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COMMUNICATION CONVERGENCE FOR IMPROVEMENT OF THE UNMANNED AERIAL SEARCH AND RESCUE MISSIONS

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Abstract:
Exponential progress in integrated circuits, best described by Moore's Law, has enabled tremendous advances in applied computing. Today, more than ever, there are palm-sized embedded devices with computational capabilities millions of times greater than those of what was once the lead computer on the Apollo 11 mission. Such levels of integration enable the fusion of functionalities that were once unimaginable, or at least impractical. Furthermore, today's existing technologies rely mostly on one or two communication technologies to organize UAVs for efficient search and rescue missions that largely do not utilize the communication convergence principle, thus omitting the potential for better search yield and rescue success. This paper recognizes that niche where communication convergence lacks its potential and presents a concept for the convergence of Wi-Fi, Bluetooth, LoRa and/or satellite IoT communication technologies to serve as an airborne communication infrastructure, a backbone generally, and enables a swarm of unmanned aerial vehicles (UAV) to communicate efficiently wherever there is no local terrestrial communication infrastructure (such as GSM, Wi-Fi, digital radio, etc.). The concept was elaborated and applied to a use-case localization application scenario (of Wi-Fi enabled devices) for the purpose of search during rescue operations.

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1. INTRODUCTION

In related works, numerous authors have proposed solutions that include different uses of UAVs to support the location of people during search and rescue missions (SAR) [1-3]. The recent development of UAV devices has enabled such a concept. The increase in UAV payload has enabled the installation of more and more electronic components on board. This has allowed for greater capabilities in terms of communication, sensing, and data processing. As a result, UAVs have become an increasingly valuable tool in SAR operations, allowing for more efficient and effective searches in difficult terrain or hazardous conditions. In the research paper [4], the authors hypothesized that it would be possible to deploy a swarm of unmanned aerial vehicles using communication technologies such as GPS, Bluetooth, and Wi-Fi to maintain their flight and formation and perform advanced search and rescue missions in remote areas to search for people with Wi-Fi enabled devices (smartphones, laptops, etc.). This innovative approach to search and rescue missions has the potential to revolutionize the field. By utilizing unmanned aerial vehicles equipped with advanced communication technologies, emergency responders can quickly and efficiently locate individuals in remote areas. The use of GPS, Bluetooth, and Wi-Fi allows for precise tracking and communication between the drones, ensuring they maintain their formation throughout the mission. In addition to locating individuals with Wi-Fi-enabled devices, these drones could also be used to survey disaster zones and provide real-

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time data to aid in rescue efforts. While there are still challenges to overcome, such as battery life and weather conditions, the potential benefits of this technology are immense. It could save countless lives and improve response times in emergency situations. In addition, authors in research [5] presented Wi-Fi communication technology that was used to ping and find terminals, with great success. By including additional communication technologies, such as Bluetooth or Bluetooth mesh technology [6], it can be used to synchronize UAVs and share data, and in synergy with GPS technology that is used to determine the location of each UAV, a tremendous localization potential is achievable. Furthermore, the use of this technology can also enhance the safety of UAV operations by providing real-time monitoring and control. It can also improve the efficiency of UAV missions by enabling multiple UAVs to work together seamlessly. The authors of those studies have presented some of the challenges as well as solutions to the problem in the current research. The research is largely based on the experiment presented by research [5], which provided a proof of concept using an ALIX x86 system board to ping and detect Wi-Fi devices at an effective range of 240 m and up to 15 m height (an optimal height). In the study [4], the authors propose an arbitrary search pattern and UAV formation but do not propose any inter-drone communication or real-time result uploading solution, so this search mission cannot be used in a time frame of up to one minute since their proposed approach requires manual data downloading once all UAVs have landed or returned to the initial location. The proposed UAV flight path was predefined off-site, a concept that the authors of this paper will maintain. In this paper, the authors propose an additional extension of the concept presented in study [5] and extended in study [4], in such a way that the UAVs will be able to communicate with each other by applying the principle of convergence of communication technologies. In addition, they will be able to communicate with a command center (CC) in near real-time once a target is detected, regardless of the UAV's location or possible (or lack of) terrestrial communication infrastructure. With defined upgrades, the proposed technology could greatly enhance search and rescue efforts.

The article is structured as follows: A detailed insight into UAV use, formation, and control for on-terrain surveillance missions is given in Section 2, along with the state of the art on the survey and the problem statement of current approaches and their benefits, or lack thereof. A proposed methodology for the communication convergence of currently available communication technologies, with emphasis on their uniting (converging), is laid out in Section 3, along with the resolutions and proposals for efficient data-path optimization and layer topologies in data exchange and its flow. A search and rescue mission using such a formed and controlled swarm of UAVs is the subject of Section 4, which applies the findings and solutions and then conducts application analysis. Furthermore, a discussion is given as a post-result analysis, where it is additionally discussed on the proposed use of technology by the authors in the paper [7], where it (LoRa) can be employed to utilize other available communication technologies (Satellite IoT network using Low Earth Orbit satellites) to reach CC while eliminating limitations when using such technology in terrestrial setups. The research also presented a comparative financial calculation when using the concept in real cases against the price of an average SAR mission.

2. RELATED WORK

The development of UAVs and their widespread availability have laid a good foundation for the development of new products and applications that address niches that were previously unknown. One such application is the use of UAVs in search and rescue missions, which has proven to be cost-effective and efficient. Additionally, the use of UAVs in SAR missions reduces the risk to human life by eliminating the need for human rescuers to enter dangerous or inaccessible areas. Such UAVs are often equipped with multispectral imaging, thermal imaging, surveillance, and other applications that are of use in a given situation, as described in research [8]. Furthermore, UAVs can cover large areas quickly and provide real-time data, making them ideal for disaster response and search and rescue operations. The use of UAVs in these missions has also been shown to increase the chances of finding survivors and reduce response times. Finally, among these UAV applications, the search and rescue niche has been the subject of numerous studies and is the main concern of this paper.

Several authors mentioned the use of Wi-Fi technology to locate Wi-Fi-enabled devices as a method for finding stranded individuals [9–11]. Some authors focused on the fact that a targeted device (a device of interest) regularly sends pings when searching for access points and wanted to exploit this technological fact to locate such a device (e.g., passive method). The work of research [4] clearly distinguishes between active and passive Wi-Fi search technology, a concept that is not widely used among authors of related work. The difference lies in the initiation of communication between the drone (UAV) and the target device, making the chosen method active. As previously mentioned, the majority of authors used a passive approach, assuming that the target device would send an active ping, which a drone-mounted communication array would then receive and process. This passive method was flawed because the UAV's time in the air (and time over a given point in space above the targeted Wi-Fi device) is limited, so the target device was expected to be on at the right time. Sending a ping at the right time was a risk factor that could make search and rescue impossible or significantly degrade search results. Instead, as suggested by research [5] and accepted by the authors of research [4], the active method should be used. The active method assumes that an active ping signal was sent from the communication network to the drone (UAV). It could and would be received by the targeted device, which would then respond to this ping. This method ensures an immediate response from the targeted device once it is within range of a pinging device (UAV). Since the Wi-Fi standard provides for 11 (14) available channels in the 2.4 GHz spectrum, a given device can use one of the channels at any given time. For this reason, a method has been described in research [4] to ensure that a ping drone always sends the correct ping on the correct channel so that the target device is able to send a response and be processed. As presented in research [7, 12-15], LoRa technology could be used in some cases to successfully detect a target device or to transmit information between different elements of the communication system. Like the previous research, they also used the passive method for Wi-Fi scanning and relied on LoRa technology for long range penetration to provide successful detection information. However, the mentioned study does not take into account a possible complex geomorphology that may hinder the LoRa signal from being sent to a listening station on the ground, as UAVs tasked with detection cannot fly too high although some authors suggest a higher flight altitude). In most of the research papers mentioned above, a clear case of data processing and logic for detection and transmission of data is presented without obvious limitations. In research [10], a similar consideration is made (based on the passive method), but the author adds an interesting layer of research that focuses on micro-location detection and triangulation of detected signals using a multi-pass method of UAVs. This approach works well for the micro-location of the target device but reduces the flight time of the UAVs and their overall coverage of the search area. In research [9], an innovative approach to search pattern and localization was presented by the authors. Emphasis was also placed on the technology used to build the communications system, as well as additional considerations for performance versus power requirements and area coverage using commercially available drones and devices. This was another example of a passive search method, where the communication field was divided into two segments (two Wi-Fi maps) for better communication with the target device. When searching outside the Wi-Fi spectrum, the research presented mainly cases where the search was in the visual or infrared (thermal) spectrum (apart from the agricultural application), adding beacon integration and cross-flight search patterns to better locate the person (the example of avalanche search and rescue). An example of such integration was presented in the study [16]. The study also highlighted the importance of real-time communication between the search team and the person being rescued. Additionally, the study emphasized the need for proper training and equipment for search and rescue teams to effectively carry out their tasks.

Among the research presented, the authors could not find any related work dealing with the active Wi-Fi search method in combination with the geographically secure communication method that would ensure the delivery of useful data to the CC (Command Center) independent of the terrestrial communication network infrastructure. This niche has been used to propose a novel solution that uses communication convergence to transfer information from one endpoint to another.

3. COMMUNICATION CONVERGENCE METHODOLOGY AND UAVS FORMATION TOPOLOGY IN LOCALIZATION AND RESCUE MISSIONS

The aim of this research was to investigate related work and technological solutions, especially in the last 2-3 years, trying to establish a commonality between the discovered research in terms of communication technologies used and finally proposing new communication technologies for maintaining end-to-end communication. A focus was placed on the active vs. passive search method in the edge layer and on the use of LoRa technology in the fog and cloud layers, with a critical overview of the approaches used in the referenced research. An innovative setup was designed and tested by selecting current products (UAV) and introducing new communication technologies (Satellite IoT for the cloud layer, LoRa for the obstacle-free fog layer) to transform the previously known setups from related research into an innovative setup that enables an uninterrupted communication flow without the existing terrestrial communication network. Finally, the research results were presented using known factors (cost of an average SAR mission, number of missions, etc.) to prove that the presented innovative solution is sound. The proposed solution was based on the best practice of active Wi-Fi scanning and the experimental solution presented by the authors in research [5] and swarm upgrades presented by the authors in research [4], adding new communication layers to ensure up-to-the-minute propagation of success detection information in a layered approach using communication convergence methods regardless of geomorphology (terrain). This paper does not address the actual flight speeds of UAVs, as this topic has already been discussed in detail. Usable flight speeds were defined as 5 m/s in the detection portion of the flight and as fast as possible in the non-detection portions of the flight.

The proposed solution is based on the use of multiple swarms of UAVs (horizontal) and divided into three communication layers (vertical), which together form a communication convergence:

- ***Edge Layer***; consisting of a ping and a detection UAV that flies a predefined search pattern for the targeted Wi-Fi device.
- ***Fog Layer***; consisting of the detection UAVs capable of transmitting status messages via LoRa technology to a master UAV at the site and via Bluetooth or Bluetooth mesh technology to other UAVs in the pattern.
- ***Cloud Layer***; consisting of master UAVs capable of sending status messages to the Internet Control Center via a low-earth orbit IoT satellite network.

Other UAV functionalities, control methods, or communication via proprietary protocols were not considered in this paper. An overview of the proposed concept in terms of communications is shown in Fig. 1.

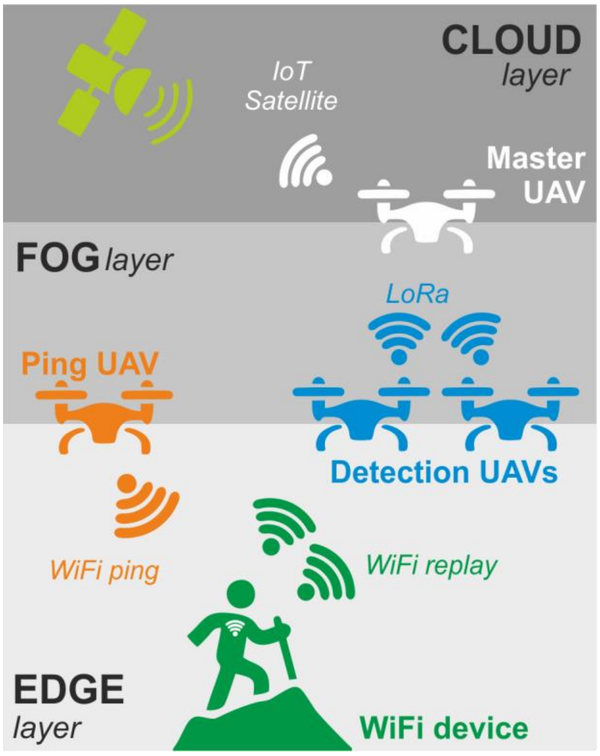

Fig. 1. High-level conceptual convergence design - communication overview with defined layers

The ***edge layer***, as presented in the research of [5] and [4], was used as it is, and this research did not contribute specifically to this layer. Since the publication of the cited work, new technology has become available that allows for some improvements in this segment of the communication field. As defined in [5], the target device was or could be tuned to one of the 11 (or 14) Wi-Fi channels in the spectrum. For this reason and to maintain adequate UAV movement speed, a multimodal ping device should be placed on a UAV so that it sends a ping on all 11 (14) Wi-Fi channels at once or cycles through them in the manner described in research [5]. This behavior greatly increases the chances of positive identification of a Wi-Fi target device in a shorter time. The target device would respond to the ping signal and reply on the same channel. At this point, the communication array on the board of the detection group drone (UAV) could detect the signal and relay the confirmation to the main drone. Communication within the swarm could be maintained via a Bluetooth communication protocol if needed, especially if faster coordination between UAVs is required (e.g., to maintain formation or to reduce or extend a separation distance since each UAV follows a pre-planned route but actual field conditions, such as wind or gusts, may be different for different UAVs). Upstream communication between the detection group UAV and the master UAV was maintained using LoRa communication technology. LoRa takes advantage of long-distance transmission and a relatively low speed and content capacity. In addition, LoRa is limited to 1% transmission time by a legal standard.

The communication layer between the UAVs in the detection group and the master UAV was considered the ***fog communication layer***. This means that additional computational and information processing has been moved to this layer. In addition to positive detection information, the fog layer devices can also exchange location data or mission completion data that can be uploaded to CC at any time or upon request via a master UAV. All communication in this layer occurs between UAVs and does not reach any external receivers. For this reason, no external or terrestrial infrastructure was required.

Upstream of the master drone was a ***cloud communication layer***. A master UAV transmits data to a control center via a satellite uplink. This method used as a use case (UC) for search and rescue missions, is often conducted in remote areas without any communications infrastructure. Since the success of the mission depends on the timely and accurate location of those in distress (targeted Wi-Fi-enabled devices), the information about successful identification should be transmitted without delay and over a channel that ensures connectivity regardless of location. Due to the cost, mass, and complexity of electronic devices, only one main drone was equipped with a satellite uplink communication array. Once information is successfully sent to the IoT satellite network, it is relayed to CC within minutes.

3.1 Edge layer structure and topology

In the entire formation and communication topology, there were two groups of UAVs that represented the edge layer of communication. Edge layer UAVs are arranged into:

- Ping UAV (group);
- Detection UAV (group).

These groups, as presented by the authors in research [4], had different functions within the presented solution, which included active search for Wi-Fi enabled devices. The ping drone or a group of drones was to fly ahead of the detection group in formation flight and send ping signals to the detection area, preferably from a higher altitude to enable better signal reception.

In the experiment conducted by the authors in research [5], an empirical limit of about 15 m above the ground was set for the detection drones to achieve successful detection in the range of up to 240 m using the system board ALIX with a 500 MHz CPU. However, this limitation did not apply to the ping group, since its main purpose was to transmit a wake-up or ping signal, which can be done from a higher altitude without the 15 m restriction. In the research presented by research [5], the authors also addressed the different Wi-Fi channels. These channels were limited and had to be managed.

Theoretically, the targeted Wi-Fi-enabled device (at the time of the drone overflight) could be set to any Wi-Fi channel. At this point, it was important to explain that the experiment and research were based on the 2.4 GHz spectrum, since most (if not all) devices still had a (basic) frequency range enabled, and signal propagation on 2.4 GHz is much less affected by obstacles than on 5 GHz. The ping group drone must either be equipped with a multi-channel communications array to ping all channels simultaneously (for a higher success rate), or be able to cycle through the channels relatively quickly to ensure that a ping signal was sent to all channels. As described in research [4], the flight path of the ping group (as explained in research [17] in a different but relevant area) could be pre-determined in the control center when planning the site flight. Optimizations were possible and are not part of this research. A detection group is where useful information is received. As illustrated in research [5], a device receiving a ping signal would respond and attempt to make contact.

This event enables detection by the UAV detection group. For the same reason that the ping group UAV must be able to transmit on any Wi-Fi channel, a detection group UAV must be able to receive such a signal. Ideally, the UAV should be equipped with multiple Wi-Fi modules. Since the payload of a drone of this size is limited, cycling through channels with a single module was an acceptable method, but one that carries risks and leaves room for future upgrades and enhancements to this concept. This means that in future experiments, the detection group drone could be equipped with a different type of communication array for the edge communication layer and may have different payload requirements on the drone itself. A visual representation of the edge layer can be seen in Fig. 2.

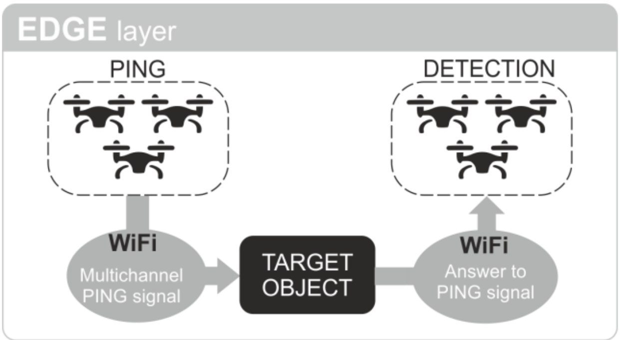

Fig. 2. Edge layer structure and topology

The basic organization and utilization of the messaging/pinging and acting in edge communication layer can be summarized as:

- Ping/pinging; conducted by a Ping UAV;
- Reply; data management given/received by the target device(s);
- Detection; actions for sensing and detection of objects, managed by Detection UAV.

3.2 Fog layer structure and topology

A fog layer consisted of detection group UAVs and master UAVs. The detection group of UAVs was discussed in more detail in the previous chapter. A master UAV was a dedicated UAV responsible for collecting data from a group of detection groups. This (master) UAV was equipped with a LoRa receive communications array at the bottom of the UAV and a satellite uplink communications array at the top. For this communication layer, only the LoRa communication array on the master UAV is relevant. The UAVs in the detection group were equipped with a LoRa transmit communications array on the top of the UAV. As a communication technology, LoRa can provide an extended range that is more than sufficient for the application described in this research (up to 15 km at line-of-sight, as described in [18]). The previously mentioned LoRa-related research used various devices (such as Arduino or Raspberry boards) to incorporate LoRa communication technology. The authors of this paper proposed to use the same or more industrial products as suggested in research [18]. In the event of a positive detection, the UAV would combine the data received from the receiving array with the data from the internal system (date, time, exact location, UAV ID) and transmit this data packet to the master UAV using LoRa communication technology in the fog communication layer. This information could also be shared between UAVs using Bluetooth technology in the same layer to keep it safe or upload redundant information when needed. A LoRa transmitter could be placed on the top of the UAV to provide a clear line of sight to the master UAV. This communication method followed the logic presented in the study [7]; however, it eliminated the challenges associated with available terrestrial receiving towers or problems reaching those receiving towers when the UAV is flying low and is hindered by local terrain, which was an obvious drawback of the solution proposed in the study [7]. Based on the conducted research, it was proposed that the LoRa signal with positive detection data be sent to the master UAV to be positioned high above all detection groups of UAVs. In this way, communication transmission to the top of the fog communication layer is guaranteed since there are no obstacles between the detection UAVs and the master UAVs. A message reception acknowledgement method can be used to complete a positive information transfer between units. This is native LoRa functionality that can be used. Aside from positive detection data, the UAVs in the detection group can also send position reports or percentages of path completion reports across the fog layer to the master UAV, which can then forward this data to CC. A visual representation of the fog layer is shown in Fig. 3.

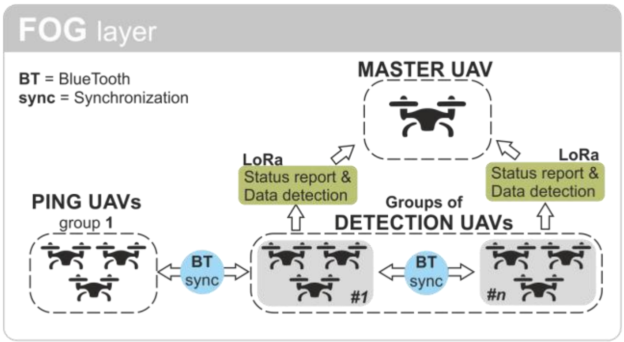

Fig. 3. Fog layer structure and topology

The following structural and functional topology represents the basic application and functional role of the fog communication layer:

- Transmission of information; for successful data detection, management and routing;
- Status update; for data management and validation;

- Synchronization between the units of the recognition group or the units of the ping group(s).

3.3 Cloud layer structure and topology

Elements of the cloud layer were master drones (UAVs) and satellite communications infrastructure (and further via the Internet to CC). In the paper presented by research [7], a terrestrial LoRa receiving station (or person) was expected and required to maintain communication between the UAV and the CC. Although the authors did not refer to the communication layer used as the cloud layer, they proposed to use terrestrial LoRa reception to receive information from the UAV. The hypothesis previously stated was that there is no terrestrial GSM network or other means of digital communication over long distances. Since search and rescue missions are conducted in the most remote areas where there is no communications infrastructure and (perhaps more importantly) where terrain configuration could pose a challenge to propagating an electromagnetic signal from the UAV to a terrestrial station or person, another method of communication must be secured.

This research proposes a cloud communication layer and an upstream satellite communication method. Master UAVs are potentially larger aircraft that can perform multiple tasks. For the purpose of this research, these UAVs would collect positive identification data sent by the UAVs in the detection group and transmit it to the Internet via IoT satellite communication methods such as the Starlink SWARM IoT Network or a similar low earth orbit satellite communication network (LEO). A master drone was planned for each of several search areas and detection groups. Individual experimentation or a use case (or budget) can define the exact need and setup. LEO satellite networks provide better connectivity characteristics than traditional geostationary satellite networks. The higher speed and lower latency provide better conditions for the current use case but also for future enhancements, such as streaming thermal imagery, etc.

Although the master drones could be larger and have a longer flight time, it was imperative to maintain the lowest possible load to ensure maximum flight autonomy. To this end, the basic IoT facility was selected from the range of narrowband IoT products within the LEO satellite services. This was the limitation of the research, and future revisions may address a broadband communications channel transmitted on a satellite network capable of carrying more data.

Swarm IoT technology [19] provides an option to use low-power and lightweight aerial vehicles to send data to the LEO-based IoT satellite network. A visual representation of the cloud layer can be seen in Fig. 4.

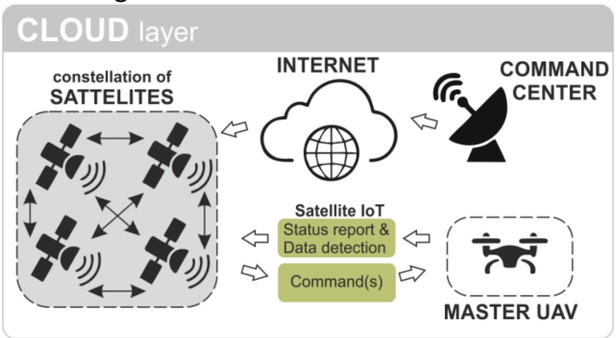

Fig. 4. Cloud layer structure and topology

Briefly, the cloud communication layer manages following tasks and actions in UAVs group/swarm:

- Transmission of information; for successful data detection, management and routing;
- Status update; for data management and validation;
- Receiving commands from CC via the satellite network.

4. COMMUNICATION CONVERGENCE IN UAVS FOR SEARCH AND RESCUE MISSIONS – APPLICATION AND ANALYSIS

In search and rescue missions it is of great importance to do the sweep search of targeted terrain as fast as is possible. Right choice of searching formation is crucial, and that is applied also in case of UAVs use for search and rescue. The intended range for conducting search missions depends on the selection of UAVs and their particular characteristics (flight time, speed, range, total flight distance, service ceiling, flight conditions, etc.). In all the mentioned research papers, the authors proposed or conducted experiments with different commercially available UAVs. The common features are a flight time between 30 and 45 minutes, a usable speed at detection of about 5 m/s, and a maximum speed in the range of 18-20 m/s for the non-detectable parts of the flight. These numbers are used in this paper to create as comparable a scenario as possible.

As larger UAVs become available at the prices mentioned in this paper, these numbers may be revised in the future. For UAVs performing ping and detection functions in the boundary layer, the maximum flight time of 45 minutes proposed in research [20] was used. The flight speed is 5 m/s for detection and 20 m/sec for a flight without detection. Commercially available UAVs for ping and detection functions were available for under 1000 EUR/piece at the time of writing [20].

Table 1 lists the approximate area coverage when no crosswinds or turbulence are expected in the interest of a search mission of 4 square areas of about 3x3km each side by side.

Table 1. Flight times and distances for ping and detection UAVs according to UAVs with the declared maximum flight time of 46 minutes

Category	Area 1	Area 2	Area 3	Area 4	Master UAV
Distance from the control center to the start of the search area	Approx. 1 km				Approx. 4 km
Flight time and distance to a specific search area	1 min	1 min	3.5 min	3.5 min	Appx 4 min
Flight time in a specific search area	30 min	30 min	30 min	30 min	Appx 30 min
Search area coverage	9 km^2	9 km^2	9 km^2	9 km^2	-
Total search area coverage	Approx. 36 km^2				-
Total search area dimensions	Approx. 6x6 km				-
Flight time back to the control center	4.5 min	4.5 min	8 min	8 min	42 min
Total flight time	35.5 min	35.5 min	41.5 min	41.5 min	42 min
Spare time	10.5	10.5	4.5	4.5	4

The search pattern is taken from research [4]. The control center is the launch position for the UAVs and is located (arbitrarily) 1 km from the beginning of the search area.

Fig. 5 shows a top view of the search area and a UAV swarm formation. According to research [4], this formation was sufficient to cover ping and detection at the indicated latitude. Since ping drones can operate from higher altitudes, one ping drone was sufficient.

A search area is represented in the form of 2x2 boxes, each 3x3 km in size. A theoretical evaluation was performed according to the specifications of the UAVs used. For the function of the master drone, another drone was planned. The UAVs of the detection group have a maximum lateral distance of 4.25 km from the master UAV and a height difference of up to 2 km, resulting in a maximum total distance of 4.7 km, which is within all LoRa line-of-sight parameters of the cited work, even for lower-spec devices, ensuring connectivity in the fog layer.

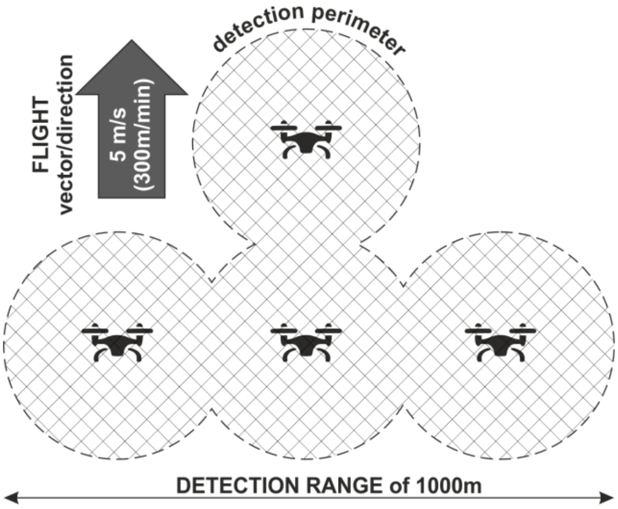

Fig. 5. Formation width and flight speed

The master UAV maintains a central position 2000 m above the ground. This altitude ensures a clear line of sight between the acquisition group and the master UAV, as the acquisition group has a lateral coverage of 1000 m with a lateral distance between the units less than 200 m, ensuring Bluetooth 5.3 [21] connectivity for redundant transmission of acquisition events. Fig. 6 illustrates the search area.

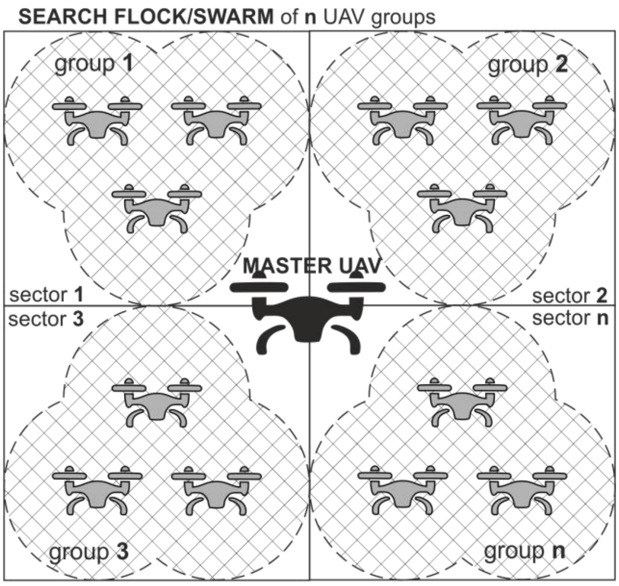

Fig. 6. Example of the search area

Table 2 lists the required investments for UAVs, spare parts, IT parts, services, battery cycles, and the average cost per square kilometer.

Table 2. Total cost per km² searched considering that the initial investment is less than 30.000 USD including all needed IT equipment

Category Title	Values net or average
Cost of UAVs*	Appx 20.000 USD
Cost of spare parts*	Appx 5.000 USD
Cost of IT parts, [18]	Appx 4.200 USD
Cost of satellite subscription, [19]	Appx 1000 USD /year
Total	< 30.000 USD for products Appx 1000 USD for services/year
Investment per km²	Appx 861 USD for a single use
Average battery cycle	Advertised 250 cycles; real appx 150 cycles
Minimum cost per km²	861 USD/150 cycles = 5.74 USD

* Obtained from [20] – Although this paper does not propose a specific brand and model, an estimate was taken from the pool of the most well know manufacturers with model DJI Mini 3 Pro for UAVs and DJI Mavic 3 Classic for the master UAV.

5. DISCUSSION

As the authors point out in a study [22], in 1912, search and rescue missions were conducted in Yosemite National Park over a 10-year period, helping over 2300 people. The average mission lasted 5 hours and involved 12 people, at a cost of $4400, totalling $8.4 million. Since this research focused on events during the period from 1990 to 1999, this figure, adjusted for inflation, is approximately 17.35 million USD (calculated for the year 2023), giving an average value of almost 9100 USD. The above figures are an average, and some of the missions of SAR were marginal, e.g., the search for a missing person lasted several days and more than 200 people were involved. In situations such as this (uncertain whereabouts of a missing person), UAV-assisted SAR missions can be of great benefit. Since today's UAVs for the above functions and purposes each cost approx. 1000 USD (adjusted for additional equipment on board IT on average no more than 250 USD each), a simple calculation proves that the use of UAVs is an extremely profitable investment, this is especially true for searching for people in remote areas and areas without communication infrastructure, where any attempt at local search with human personnel would be a much slower and more expensive solution, as the cost per square kilometer can drop to less than 10 USD after being deployed for as long as their battery capacity allows (the simple calculation already takes into account spare parts for maintenance, as shown in Table 2). The proposed search pattern theoretically allows a swarm of UAVs to be launched from the CC site and reach the beginning of the search zone, which is about 1 km away and has a size of 6 x 6 km. 16 ping and detection UAVs would cover this area in about a 30-minute flight and return to the launch area within 45 minutes of launch. After changing batteries and loading new trajectories, the same group of drones can continue to the next segment, covering at least 36 km² per hour. This means that an entire urban area of Vienna (414 km²) can be covered in less than 12 hours with just 16 drones. Since each search and rescue mission is divided into two logical segments (1: search and 2: rescue), in order to start the main activity (rescue), it is essential to perform and complete the search function as quickly as possible. The presented solution enables much faster detection of target devices and can lead to a faster indication of the location of a missing person. The information about the positive detection event must be transmitted to the CC as soon as possible and in such a way that the communication infrastructure used reduces the possibility of communication loss to the lowest possible value. For this reason, it is of utmost importance to ensure a suitable communication infrastructure, as presented in this paper. A novel methodology for communication convergence has been presented. It ranges from Wi-Fi for pinging and detecting target devices, to Bluetooth for possible synchronization between UAVs, LoRa communication technology for transmitting important information and communication nodes (master UAV), and a low earth orbit IoT satellite communication network for extracting information from remote areas to the Internet and back to the control center.

6. CONCLUSION

Technological advances have recently opened new niches in embedded computing and communications integration, while the rapid development of various types of unmanned aerial vehicles (UAVs) has provided a mobile platform for innovation. A combination of the above advances led to excessive production of remotely piloted quadcopters and similar flying devices, mainly for business and recreational purposes, with most concepts involving video recording and transmission of recorded data from the UAVs to the operator's location. Innovations followed shortly, and new application concepts were introduced. The use of UAVs was mostly associated with remote assistance or search and rescue missions. Methods ranged from simple video surveillance during short-range missions while maintaining line-of-sight, to long-range missions or missions under difficult geographic conditions. In such scenarios, various communication technologies were used, all with certain advantages and limitations. The authors presented a conceptual improvement to an existing proposed solution based on a swarm of UAVs with a pre-programmed flight path actively searching for a Wi-Fi enabled device that divides the communication layers into three layers: the edge layer, where ground-based UAVs actively search for target devices; the nebulous layer, which is used by detection UAVs to synchronize and transmit status updates and positive detection information to higher-positioned aircraft; and the cloud layer, which is used by main UAVs to transmit information via a narrowband IoT communications channel to low-earth orbit satellites and back to the control center via the Internet. The proposed approach addresses flawed attempts where terrestrial infrastructure is required to facilitate information reception or where the passive search method is used to detect Wi-Fi enabled devices. The limitations and potential improvements are explained. Future advances in aircraft technology and communications modules will enable different uses of communications layers and may even enable live image streaming over satellite communications channels in the same price range as the current solution within this decade.

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