Wi-Fi 6 Aerial Relay Node for Emergency Operations

Michael C. Batistatos
Department of Informatics and Telecommunications
University of Peloponnese
Tripolis, Greece
mbatist@uop.gr

Michail-Alexandros Kourtis
Institute of Informatics and Telecommunications
National Centre for Scientific Research "DEMOKRITOS" (NCSRD)
Athens, Greece
akis.kourtis@iit.demokritos.gr

George K. Xilouris
Institute of Informatics and Telecommunications
National Centre for Scientific Research "DEMOKRITOS" (NCSRD)
Athens, Greece
xilouris@iit.demokritos.gr

Dimitris Santorinaios
Institute of Informatics and Telecommunications
National Centre for Scientific Research "DEMOKRITOS" (NCSRD)
Athens, Greece
dsantorinaios@iit.demokritos.gr

Andreas Oikonomakis
Institute of Informatics and Telecommunications
National Centre for Scientific Research "DEMOKRITOS" (NCSRD)
Athens, Greece
a.oikonomakis@iit.demokritos.gr

Emmanouil-Zafeirios G. Bozis
Department of Informatics and Tecommunications
University of Peloponnese
Tripolis, Greece
mbozis@go.uop.gr

Ioannis D. Moscholios
Department of Informatics and Telecommunications
University of Peloponnese
Tripolis, Greece
idm@uop.gr

Nikos C. Sagias
Department of Informatics and Telecommunications
University of Peloponnese
Tripolis, Greece
nsagias@uop.gr

Anastasios Kourtis
Institute of Informatics and Telecommunications
National Centre for Scientific Research "DEMOKRITOS" (NCSRD)
Athens, Greece
kourtis@iit.demokritos.gr

Abstract— **Reliable and ubiquitous communications, offering high data rates, low latency and supporting large numbers of connected devices, are critical requirements for modern emergency rescue missions. Multiple teams of First Responders, operating at remote areas, on rough terrain or under harsh conditions (e.g. wildfires, earthquakes, flooding etc.) need seamless connectivity to send/receive mission data and organize their operations. This paper, based on the communication platform of RESPOND-A project for supporting First Responders' missions, proposes a communication relay architecture for extending the 5G network, covering network gaps or underserved areas, while still supporting the mission requirements. Preliminary field measurements were also taken for providing a proof-of-concept and evaluating the systems' performance.**

Keywords—first responders, 5G network extension, 5G relay, Wi-Fi 6

I. Introduction

In cases of catastrophic natural events (e.g. forest fires, earthquakes, flooding etc.) or severe accidents (e.g. multi-vehicle collisions, oil spills etc.), multiple units of First Responders (FRs), like firefighters, police, paramedics or volunteers, try to reach the emergency area and perform rescue actions. Efficient units' coordination and maximum situational awareness are the key aspects for a successful mission.

European Union (EU), taking account the constantly increasing demand for effective rescue missions, tries to boost both FRs efficiency on the field and operations management by funding a number of research projects. RESPOND-A is a scientific research project [1], funded by EU HORIZON 2020 program [2], targeting to leverage FRs mission efficiency and safety, offering innovative technological tools for situational awareness maximization, clear common operational picture provision and effective mission management.

One of the first and most important tasks of the project was to acquire the FRs requirements and needs for their missions. According to the collected data and the received feedback, todays rescue missions lack of reliable fast communications and ubiquitous units coordination, which are critical for the success of the mission, especially under harsh conditions and at remote areas,. If communications fail, then everything else collapses. RESPOND-A answers the FRs needs by proposing a novel platform, offering continuous local connectivity on the field and efficient units coordination, even when the public communications are out of service or not available (e.g. remote areas, damaged communications infrastructure, overloaded network etc.).

However, even when the public network is still available or the RESPOND-A platform provides local connectivity in the wider emergency area, there are still cases where communication gaps exist or there is a demand of more bandwidth, especially at the cell edge or in remote areas. And these are mostly the cases where the FRs need communications and mission coordination more than ever. In this context, this paper, based on the RESPOND-A platform, suggests an architecture for reliably extending the network coverage during emergency rescue missions, while still meeting the mission network requirements for fast and guaranteed communications, both between the operational units and the officers at the operations center.

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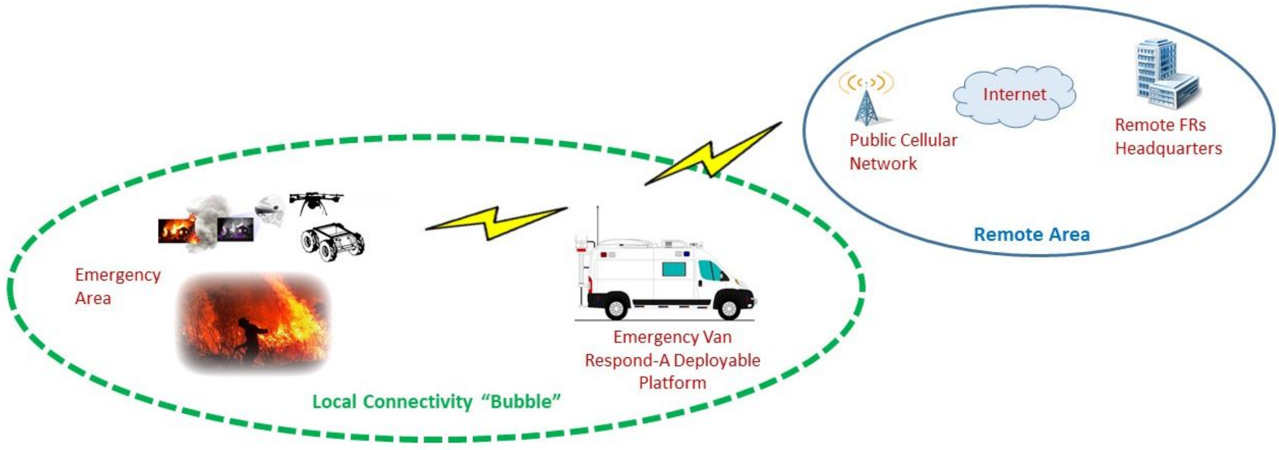

Fig. 1 Conceptual diagram of RESPOND-A platform

Chapter II presents the conceptual RESPOND-A system architecture for reliable communications and mission coordination, chapter III discusses the proposed relay architecture, chapter IV analyzes the field measurements and chapter V concludes the paper, summarizing the results and discussing future work.

II. RESPOND-A CONCEPTUAL ARCHITECTURE

Fig. 1 shows the conceptual approach of RESPOND-A system. The multiple operating units on the field are coordinated by a mobile Command and Control (C&C) center, hosted in a van that approaches the emergency area. The officers in the van, having proximity to the incident, directly manage the mission, without trying to reach the FRs at distant operational areas or communicate with multiple operational distributed centers. In order to achieve efficient and reliable mission coordination, the van utilizes a deployable 5G base station that creates a private connectivity "bubble" in the emergency area, offering wideband communication network and guaranteed Quality of Service (QoS). The operating units on the field and the officers in the van, using novel equipment and applications, exchange mission critical data (e.g. sensors data, tracking information, audio/video stream etc.) through the provided 5G local network, exploiting the autonomous operational system. In addition, the mobile 5G base station is capable of connecting to the public network, when a link is available, offering connectivity to the internet and reaching remote headquarters [3].

However, considering the large size of a remote operational area (e.g. wildfire), the landscape variety (e.g. buildings, trees, hills etc.) and the harsh conditions (e.g. rain, fire, smoke etc.), ubiquitous network coverage is a challenge. Even when a local connectivity "bubble" is provided, connectivity gaps still exist and higher QoS is required at specific spots. The utilization of network relays, covering the underserved areas would be a solution. During an emergency rescue mission though, the communication gaps are not predefined. The rescue units will possibly experience unexpected communication failures and they will ask for network support on spot. So, not only the relay node should still serve the pre-existing FRs requirements (e.g. high data rates, adequate QoS, data security, large devices number support etc.), but also should be implemented on demand, directly and fast, as every second counts, without interfering with the already existing 5G cellular network (public or local).

III. PROPOSED SYSTEM

Due to the requirement for fast and direct response in rescue missions and the variety of operational characteristics and environments – every mission is different – not only the technology of the relay system is important, but also its ability to work efficiently in every rescue scenario. The deployment of the relay should be flexible and capable of be transferred to the appropriate position for optimized relay services. Based on the initial RESPOND-A platform (Fig.1), a second vehicle, carrying the relay equipment, could move to the appropriate location and provide network extension. As ground vehicles mainly move only on certain routes and free from obstacles roads, a flying aircraft (e.g. UAV, balloon etc.) offers a more efficient solution for demanding missions, as it can move fast and accurately to the desired position, without ground restrictions [5]. In such a case though, more system parameters should be considered, like the relay device weight, the power consumption, the flight plans and the transmission range. At the same time, the emergency relay device, should be embedded to the existing mobile network as a new physical node, without interfering with the rest of the deployed network.

Fig. 2 shows the proposed architecture for relaying data during emergency situations, suitable for fitted on UAVs. The selected relay physical node is a Wi-Fi 6 device, capable of connecting to the 5G cellular network (using it as a backhaul link) and offering a Wi-Fi coverage for accessing the users.

Wi-Fi 6 is the latest version of the wireless networking protocol by Wi-Fi Alliance [6], based on IEEE 802.11ax

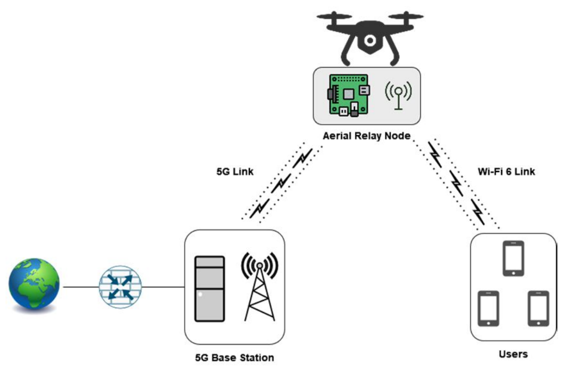

Fig. 2 Wi-Fi 6 relay system

standard [7]. Using orthogonal frequency-division multiple access (OFDMA) [8], multi-user multiple input multiple output (MU-MIMO) [9] and operating at frequencies between 1GHz and 7.25GHz, offers high data rates, low latency, multiple devices support and low power consumption (long battery life). Thus, a Wi-Fi 6 relay has all the potential to support the FRs requirements for high data rates, comparable to already deployed 5G local network of the van, massive UEs connectivity and low latency. In the suggested architecture, the Wi-Fi 6 relay is connected to the RAN side of the ground 5G Base Station (BS) as a normal UE. So, no interference exist between the BS and the relay node, as the Wi-Fi 6 device uses different technology and frequency bands to reach the users. In addition it is a battery powered, lightweight device, that can be easily fit and carried on even a small UAV.

IV. Field Measurements

In the context of proof-of-concept assessment, the proposed architecture was implemented and preliminary measurements were taken. Specifically, the throughput and the latency both of the system downlink and uplink were measured, in relation to different received signal strengths.

The 5G BS that was used, supports stand-alone (SA) mode and a flexible Time Division Duplex (TDD) transmission scheme [10]. The latter offers the ability of allocating different time slots to the downlink and uplink channel, for asymmetrical deployment option and various enhanced Mobile Broadband (eMBB) slicing requirements [11]. However, in a rescue mission scenario, both the C&C center and the operating teams on the field send a variety of data (e.g. video stream, high resolution pictures, massive sensors data etc.). So, both the downlink and uplink performance is of high priority. Thus, the TDD scheme that was selected for the preliminary set of measurements, assigned the same number of timeslots for the downlink and uplink channel, for providing adequate data rates to both of them.

As the relay node moves to different locations and away from the ground 5G BS, its reception level of the 5G signal changes, due to free space loss or other obstacles. Four different Reference Signal Received Power (RSRP) levels were used, evaluating the system under different network conditions, according to table 1.

In these preliminary measurements one UE was used. Prior to the actual system performance evaluation, reference measurements were held, evaluating the performance of the existing 5G BS when the UE is directly connected to it, without the use of the relay node.

Signal Strength / Conditions	RSRP (dBm)
Excellent	≥ -80
Good	-90 to -80
Cell Middle	-100 to -90
Cell Edge	≤ -100

Table 1 Received signal strength in relation to propagation conditions

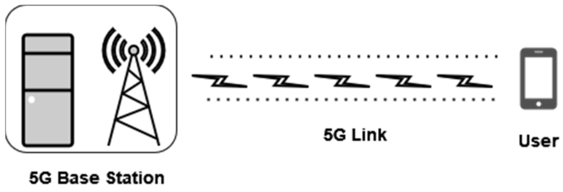

Fig. 3 Reference measurements system setup

A. Reference Measurements

Fig. 3 shows the setup for the reference measurements. The 5G UE is directly connected to the portable 5G BS of RESPOND-A platform. As the user moves towards the cell edge or obstacles exist between the BS and the UE, the signal strength decreases. The throughput and latency of one user was measured, for four different levels of received signal strength. A total number of 35 measurements were recorded for each RSRP level, resulting averaged values for the throughput of the uplink and downlink.

Fig. 4 shows that the maximum system throughput is 95 Mbps and 78 Mbps for the downlink and uplink respectively, while the performance decreases as the signal strength weakens, reaching the low values of 48Mbps and 34,5Mbps for RSRP level of -110dBm.

The RTT of the system, depicted in fig. 5, is in the range of 10,45msec to 11,16msec and it is considered almost stable for all the different levels of signal strength.

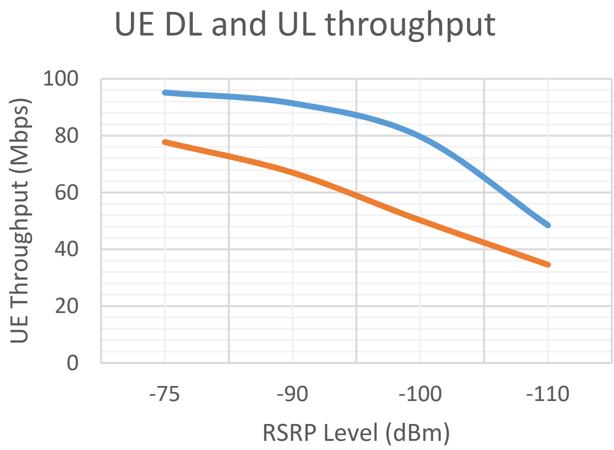

Fig. 4 UE throughput for downlink and uplink channel

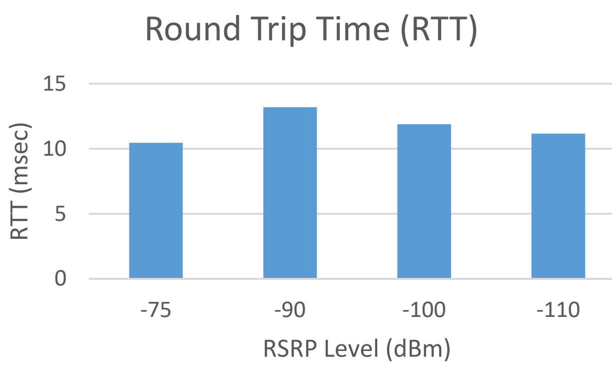

Fig. 5 Round trip time of reference system

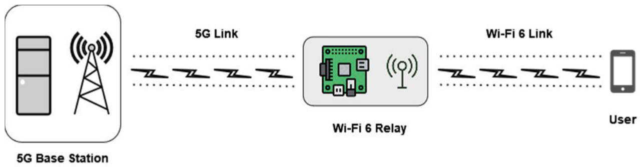

Fig. 6 Wi-Fi 6 relay system measurement setup

B. Proposed system measurements

Fig. 6 shows the setup for the performance evaluation of the proposed system. For the purpose of proof-of-concept evaluation, the relay physical node was placed on the ground, between the 5G BS and one UE, at different distances, experiencing various levels of signal path loss.

Throughput and RTT measurements were performed for four different levels of RSRP (i.e. -75dBm, -90dBm, -100dBm and -110dBm) at the 5G interface of Wi-Fi 6 node and for four different levels of Wi-Fi signal strength reception of the UE, simulating various transmission conditions. Each presented throughput and RTT value is the average of 35 instant measurements.

Fig. 7 shows the achieved throughput at the downlink channel. The colored lines correspond to different received Wi-Fi signal levels at the UE side, namely 100% signal strength (~ -34dBm), 75% (~ -60dBm), 60% (~ -70dBm) and 45% (~ -80dBm). The diagram shows that when the W-Fi signal level is more than 45% and the RSRP values more than -100dBm, the DL throughput level of the UE is in the range of 75 to 95Mbps. When both the RSRP and the Wi-Fi signal decrease, the throughput drops to lower values, with RSRP reduction affecting the throughput more severely and rapidly, resulting to very low data rates of almost 20Mbps, independently of the Wi-Fi signal reception level.

The uplink channel follows the same behavior, as it is depicted in Fig. 8, with maximum throughput values of around 80 Mbps, for good reception conditions. The maximum uplink bit rate drops to almost 60Mbps for bad Wi-Fi signal reception, while the throughput falls under 25Mbps at the cell edge (RSRP ≤ -110dBm).

Fig. 9 shows the RTT of the system. It fluctuates in the range of 11,5msec to 14msec, with most of the values being close to 12msec. It seems that there is no any derived pattern for the RTT in relation to the signal strength, as the latency fluctuation is relatively small and does not follow any rule.

The analysis of the aforementioned measurements shows that the proposed network extension architecture successfully relays data from/to remote users, achieving comparable data rates to the initial 5G network implementation of RESPOND-A platform. When the Wi-Fi signal does not suffer severe losses, both the uplink and downlink throughput is similar to the throughput of the direct UE-BS connection scenario. When the Wi-Fi signal reception is bad, the throughput drops almost 20Mbps, but still is capable of providing adequate bit rate. Lower RSRP values affect the overall system performance, resulting to throughput values below 25Mbps, while the corresponding throughput values in the case of direct

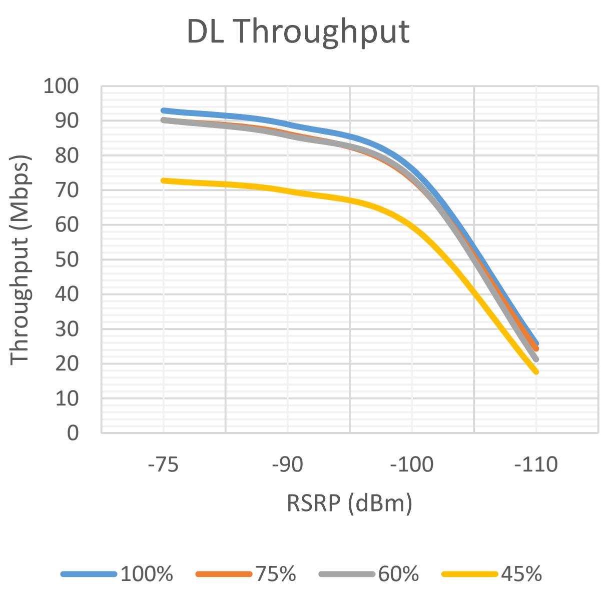

Fig. 7 Throughput of the downlink channel

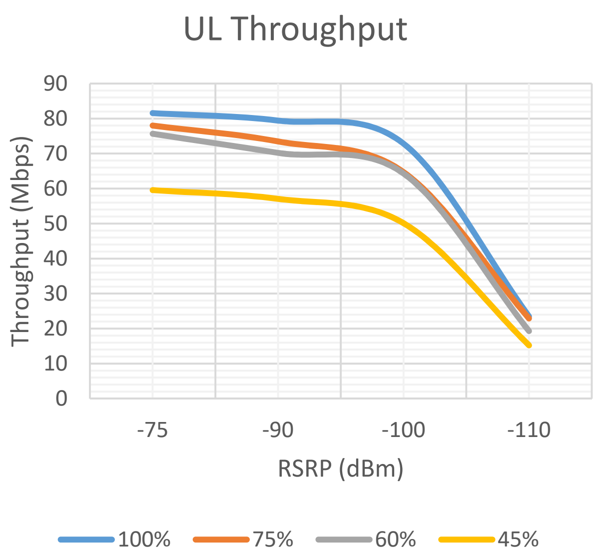

Fig. 8 Throughput of the uplink channel

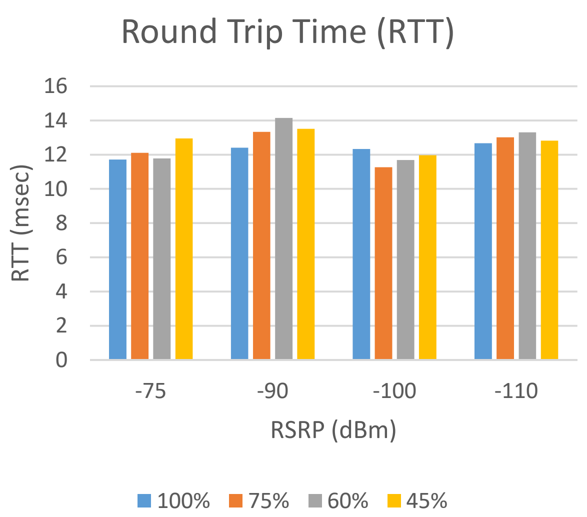

Fig. 9 Round trip time of the proposed system

5G BS-UE connection, are 48.5Mbps for the DL and 34.5Mbps for the UL.

The RTT of the proposed system is slightly higher than the one of the reference system, but this is expected, as one more network hop is added, when the relay node is used between the 5G BS and the UE. However, the additional latency is in the range of 2msec, so the system performance is not significantly affected.

V. Conclusions

Ubiquitous, reliable and fast communications are critical for the effective coordination of rescue missions in emergency situations. RESPOND-A project utilizes a portable 5G BS for creating a connectivity "bubble" in the incident area, supporting the needs of FRs. However, due to ground obstacles and large scale operations, there are still underserved areas like at the cell edge or at blind spots. This paper proposes a lightweight relay system for expanding the already implemented 5G network, fast and effectively. The relay node is a Wi-Fi 6 device capable of connecting to the 5G network as a network node and relaying data to the users through Wi-Fi 6 technology. Different access and backhaul frequencies and technologies (i.e. Wi-Fi 6 and cellular 5G) offer an interference free network extension, while the small size and weight of the relay device allows even a relatively small UAV to carry it, flying directly to the optimized locations.

Preliminary measurements were performed for assessing the feasibility of such a system. Measurements analysis showed that the proposed system throughput, both in DL and UL was close enough to the initial implementation (direct connection between 5G BS and UE), still achieving high bit rates and satisfying the initial mission communication requirements. The added system latency was not more than 2msec, so the extra network hop does not significantly affect the overall network performance.

As the Wi-Fi 6 is mainly intended for indoor usage, more measurements campaigns should be held, simulating various environments, propagation conditions and use cases for better evaluating the range and the performance of a Wi-Fi 6 device, as a relay node in a 5G cellular system. Furthermore, as a UAV could be potentially used to lift and transfer the device to the appropriate locations, more system parameters should be evaluated, like power consumption, antennas radiation patterns and cellular signal interference.

Acknowledgment

The research work presented in this article has been supported by the European Commission under the Horizon 2020 Program, through funding of the RESPOND-A project (G.A. no. 883371)

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