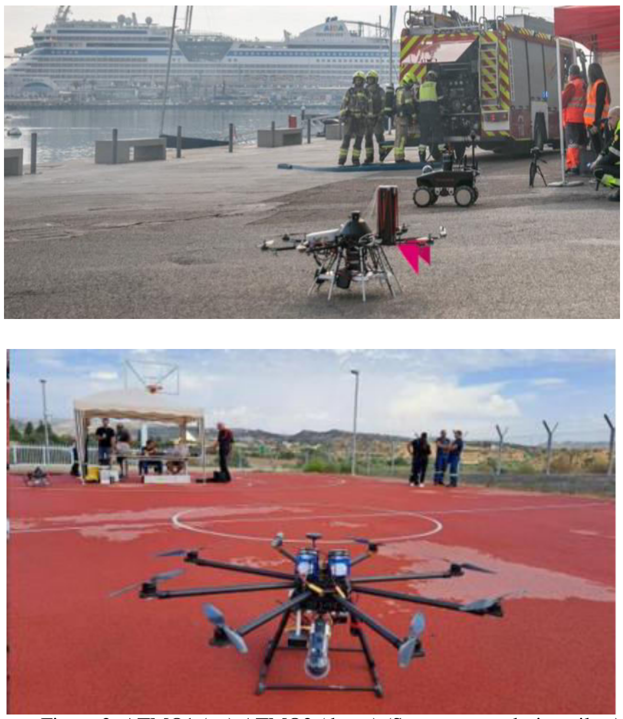

Figure 2. ATMO1 (up) ATMO2 (down) (Source: own, during pilots)

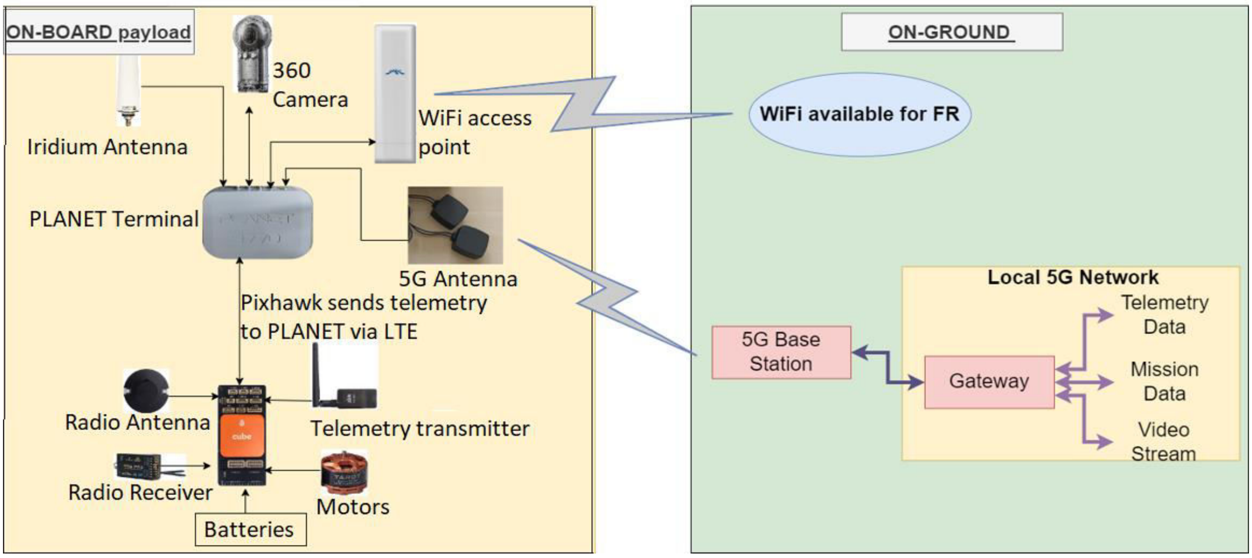

Figure 6. UAV air-to-ground communications (Source: own)

A remote radio head was additionally used to enhance the 5G signal strength, as the main idea of the 5G network deployment was to demonstrate the radiation of a reliable 5G network over >1000m^2 for the use case locations, aiding first responders to be able to reach the 5G network over certain distances around the disaster zone during a rescue mission.

In order to make use of the remote radio head (RRH) and the 5G antenna, certain hardware modifications had to be made, where the Software-defined radio (SDR) card of the Amarisoft callbox mini had to be replaced.

Figure 3. 5G Radio Access Network (Amarisoft callbox mini) (Source: own)

The 5G antenna covers an area of a few hundred meters providing 100+ Mbps of bandwidth, however, these specs are dependent on the characteristics of the area, as certain obstructions can certainly tamper with the RF signal quality of the 5G link radiating from the antenna.

The remote radio head with the 5G antenna is connected to the 5G base station over a long fiber optic cable. Such a setup allows the connection of the 5G network over long distances. In the demonstrations of the pilots at the simulated disaster zones, the 5G base station was set up in the command and control center, with the 5G antenna connected outside the building of the command and control center as visualized in Figures 4 and 5 (in the Cypriot use case).

The UAV flies with *Atmosphere*'s connectivity solution, the PLANET terminal, used as a processing unit for all the UAV onboard components (VR360 camera, Wi-fi access point, telecommunication via 5G link, and satellite link). The PLANET terminal has an integrated 5G modem, which receives a 5G signal through two 5G antennas connected to the terminal. UAV payload air-to-ground architecture is displayed in Figure 6.

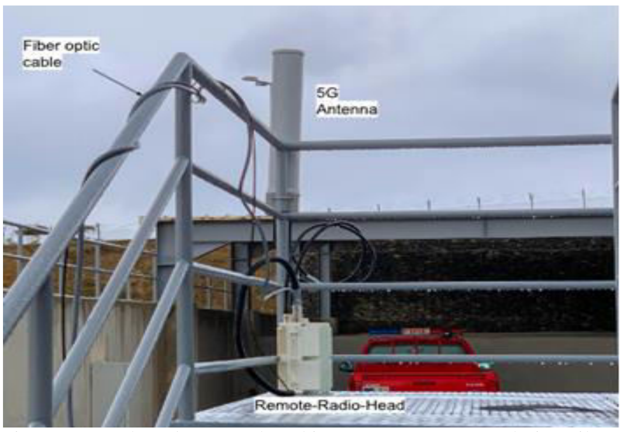

Figure 4. Out-door 5G network architecture (Source: own, during pilots)

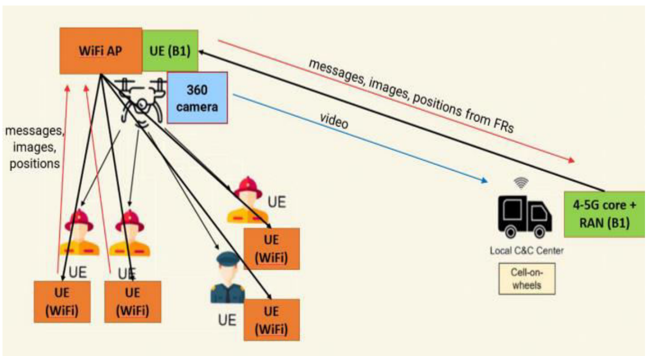

Figure 5. 5G local network infrastructure (Source: own)

On-board data from the UAV, the live video stream, and telemetry data for live localization are sent to the PLANET ground server via the 5G link, and it forwards the data to the command and control tools, to be visualized on the screens (Fig. 6). The camera onboard the UAV connects to the PLANET terminal via an ethernet cable, the camera can then be accessed from the ground via the 5G link. PLANET forwards the video stream from the camera to the processing station on the ground in Command and Control Center (C&C) (Fig.7).

The Wi-Fi access point integrated on the drone, cabled to the PLANET terminal via Ethernet provides Wi-Fi connectivity through the 5G uplink. The main purpose of this feature was to demonstrate to first responders the added communication means to the command and control center, where they are able to send pictures, messages, and other key information under the local Wi-Fi bubble of connectivity provided by the UAV.

Figure 7. Live video stream sent over 5G from the on-board camera (Source: own, during Cyprus pilot)

2. Interactive social 360º viewing for SAR missions

Beyond doubt, the availability of real-time and high-resolution video from emergency and/or surveillance missions, like SAR, can provide huge benefits in terms of safety and decision-making. In this context, 360º videos can provide added value compared to 2D video given relevant facts, like (i) the whole omnidirectional area is captured (and not just a given field-of-view as in directive 2D cameras); and (ii) 360º videos can be watched on Virtual Reality (VR) headsets, allowing for a natural omnidirectional inspection, with high levels of realism and presence (i.e., the feeling of being there, inside the captured scenes).

In this context, recent studies have shed some light on the potential advantages provided by 360º videos compared to traditional 2D videos in education and health sectors for examination of information of interest ([13],[14]).

Real-time and low-latency video streaming from UAVs is currently a technical challenge due to the typically restricted and varying communication (in terms of coverage, and bandwidth availability…) channels between flying UAVs and reception entities on the ground. This challenge is magnified if high-resolution (e.g., >=4K) and immersive video scenes need to be provided. This challenge can be overcome by making use of the latest-generation (e.g., 5G-powered) communication networks and equipment.

Although being provided with 360º video scenes of interest in real-time already provides remarkable benefits, such benefits can be magnified if multiple video feeds can be provided and dynamically selected, and even further if the video feeds are concurrently made available to multiple geographically distributed first responders for collaboratively inspecting the target mission or environment. In this context, recent studies have shown multiple benefits provided by social viewing tools and scenarios, in a variety of use cases, like entertainment and education ([15],[16],[17]).

In response to the existing scientific evidence and gathered user-centric requirements, an interactive social viewing tool for multi-cam 360º videos has been designed and implemented to support SAR missions. In a nutshell, the tool provides a set of technical and interactive features to maximize the benefits in this sector:

- Use of web-based technologies. This maximizes the chances of ensuring cross-platform and cross-device support and eliminates the need for any installation and/or update on the client device to use the tool.
- Low-latency and adaptive streaming capabilities. Provides adapted versions of video streams according to the device being used and the available bandwidth, including to remote consumers via IP networks.
- Free omnidirectional exploration for each deployed 360º camera.
- Dynamic selection of the camera of interest, minimizing switching delays in a synchronized manner (i.e. guaranteeing that video feeds from the different cameras refer to the same time).
- Zoom in / out for each of the video feeds.
- Support for watching on 2D screens (e.g., desktops, laptops, videowalls, smartphones) and 3D VR headsets.
- Availability of text, audio, and video chat channel between the users involved in the mission. Any of these chat modalities can be enabled and disabled, based on needs and preferences.
- Remote users' viewports awareness and selection. Indicates what camera and region of the 360º video the other involved users are watching and is able to select that viewport with just one click (e.g. if another user has detected anything relevant).

Figure 8 shows a UAV equipped with a 4K 360º video camera, connected to a 5G-powered communication terminal. Figure 9 provides a capture of a first responder using that tool to inspect a simulation of an accident in a port area and an associated fuel spill.

A demonstration video of three first responders using that tool in the depicted simulation can be accessed at: https://www.youtube.com/watch?v=hMOAj9Hh1uw. The tool and associated demonstrations have been developed under the umbrella of the EU H2020 Respond-A project (https://respond-a-project.eu/).

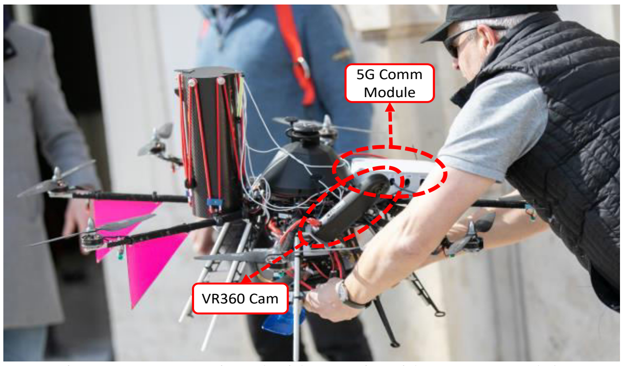

Figure 8. UAV equipped with 4K 360º video camera and 5G communication module (Source: own, during Valencia pilot)

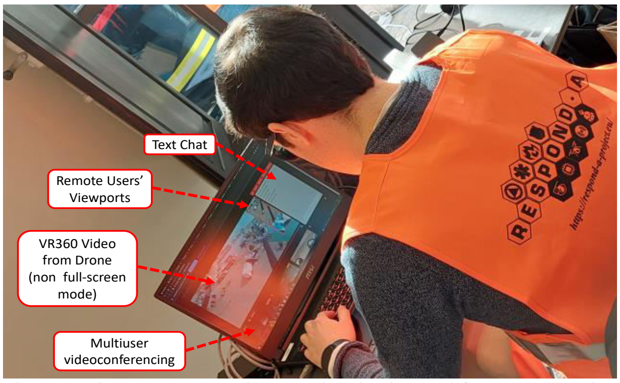

Figure 9. First Responder using a social viewing tool for a collaborative examination of a SAR mission (Source: own, during Valencia pilot)

V. CONCLUSION

The paper shows the overview of the recent developments in UAV capabilities supported with a 5G network, used for enhancing surveillance and control over marine or land areas where disasters, accidents, or environmental risks might occur. The latest advancements in UAVs provide significant support to operating FRs' organizations in SAR actions while the current 4G and 5G mobile networks enable high-quality mission-critical communication, data, video, and relevant information sharing, as well as the use of various types of sensors, devices and equipment, contributing to overall high situational awareness and broader operational picture.

The 5G networks significantly enhance the performance of UAVs making them the most appropriate assets for various emergency use cases. An additional enhancement to overall UAV performance is provided by end-to-end 360° video cameras mounted on the drones with real-time messaging and live streaming protocols ability, interconnected with a 5G powered on-board terminal (PLANET) aiming to show a single 360°, high-resolution panoramic video of surveilled areas. This jointly contributed to efficient communication between involved FRs and C&C centers raising the operational preparedness of all stakeholders. The results of this approach are advanced monitoring and mission-critical communications over 5G with improved response in emergency, safety, security, SAR, and environmental issues, as proved by pilots of the RESPOND-A project.

Finally, further work on this topic will elaborate on the integrated approaches of using the 5G network to cover various applications in maritime environments including mission-critical communications, data sharing, and advanced IoT systems.

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REFERENCES

[1] V.S. Ajith, K.G. Jolly, "Unmanned aerial systems in search and rescue applications with their path planning: a review", Journal of Physics: Conference Series, 2021, Vol. 2115, pp. 012020.

[2] R. Fiedler, C. Bosse, et al., "Autonomous Vehicles' Impact on Port Infrastructure Requirements", Fraunhofer Center for Maritime Logistics and Services CML, Hamburg, April 2019.

[3] S. Bauk, N. Kapidani, Ž. Lukšić, F. Rodrigues, L. Sousa, "Review of Unmanned Aerial Systems for the Use as Maritime Surveillance Assets", 24th Conference on Information Technology (IT), 2020.

[4] S. Bauk, N. Kapidani, et al, "Advantages and disadvantages of some UAVs deployed in maritime surveillance", 8th Int. Conf. on Maritime Transport, Barcelona, 2020, pp. 91-102.

[5] Z.Paladin, N. Kapidani, P. Scrima, G. Vosinakis, et al., „Maritime information sharing environment deployment using the advanced multilayered Data Lake capabilities: EFFECTOR project case study", Journal of Maritime Research, Vol. 36(2), pp. 291-304.

[6] F.A. de Alcantara Andrade, A Hovenburg, L. Lima, C. Rodin, T. Johansen, R. Storvold, "Autonomous Unmanned Aerial Vehicles in Search and Rescue Missions using real-time cooperative model prediction control", MDPI Sensors, vol. 19, 4067, 2019.

[7] M. Mahbub, „UAV Assisted 5G Het-Net: A Highly Supportive Technology for 5G NR Network Enhancement", EAI Endorsed Transactions on Internet of Things, Volume 6, Issue 22, 2020.

[8] S. Lins, K. Cardoso, C. Both, et al., "Artificial Intelligence for Enhanced Mobility and 5G Connectivity in UAV-Based Critical Missions", IEEE Access, Vol.9, pp. 111792 – 111801, 2021.

[9] Z. Paladin, E. Fountoulakis, Ž. Lukšić, N. Kapidani, D. Ribar, G. Boustras, „Advanced Mission-Critical Communication in Maritime Search and Rescue Actions", 27th IT Conference, 2023.

[10] Z. Miličević, Z. Bojković, „From The Early Days Of Unmanned Aerial Vehicles To Their Integration Into Wireless Networks", Military technical courier, 2021, Vol. 69, Issue 4, pp.941-962.

[11] Ph. Gorczak, C. Bektas, F. Kurtz, Th. Lubcke, Ch. Wietfeld, „Robust Cellular Communications for Unmanned Aerial Vehicles in Maritime Search and Rescue", 2019 IEEE Symposium SSRR.

[12] R. Alfaia, A. Souto, E. Cardoso, J. Araújo, C. Francês, „Resource Management in 5G Networks Assisted by UAV Base Stations: Machine Learning for Overloaded Macrocell Prediction Based on Users' Temporal and Spatial Flow", Drones 2022, 6, 145.

[13] F. Hekele, J. Spilski, S. Bender, T. Lachmann, "Remote vocational learning opportunities—A comparative eye-tracking investigation of educational 2D videos versus 360° videos for car mechanics". British Journal of Educational Technology, 53(2), 248-268, 2022.

[14] Y. Chao, C. Kang, H. Chuang, et al. "Comparison of the effect of 360° versus two-dimensional VR video on history taking and physical examination skills learning among undergraduate medical students: a randomized controlled trial". Virtual Reality, 2022.

[15] F. Boronat, M. Montagud, P. Salvador, J. Pastor, "Wersync: A web platform for synchronized social viewing enabling interaction and collaboration". Journal of Network and Computer Applications, 175, 102939, 2021.

[16] S. Rothe, A. Schmidt, M. Montagud, D. Buschek, H. Hußmann, "Social viewing in cinematic virtual reality: a design space for social movie applications", Virtual Reality, 25(3), 613-630, 2021.

[17] M. Montagud, J. Li, G. Cernigliaro, et al. "Towards social VR: evaluating a novel technology for watching videos together", Virtual Reality 26, 1593–1613, 2022.