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On the Involvement of IEEE 802.11ah Enabled Unmanned Aerial Vehicles (UAVs) in Emergency Networks

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***Abstract*—In this work, a practical evaluation for IEEE 802.11ah enabled Unmanned Aerial Vehicles (UAVs) is carried out. The proposed aerial devices can be involved and help significantly in dealing with natural disasters, by providing extended network capabilities in long distances. The major advantages of those developed emergency networks are indicatively the easy deployment, the low power consumption and the dynamic wide extension. In contrast with prior approaches which solely based on simulations, in this work the experiments are conducted with the use of real IEEE 802.11ah network adapters and drones. Finally, the examined experimental scenarios reveal the realistic limits of the aforementioned wireless protocol, which constitutes the main criterion for whether this can be used in emergency scenarios.**

***Index Terms*—UAVs, IEEE 802.11ah, Wi-Fi HaLow, Natural Disaster Scenarios, Emergency Networks, Internet of Drones**

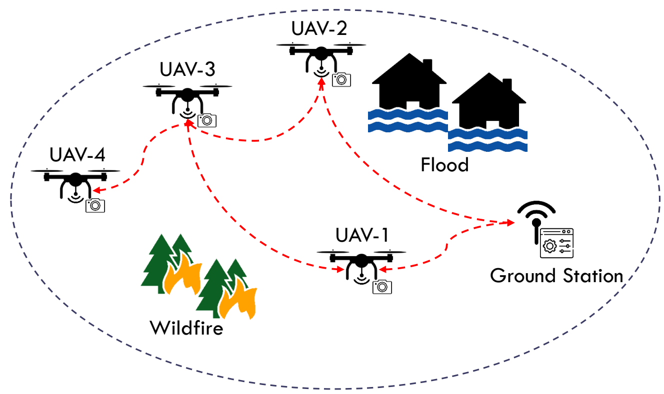

Fig. 1. Internet of Drones (IoD) example architecture.

I. INTRODUCTION

During the past decade, the world witnessed several severe natural disasters like earthquakes, hurricanes, wildfires and floods. Devastating consequences were caused by them, such as loss of life, displacement of people, destruction of properties and economic losses. As the climate change is believed to be a major factor contributing to the frequency and intensity of some of these disasters, these phenomena are expected to be further intensified in the future. Thus, strategic planning and readiness from governments, organizations, and individuals, is required in order to face these disasters efficiently and minimize the consequences. Modern wireless networks play an important role there, by increasing the real-time information exchange between the involved entities (Police, Fire Departments etc), that operate during and after the natural disasters hit. Several approaches have been proposed [1] for such kind of situations, as they offer important advantages compared to fixed network infrastructures, which their operation is highly prone to failures. This is mainly due to the fact that fixed base stations (BSs), are operating with wired power and networking supplies. On the other hand, IoT networks are easily developed by providing the capability of dynamic expansion and may include nodes with very low power consumption profiles.

The Internet of Things (IoT) concept appeared and widely established in our daily life, partially as a posible solution to the aforementioned problems. The proposed IoT architectures typically consist of several physical network devices, vehicles and home appliances, which carry sensors and software, that enable the collection and exchange of data over the internet. This mainly revolves the idea of interconnecting various objects and devices, in order to create a smarter and safer world. This connectivity allows the real-time communication between devices, by also enabling the ability to monitor and control them remotely. All the data collected by IoT devices, can be used for numerous purposes such as improving the communication efficiency, reducing monetary costs, and enhancing public safety.

Alongside with the evolvement of the IoT application scenarios [2], several communication protocols [3] were also appeared for achieving the desired communication between the involved wireless nodes. Indicatively, there is plethora of different IoT approaches, which include Point-to-Point, Star and Mesh communication topologies. In the vast majority of them, one or more Gate Way (GW) nodes are involved, which undertake to forward through the internet, the collected measurements from all nodes for further processing. Additionally, each IoT communication protocol is operating under a wide range of parameters, resulting in different transmissions coverage and data rates. It is worth to be noted, that both licensed (NB-IoT [4]) and unlicensed (LoRaWAN [5], XBee [6], IEEE 802.11ah [7]) spectrum frequencies are used depending on the specific IoT communication protocol, with different channel bandwidths which vary from narrow (KHz) to wide (MHz). Thus, the achieved data rates can be differentiated from a few bits per second (bps) to several Mbps, depending on the requirements of each target application.

UAVs have been increasingly involved in natural disaster response efforts, due to their ability to quickly and efficiently gather important information and thus improve situational awareness. Indicatively, UAVs (drones) participate in search & rescue as well as at damage assessment scenarios, through the establishment of communication networks in disaster-stricken areas and where traditional communication infrastructure has been damaged or destroyed. Utilizing UAVs in natural disaster scenarios is vastly preferred, both because they operate under high mobility profiles, as well as they can approach impassable or hazardous areas with zero human life risk.

The context of this work is to initially examine and experimentally evaluate, how IEEE 802.11ah wireless adapters perform, when they are deployed in actual UAVs. To the best of our knowledge, this is the first work which takes into consideration real-world environments and experiments, since the research approaches proposed so far, are solely based on simulation results [8]. Through the proposed Internet of Drones (IoD) architecture, we foresee to discover per link, the realistic limits of the aforementioned wireless protocol and estimate if this is capable of being applied in specific natural disaster scenarios. The remainder of this work can be summarized as follows. Initially, Section II describes all the Hardware and Software components, which are used in the proposed work. Furthermore, Section III and IV, contain the experimental set-up, scenarios, as well as the the results arose from them. Finally, Section V concludes the work and present possible extensions.

II. Framework

In this work, we focus on utilizing IEEE 802.11ah wireless interfaces on UAVs, for deploying emergency networks in natural disaster scenarios. To the best of our knowledge, this is the first development of real IEEE 802.11ah enabled UAVs. The specific protocol is being selected among others, as it offers several enticing advantages. First of all this is considered to be a long-range standard, as it promises coverage areas of up to 1km [9], which of course is directly correlated with the transmission configurations such as the power, channel bandwidth (BW), Modulation and Coding Scheme (MCS) used, antenna gain etc. Large emphasis was also given on the protocol's achieved throughput, as the search & rescue scenarios which are considered in this work, highly depend on network hungry live video streaming and real-time image processing mechanisms. These network requirements, can not be fulfilled in any case in such distances, from alternative IoT protocols like LoraWAN and xBee, as they only achieve up to some Kbps throughput. However, the main reason for deploying drone prototypes with IEEE 802.11ah adapters instead of using commercial aerial vehicles, is not only the performance which can be achieved per link in long distances. These drones utilize open-source software, which under proper configurations and alongside with the high throughput achieved, may lead to a swarm of networked drones that is able to operate and act autonomously without external human interactions.

Fig. 2. Developed drone kit.

A. Hardware

This section contains a short description for the hardware, which is involved in the under test architecture. Initially the NXP-HGDRONEK66 drone development kit [10], is being used as the basis for deploying all the peripherals of the proposed system. Under proper configurations, a Raspberry Pi 3 Model B [11] has been deployed in the drone, which carries the IEEE 802.11ah wireless adapter [12] with a Newracom NRC7292 chipset [13]. In the context of this work, conventional 868MHz omni-directional antennas with 3dBi gain are installed both in the drones and in the Ground Station (GS) as well. Finally, the Raspberry companion computer is being fed directly from the drone's Power Distribution Board (PDB), through a 14.8V to 5V voltage regulator. The developed under test aerial hardware is depicted in Figure 2.

B. Software

The NXP drone kit comes with a RDDRONE-FMUK66 Flight Management Unit (FMU), which is supported by the well known, open source PX4 [14] flight stack. Except from the conventional functionalities given from the PX4, additional customized software was built on the Raspberry Pi side, in order to collect additional useful information during the system's evaluation. More specifically, timestamped GPS coordinates, the drone's velocity and the relative altitude are retrieved periodically from the FMU to the Raspberry PI, which are connected through a USB cable. Finally, with the use of conventional Linux commands on the companion compter, we are able to log also the Received Signal Strength Indicator (RSSI) of the IEEE 802.11ah adapter. All the aforementioned measurements are contributing to the evaluation of the proposed system, as described in Section IV. It is worth to be noted, that such kind of configurations in the open-source software of the utilized FMU, can be translated as messages and exchanged between the involved aerial vehicles in an IEEE 802.11ah network. These kind of messages can trigger any desired action in each drone participates in the network.

In the following sections, an analytical description is given both for the experimental setup and the evaluation results, which were conducted in the context of this work. Through these experiments, the proper operation of the examined protocol and its ability to take part in various emergency operational scenarios is proved.

III. Experimental Setup

In order to evaluate the proposed hardware, two nodes were utilized in the context of this work, which are connected in a conventional Access Point (AP) to Station (STA) mode. More specifically, the examined architecture contains a GS which is fixed in zero altitude / velocity and a drone functions at various relative altitudes and with different configurations for the link's channel bandwidth as well. The primary goal for this work is to observe the performance of a single IEEE 802.11ah link under various scenarios, in order to verify the suitability of this technology in natural disaster conformation. It is worth to be noted that the maximum examined distance between the GS and the flying node is 1km in all the following scenarios. However, this distance may be easily increased if additional nodes join the architecture and operate in a mesh network mode, which is supported out of the box in the IEEE 802.11ah protocol. Four different scenarios were executed in order to examine the proposed solution. More specifically, the relative altitude difference between the GS and the drone was either 35m or 70m (Table I - Column 2), with channels of 1MHz and 2MHz wide. Additionally, the moving vehicle's velocity was configured to 6.6m/s (23.76km/h), thus covering the distance of 1km in 150 seconds (2.5 minutes). It is worth to be noted the results which are given in Figure 3 as well as in Table I represent only the one-way from 0-1000m away and not the round-trip for the UAV. Finally, at all scenarios examined, the GS and the UAV were operating under Line-of-sight (LOS) conditions.

IV. Experimental Results

Figure 3 represents the analytical results for all the four scenarios executed. At the top, the throughput achieved for each configuration is represented. At the bottom, the RSSI values captured during the experimental execution between the GS and the UAV are depicted as well. The throughput measurements were retrieved and recorded through the use of the Iperf [15] software. More specifically, the server side of the iperf was employed in the GS and the client side at the UAV. In such way, the UAV was practically the transmitter of the network. Additionally, the throughput demands for the iperf client side were static and configured to 2.5 Mbps and 5 Mbps, for 1MHz and 2MHz channel bandwidths accordingly. The average throughput achieved from 0-1000m and the minimum value of the RSSI captured at each case, are stated in Table I.

The following observations may be extracted based on the experimental results retrieved. Initially, at 1MHz scenarios and for both relative altitudes configured, the link achieves on average 82% (1.85 Mbps) of the demanded throughput, up to the point that the UAV moves away from the GS to 500m. At the same distance range of 0-500m, the case for 2MHz is that the link achieves on average 67% (3.35 Mbps). A difference which may be spoted between the two aforementioned cases, is that at 1MHz, it seems that the altitude does not affect the performance, as the link performs the same for both 35m and 70m. On the other hand, at 2MHz channels the performance is slightly lower at 70m altitude scenario. Furthermore, for the second half of the experiment (500-1000m) the following observations may be exported. Regarding the 1MHz scenarios, it is now obvious that the altitude affects at a small extent the performance achieved. On the contrary, in the case of 2MHz the performance is now nearly equal, except from the distance range 700-830m, in which slightly higher performance is achieved at 70m.

TABLE I
Experimental Results

Bandwidth	Altitude	Avg. Throughput	min RSSI
1MHz	35m	1.69 Mbps	-80 dBm
1MHz	70m	1.43 Mbps	-79 dBm
2MHz	35m	2.61 Mbps	-78 dBm
2MHz	70m	2.56 Mbps	-82 dBm

V. Conclusions and Future Work

In this work, a primitive evaluation for the IEEE 802.11ah protocol was conducted through the utilization of UAVs. In conclusion, the system responded successfully and with stability to all the scenarios that were executed. The throughput achieved for all scenarios in the examined distances, is much higher compared to other conventional IoT protocols, like LoRaWAN and XBee (some Kbps). This allows the considered protocol to be used in a wide range of emergency scenarios, which may include real-time video streaming between the UAVs, image processing and autonomous commands and controls. Additional advantages of the proposed solution, are the extremely low cost of the deployed wireless adapters and the ability of convenient dynamic network expansion.

In the future, we foresee to examine further parameters for the proposed system. More specifically, it would be interesting to examine higher mobility profiles, in order to observe if this may affect the achieved performance. Furthermore, the increment of the examined distance and larger altitude differences between the evolved nodes, will be also interesting extensions to consider in future experiments both for LOS and N-LOS environments. Except from the UDP traffic which was used in order to evaluate the proposed framework, in the future additional services like live video streaming between the involved aerial nodes, is planned to be evaluated as well. Finally, as the examined protocol proved to be highly promising solution, we envision to convert our IoD architecture into a testbed oriented approach. In such a way, the centralized administration and monitoring of the involved UAVs will be enabled.

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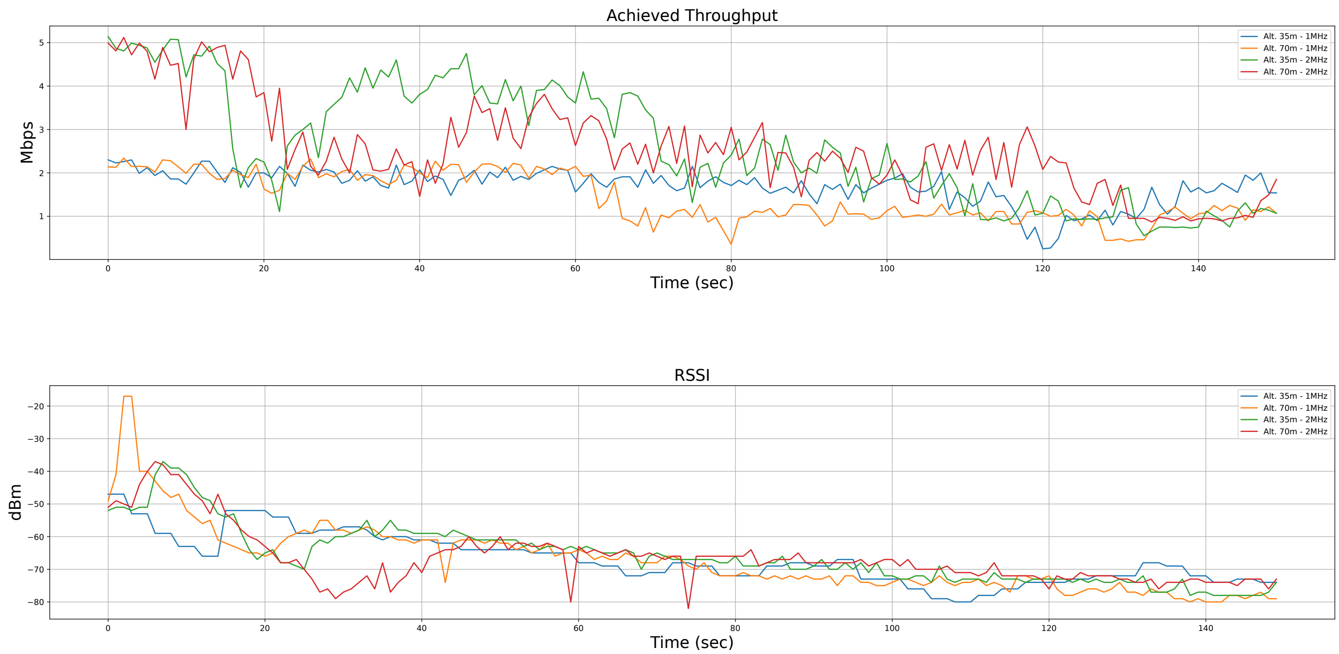

Fig. 3. Experimental Results.

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