

Determination of Subscribers Coordinates using Flying Network for Emergencies

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Abstract— In the last decade, unmanned aerial systems have emerged in different fields, such as entertainment, military, Internet of Things, emergencies. In these systems, unmanned aerial vehicles (UAVs) communicate with each other based on a flying network to provide services to customers such as live streaming, high-speed access point, etc. The mobility of UAVs can bring numerous advantages in emergency cases, for example, rescuing and searching victims in areas where the network infrastructure is not available. However, the crucial task needed to be done first is to locate the victims' coordinates. In this paper, we propose a method for detecting the coordinates of subscribers with the Wi-Fi signals generated from victims' phones in the absence of network infrastructure of communication operators using a flying network for emergencies based on UAV-swarms. We develop a new protocol for communication between UAVs and UAV-swarms. A structure of UAV-swarms is considered to optimize the searching time. The results of the proposed method are achieved by simulation.

Keyword — SAR, UAV, Flying Network, positioning, Wi-Fi, IEEE 802.11p

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I. INTRODUCTION

EVERY year, a significant number of people around the world die as a result of untimely assistance. Examples include earthquakes, tsunamis, and other natural disasters of natural and artificial origin. In addition, a considerable number of individuals disappear in forests due to the inability to contact emergency services. The effectiveness of searching and rescuing operations can be improved by using new approaches to detect victims, which are based on using a UAV group with attachments - a flying network [1], [2]. Such a network can reduce the time required to locate victims as well as reduce the number of people involved in the operations [3], [4].

When a disaster occurs, infrastructure and the communication systems in this area are destroyed, and they cannot be able to operate. The rescue team comes to the area and deploys UAVs to operate missions. UAVs will fly, do the searching and rescuing operations and establish a quick deployment flying network to make it possible for rescue teams on the side to contact each other, as well as victims who can contact outside for help. The first and most important thing is to identify the victim's location in the search area, and thanks to the UAVs, searching operations become time-saving and highly accurate. After a disaster, it's also challenging to find people, who were buried under debris, or they were unconscious. There are many ways to determine the victim's location, but searching through beacon signals from devices attached to the victims, such as smartphones, laptops, and tablets, which have a Wi-Fi connection, becomes useful and easy to deploy. To identify the victim's location through the location of the phone that the victim carries with him, at least UAV-swarms need to receive three signals [5], [6].

Nowadays, smartphones and smartwatches have become indispensable things for humans, and almost everyone carries these devices with them at any time. This factor also is an essential part of smart cities, smart countries when everything needs to be connected seamlessly. In smart cities, a public Wi-Fi network is always designed for the people in order for everyone to connect to this network and use the services of the

smart city [7]-[9]. Thanks to that, the process of searching and rescuing through finding signals from the victim's phone also becomes easier. When UAV-swarms, which have functioned as an Access Point (AP), use this public Wi-Fi network to send beacon signals to the victim's phone, the phone will confirm and respond to the signals that is the basis for detecting the location of the victim.

Related papers using UAVs to find signals from the victim's phone can be found in some studies, such as in [10], [11]. The authors of [10] proposed a system named Krypto, which addressed the challenges of maximizing the size of the searching area and minimizing the location errors with different approaches. In this paper, however, the authors did not consider the UAV-swarm Fixed-Wing type, as well as the influence of the distance measurement error and the number of received signals, and the considered area was small in comparison with our targeted area. In [11], the authors used the UAV to track indoor smartphones or watches owned by the victim by sending to the UAV the received signal's strength and the UAV location with a shallow Q-learning algorithm. However, the paper studied only one single UAV with an indoor search and rescue mission.

In this paper, we propose a method for detecting subscribers' coordinates with the Wi-Fi signals generated from victims' phones in the absence of network infrastructure of communication operators using a flying network for emergencies based on UAV-swarms. On the basis of this work, a draft Recommendation ITU-T Q.ETN-DS "Signalling architecture of the fast deployment emergency telecommunication network to be used in a natural disaster" is being developed in the 11th research commission of the standardization sector of the international telecommunication union "Signalling requirements, protocols, test specifications and combating counterfeit products" (SG11 ITU-T). The protocol of inter-communication between UAVs in flying network for emergency systems is present in Section II. The flying network and deployment models are described in Section III. The positioning methods and the assessment of positioning errors are considered in Section IV. The conclusion of the article is shown in Section V.

II. PROTOCOL OF INTER-COMMUNICATION BETWEEN UAVs IN FLYING NETWORK FOR EMERGENCY SYSTEMS

A. Basic statements

In recent years, a group of UAVs working together as a network has proven to be effective, useful, and flexible. This network often is called Flying Ad-hoc Networks (FANET), which is considered a subset of Vehicular Ad-hoc Network (VANET) and Mobile Adhoc Network (MANET). The development of an autonomous FANET depends on the quality of inter-communication between UAVs. Currently, however, there is no technology for inter-communication between UAVs and UAV groups. Since FANET is seen as a subnet of VANET, inter-communication technology in VANET is one of the great candidates.

The current inter-communication technology in VANET mainly uses IEEE 802.11p. In the process of developing to 5G, there are new technologies for VANET such as C-V2x, IEEE 802.11bd, or 5G NR (5G and new radio). However, the

C-V2x technology is still in the process of being completed, it has only been simulated on models, and it works well thanks to the existing foundation of cellular network, therefore, in the case of emergency rescue when the network infrastructure is not working, it cannot be applied. IEEE 802.11bd is a new technology that is under development based on IEEE 802.11n/ac, promising to be able to replace and be compatible with IEEE 802.11p, but there is still a long way to go. Similarly, C-V2x, 5G NR are future technologies for inter-communication of vehicles, but it is now just in the early development process [12]-[15].

IEEE 802.11p [16] protocol is a modified version of the familiar IEEE 802.11 (Wi-Fi) standard, which was originally developed for VANET. The IEEE 802.11p standard was adopted as Medium Access Control (MAC) and Physical Layer (PHY) specifications for the lower-layer Dedicated Short-Range Communication standard (DSRC), which has characteristics such as frequency range - 5.9 GHz (5.85-5.925 GHz), wide coverage (up to 1000 m), fast transmission rate (up to 27 Mbps), self-organization and fast convergence. This approach is commonly referred to as vehicle-to-any (V2X) communication. Compared to cellular networks, Wi-Fi-based V2X communication does not offer a pre-installed infrastructure and (almost) full spatial coverage. However, its direct communication capabilities among nodes with short communication latency make it a strong candidate for vehicle safety and traffic efficiency applications [17].

B. Proposed work

In a flying network for emergencies, which focuses on searching for victims of natural disasters, UAV-swarms move with a certain flight mission and have a geographical limitation. In such a network, UAVs interact with each other to receive a flight task from the mobile base station (MBS), or send the collected data to MBS.

In [18], a modified MAC sublayer was proposed based on the IEEE 802.11p and IEEE 1609.4 protocols for communication between UAVs and UAV-swarms. IEEE 1609.4 protocol [19] allowed adding a seven-channel MAC scheme to the MAC layer of IEEE 802.11p. Each channel has a total bandwidth of 10 MHz. These channels consist of one control channel (CCH - Control Channel 178) for managing the network and transmitting safety messages and six service channels (SCH - Service Channels 172, 174, 176, 180, 182, 184) for other traffics. All vehicles must monitor the control channel with safety/control messages during the CCH period and will be able to switch to the service channel to exchange only non-safety applications.

The proposed protocol (Fig. 1) includes three different sub-protocols:

- Cluster management protocol (CMP);
- Intra-cluster communication protocol (IntraCP);
- Intercluster communication protocol (InterCP).

We denote the combination of these protocols as cluster-based Multichannel MAC IEEE 802.11p protocol (CMMpP). In this case, the UAV-swarm is considered as a cluster and the UAV as a node. The protocol is focused on data transmission between mesh network elements, in which routing should be performed at the data link layer, or, in other words, based on MAC addresses. This is the difference from mobile Ad-hoc networks, in which the focus is on standardizing the functions of the network layer [26].

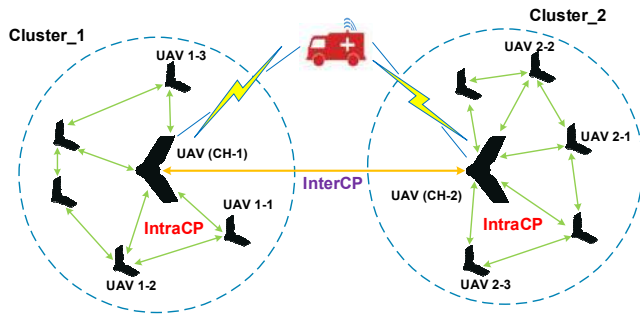


Fig. 1. UAV-swarms using protocol CMMpP

In the first step of the searching operation, the MBS moves to the searching zone. Next, UAV-swarms (clusters) are deployed to collect information, establish communications and exchange data. These clusters use the CMP protocol to select a cluster head (CH). The CH node can be reassigned during the task's execution depending on the location, and the speed of nodes in the cluster. The CH node is responsible for collecting information from cluster members (CM - cluster member) and subsequent transmission to the MBS or CH nodes of other clusters. The CH nodes also act as an intermediate for transmission, scheduling, channel assignment through message management.

Nodes will use IntraCP and InterCP for data transmissions. These protocols use the IEEE 1609.4 and IEEE 802.11p multi-channel MAC sublayer in conjunction with TDMA for each communication session. In particular, the IntraCP protocol performs the following main tasks:

- Collecting/Delivering control messages from/to CM on CCH channel;
- Allocating the available SCH channels to CM for data traffic;
- Contending to transmit data on the SCH in the cluster.

Meanwhile, the InterCP protocol is responsible for establishing communication between different clusters (transmission of both control messages via CCH and data via SCH). In the CMMpP protocol, each node is equipped with two transceivers, designated respectively "Trans_1" and "Trans_2". They can work simultaneously on different channels. "Trans_1" is always set to CCH for monitoring and transmitting control messages on the CCH channel, and "Transmit_2" is set to any SCH channel (channels 174, 176, 180, 182) to perform data transmission. Therefore, instead of the CCH (CCHI) and SCH (SCHI) intervals of 50 ms for each transceiver, the entire synchronization interval of 100 ms can be used. In addition to using the CCH channel 178 for control messages, the SCH channel 182 is proposed exclusively for InterCP. Thus, SCH channels 174, 176, 180 will be used to assign to CM nodes for IntraCP transmission data. It should be noted that only SCH channels 174, 176, 180 can be used for data transmission in a cluster (IntraCP). However, inter-channel communication (InterCP) will be carried out on SCH channel 182. These operations occur in non-overlapping channels, so they do not affect each other.

C. Simulation and results

The simulation was performed in the Riverbed Modeler, and the performance of the proposed CMMpP protocol was evaluated based on the results. As shown in [20, 21], the Riverbed Modeler package does not have an IEEE 802.11p module designed for operation in flying networks. When setting the initial data, all models with a bandwidth of 10 MHz

were selected. The data transfer rate was set to 12 Mbit/s, and CH nodes are used as the access points. As for the CCH simulation, all vehicles must operate at the center frequency with the channel 178 in the range 5885-5895 MHz. Therefore, the minimum frequency should be 5885 MHz. Other parameters are set by default or as in [21].

Four scenarios are evaluated with one central BS, one MBS, and five clusters, each of which has 1 CH node, and the numbers of its member nodes (CM) for each scenario are 4, 8, 16, and 32, respectively. The mobility of nodes with trajectories is determined by the Mobility Config and Trajectory modules. Application and profile configurations are used to create messages and configure scripts. The duration of each simulation scenario is 60 minutes, and the EDCA parameters are set by default. We analyze the transmission of service messages and voice traffic in simulation.

As an example of these four scenarios, we study five clusters, each of which has 8 CM and 1 CH. Fig. 2 shows the average throughput for each member of the nodes in one cluster (Cluster_1) from those five. The average throughput of the CH-1 node is proven to be the highest since it is the head cluster.

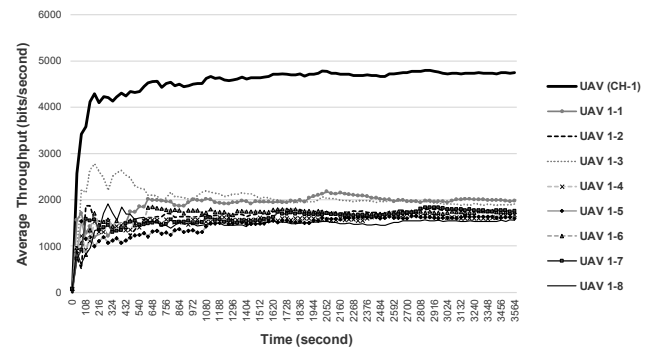


Fig. 2. The average throughput for each UAV in one cluster

The number of retransmission attempts for different scenarios is shown in Fig. 3. The result shows that an increase in the network size leads to the increase of the number of nodes using the same channels SCH. This also results in conflicts during transmission, and therefore, the number of retransmission attempts increases with time. It should be noted that the vertical axis of the graph shows the ratio of the number of packets to be retransmitted to the total number of packets.

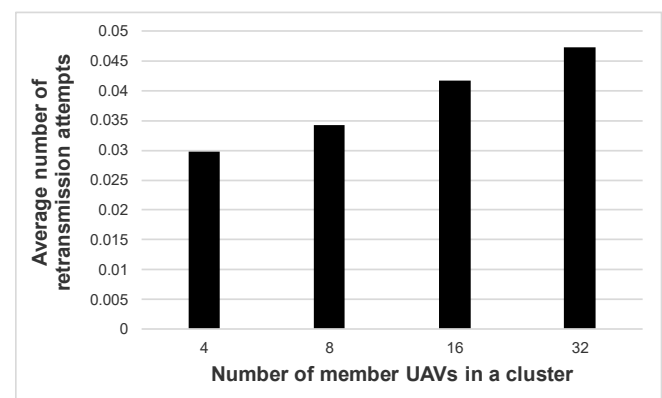


Fig. 3. The average number of retransmission attempts for different numbers of CM nodes in one cluster

Since each of the initial network configurations will produce results with different absolute values, it is important to focus on comparing the scenarios. Fig. 4 shows the normalized graphs (normalized average delay) for representing the average delay when transmitting packets in the CMMpP protocol in a scenario with one cluster, but with a different number of CM nodes. This figure indicates that the more the number of CM nodes in the cluster, the higher the transmitting delay in the network becomes.

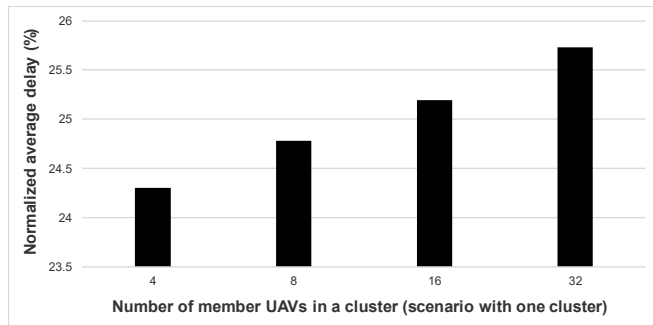


Fig. 4. Normalized average delay for a scenario with one cluster

III. FLYING NETWORK FOR EMERGENCY SYSTEMS

A. System Model

In the proposed flying network for emergencies, the UAV-swarms move with specific purposes and are subject to geographical restriction. In a mission-oriented flying network environment, UAV-swarms cooperatively communicate with each other to receive their missions from the mobile base station (MBS) or forward the collected data to the MBS.

In particular, MBSs will send UAV-swarms to scan areas around MBS and gather information, which will be disseminated among UAV-swarms and transmitted to the MBS. Besides, the UAV-swarms also act as intermediaries to make connections and transfer data between the MBS. Together, they create a timely, efficient, and effective rescue system and increase the coverage area of the flying networks. In general, there are two types of UAVs: Multi-Rotor and Fixed-Wing. For searching operations, fixed-wing UAVs are more suitable than the others because they have a high velocity and long flying time, up to several hours. An architecture of a flying network for emergencies is presented in Fig. 5.

A flying network for emergencies consists of two parts: the flying segment and the terrestrial segment. In the flying segment, UAV-swarms are interconnected by the IEEE 802.11p, using CMMpP, which is a mesh network deployed on UAV-swarms so that they can locate and communicate with each other and retransmit data to the MBS. Furthermore, UAV-swarms are equipped with IEEE 802.11n technologies to capture signals as well as communicate with devices on the terrestrial segment [18].

To begin searching and rescuing operations in a flying network for emergencies, the MBSs will move to the rescue area. There they will deploy UAV-swarms by clusters, which include a head cluster UAV (UAV (CH)) and members cluster UAV, to collect information, make connections, and exchange data. Member clusters UAV scan the area, collect information, and send this information to MBS through head clusters UAV (Fig. 5).

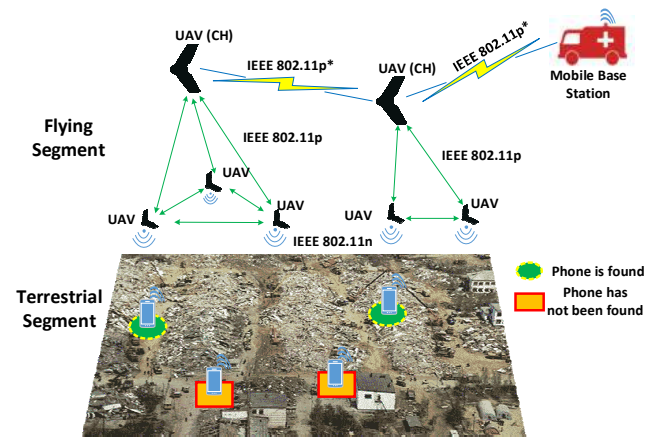


Fig. 5. An architecture of flying network for emergencies

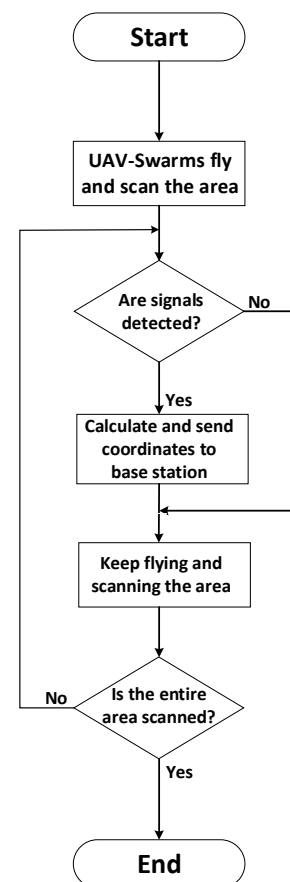


Fig. 6. Scheme of the searching process of UAV-swarms

As mentioned above, the first task of the operation is finding the location of victims. Assuming that the victims always have their smartphone and an automatically accessible Wi-Fi as well as UAV-swarms has enough power to work in the target area. Firstly, UAV-swarms receive information about the scanned area and start flying and scanning. When UAV-swarms get more than two signals from the victim's phone, they start to calculate the phone's coordinator. After getting one more new signal, UAV-swarms need to repeat the calculation of the phone's coordinator. These signals contain the phone's MAC address, which helps us distinguish among phones on the ground. Then, UAV-swarms send the latest calculation of the phone's coordinator back to MBS when no more signal of that phone is sent to them. UAV-swarms continue scanning the entire area to find all signals from smartphones of victims. The scheme of the searching process of UAV-swarms is presented in Fig. 6.

B. Deployment Models

When UAV-swarms fly for the searching, they continuously send beacon signals about the public Wi-Fi at a frequency of about 100ms. When the phone on the ground captures these beacon signals and knows about the Wi-Fi availability, it will start to feedback to UAV-swarms. Figure 7 describes the geometry approach to defining the coordinate. Assuming that the phone lay on the ground ($z_0 = 0$), therefore the coordinate of the phone's location needed to be found is $(x_0, y_0, 0)$, and the i -th position of UAV when receiving the phone signal is (x_i, y_i, z_i) . If the UAVs receive m signals from the phone, the coordinates of the searching point are required to satisfy the equations:

$$\begin{cases} (x_1 - x_0)^2 + (y_1 - y_0)^2 + (z_1)^2 = (d_1)^2 \\ \dots \\ (x_i - x_0)^2 + (y_i - y_0)^2 + (z_i)^2 = (d_i)^2 \\ \dots \\ (x_m - x_0)^2 + (y_m - y_0)^2 + (z_m)^2 = (d_m)^2 \end{cases}, \quad (1)$$

with d_i is the distance between the UAV and phone location.

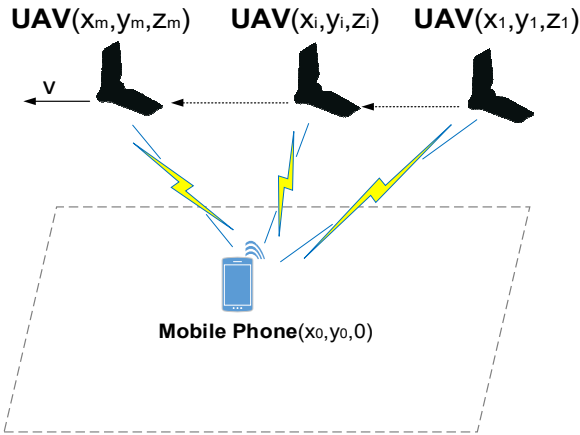


Fig. 7. The geometry approach to defining the coordinate

From a practical perspective, the UAV-swarm can consist of 3-10 UAVs [22]. In this paper, for the aim of searching victims, we assume that members cluster UAV have three fixed-wing UAVs, which always move forward with the same constant velocity $v = 25 \text{ m/s}$ at altitude $h = 50\text{m}$, as well as being able to capture signals with a radius of coverage circles in the ground of about $R = 50\text{m}$ by using the technology IEEE 802.11n.

There are three cases for the structure of the UAV-swarm in the searching process (Fig. 8): Horizontal line (Fig. 8a), Triangle (Fig. 8b), and Vertical line (Fig. 8c). By comparing different structures of the swarm, we can select the best structure for finding victims due to the time and accuracy during the searching process as UAVs have speed and energy limits.

With the parameters given above, there is time given for UAVs to be able to scan an area of $5 \text{ km} \times 5 \text{ km}$, as shown in the Table I. This table shows that horizontal line gives us the shortest scan time, but the main purpose of the article is to find out victims, so our top priority is to receive as many signals as possible because the more signals we get, the higher accuracy of the searching process for the victim's location we will have.

TABLE I
TIME TO SCAN AN AREA OF $5 \text{ km} \times 5 \text{ km}$ FOR THREE CASES

	Horizontal line	Triangle	Vertical line
Time to scan (s)	4400	7224	13056

Assuming that there is a phone located in a certain zone and in a certain flying time t (time of receiving-signals) through this zone, the UAV group always is able to receive at least one signal from the phone. Figures 8a, 8b, 8c, the time t is illustrated according to three considered cases. With different UAV structures, this time is different and is calculated according to the following formulas:

$$t_{\text{horizontal line}} = \frac{2 \cdot R}{v}, \quad (2)$$

$$t_{\text{triangle}} = \frac{2 \cdot R + R \cdot \sqrt{\frac{3}{2}}}{v}, \quad (3)$$

$$t_{\text{vertical line}} = \frac{3 \cdot 2 \cdot R}{v}, \quad (4)$$

The experiments were performed to measure the number of signals sent from the phone to UAV-swarms and the time of the receiving-signals process, which can be calculated from equations (2), (3), (4). The results in Table II show that the Vertical line shape has the possibility of getting a maximum number of signals, which means that the Vertical line shape is capable of finding the victims with the highest probability.

TABLE II
MAXIMUM NUMBERS OF RECEIVED SIGNALS

	Time of receiving signals (s)	Maximum number of received signals
Horizontal line	4	31
Triangle	6.45	42
Vertical line	12	53

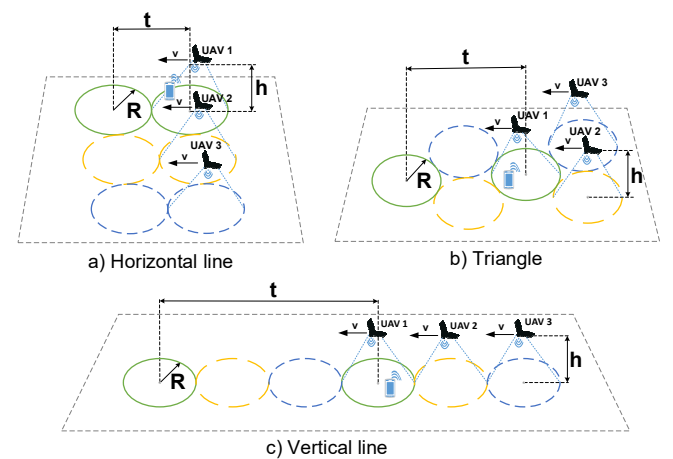


Fig. 8. Three cases of the structure of UAV-swarm for searching

IV. POSITIONING METHOD

A. Distance Calculation

In wireless communication, the radio propagation models are considered to evaluate the path loss when a signal encounters barriers over a distance. The power of the received

signal is less than the transmitted signal. A measurement of the power in each received radio signal is presented by Received Signal Strength Indicator (*RSSI*) to predict the difference between the transmitted and received signals in a transmission range [23], [24]. *RSSI* distance measurement generally is calculated in the logarithmic distance path-loss model as:

$$RSSI = A - 10 \cdot n \cdot \log\left(\frac{d}{d_0}\right) + X_\sigma, \quad (5)$$

where d is the distance between the transmitter and the receiver;

A is the path loss at the reference distance d_0 ;

n is the path loss exponent related to a specific wireless technology;

X_σ is a Gaussian-distribution random variable with zero mean and variance σ^2 .

In the calculation, d_0 usually is chosen to equal 1 meter. Hence, A is the *RSSI* at a distance of 1 meter. Since the X_σ has zero mean, *RSSI* can be expressed as follow:

$$RSSI = A - 10 \cdot n \cdot \log(d), \quad (6)$$

According to equation (6), the distance between transceivers can be calculated by:

$$d = 10^{\frac{A-RSSI}{10 \cdot n}}, \quad (7)$$

In our proposed system, UAVs act as Wi-Fi Access Points (AP), which are always ready to capture any signals from clients. The AP can evaluate the received signal's strength generated from the phone when it is connected to the AP. Hence, the distance from the AP to the phone can be determined by equation (7).

Since the path loss depends on the environment, in order to increase the positioning accuracy in our system, there is a need to estimate the parameters (A, n) before deploying the searching mission. Therefore in each specific searching environment, the UAV-swarm is set up to calibration mode, i.e., the *RSSI*, the distance between the UAVs and the starting point are measured several times. Then, the non-linear least square method is used to find the optimal parameters (A, n). With the m measurements, these parameters are founds as:

$$(A, n) = \arg \min_{A, n} \left(\sum_{i=1}^m 10^{\frac{A-RSSI_i}{10 \cdot n}} - d_i \right)^2, \quad (8)$$

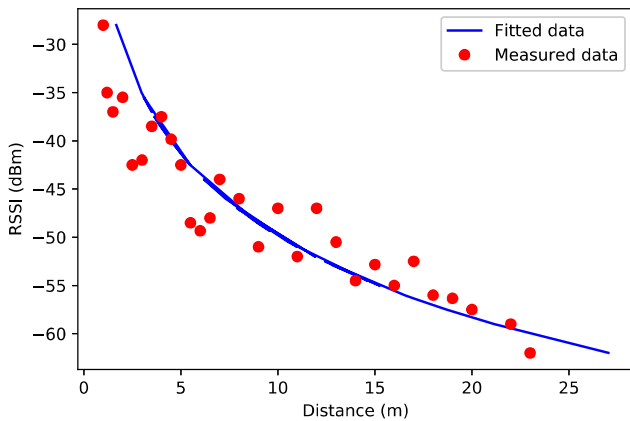


Fig. 9. Distance determination based on *RSSI*

The experiments were performed to measure *RSSI* and distance from a phone to an AP. The received measurements were used to estimate the parameters (A, n) in the distance calculation model (8). The comparison of the received data and estimated data is shown in Fig. 9.

B. Coordinate Calculation

After the UAVs measure the distance to the signal source, the next task is the coordinate calculation. Assuming that the phone position is $p_0(x_0, y_0, 0)$ on the ground and the UAV receives a signal from the phone at the position $p_i(x_i, y_i, z_i)$. The distance between these two points is calculated with the measurement error $\xi_{\mu, \sigma}$, set during the experiment. With each received signal from the mobile phone, the distance from UAV to it will be:

$$d(p_i, p_0) = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i)^2} + \xi_{\mu, \sigma}, \quad (9)$$

Therefore, the number of received signals and the measurement error influence the accuracy of the positioning process. The position $p_c(x_c, y_c)$ is found by minimizing the expression:

$$\arg \min_{x_c, y_c} \sum_{i=1}^m \left(\sqrt{(x_i - x_c)^2 + (y_i - y_c)^2 + (z_i)^2} - d(p_i, p_c) \right)^2, \quad (10)$$

where m is the number of received signals from the phone.

As the result of minimization, the coordinates and their estimation errors are found.

C. Result Assessment

In order to evaluate the positioning capability based on the Wi-Fi signal, the model is simulated in consideration of the number of received signals and the measurement error. According to Fig. 8 and Tables II, III, the group of UAVs can cover a certain zone in the t seconds. In that interval of time, the UAVs can receive at least one signal or more.

A comparison of distances between the given point and the found point is considered as a positioning error. The difference between them is calculated as:

$$d(p_0, p_c) = \sqrt{(x_0 - x_c)^2 + (y_0 - y_c)^2}, \quad (11)$$

The simulation gives the density of positioning error when changing the number of detected signals. Figures 10 and 11 show the probability density of positioning error when 30 and 3 signals are received, respectively, with a relative error of distance measurement of 20%.

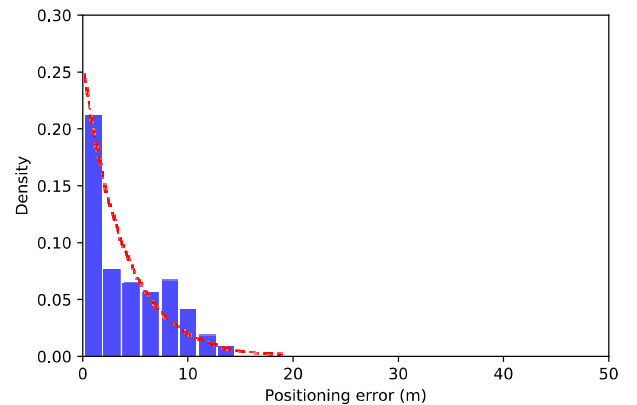


Fig. 10. Density and histogram of positioning error when 30 signals are received

The dependence of the positioning error on the number of received signals is shown in Figure 12.

According to Figure 12, the coordinates are determined with less error when more signals are detected.

On the other hand, distance measurement accuracy is an important factor that affects the positioning error. Figure 13 shows the dependence of the positioning error on the relative accuracy of distance measurement, which is generated in the simulation. The number of received signals is assumed with 30.

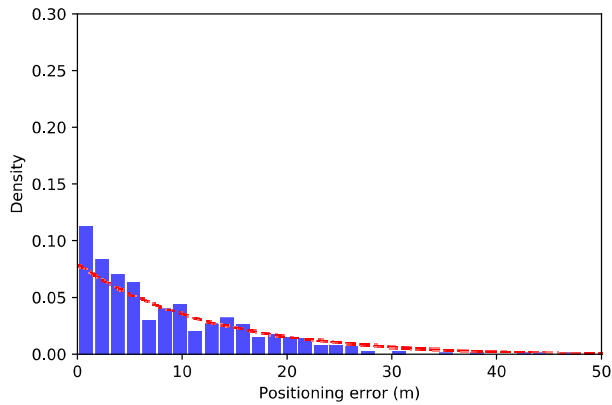


Fig. 11. Density and histogram of positioning error when three signals are received

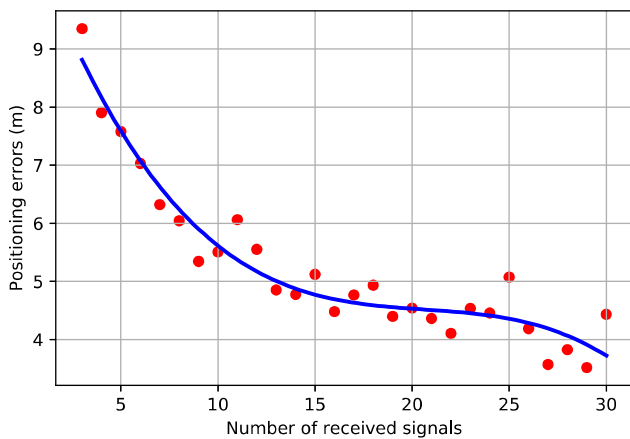


Fig. 12. The dependence of the positioning error on the number of received signals

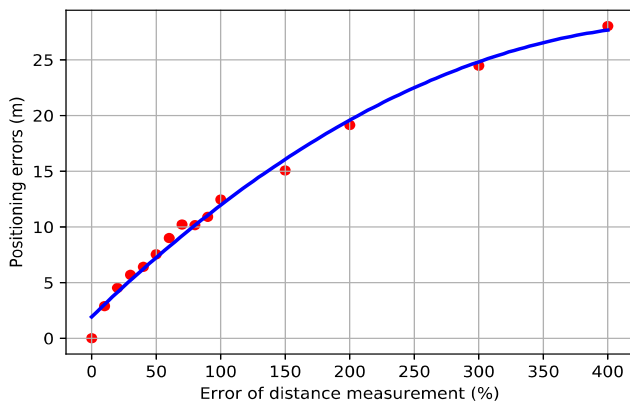


Fig. 13. The dependence of positioning error on the relative accuracy of distance measurement

The simulation results show that the positioning error increases when the error of distance measurement increases. Hence, the positioning accuracy can be achieved by increasing distance measurement quality and ensuring more signals are detected. The distance measurement mostly depends on a specific technology and the environment. Therefore, some models of distance measurement can be used in different cases. In addition, the UAV-swarm's ability to receive signals also depends on communication technology and the environment, as well as on the number of used UAVs and their speed.

IV. SIMULATION FOR POSITIONING METHOD

In order to evaluate the effectiveness of the search and rescue operation using the three cases of the UAV-swarm as mentioned above, a simulated scenario of UAV-swarm's mobility was developed by network simulator Omnet++ [25]. Assuming that the victim is in the subarea 500m x 500m, the ability to receive signals from the UAV-swarm is considered when this entire subarea is being scanned. The UAV system is designed to receive signals from the victim's phone on the 2.4 GHz frequency band with the average rate is 1 signal/second (1 signal generated per second) and with the transmission power is 10 mW. The victim location is randomly chosen 50 times (black points) in the subarea, as shown in Fig. 14. The search mission is simulated 50 times corresponding to the victim position, which also is randomly generated in each simulation time. As shown in Fig. 14, there are 50 victim positions that the UAV system needs to find. After each scanning mission, the coordinates of the victim are calculated and compared with initial random coordinates. We can conclude which structure provides the most accurate results for UAV-swarm in search and rescue operation.

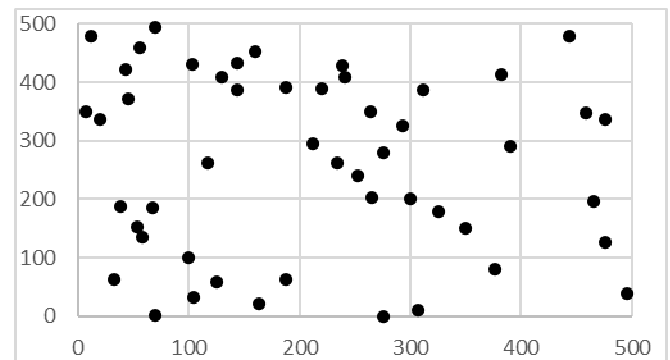


Fig. 14. Random positions for the victim in the subarea

The results shown in Fig. 15-17 indicate the locations of the UAV receiving a signal from the victim's phone in three cases (gray points) where the location of the victim is at coordinates (300,200) (black point). Fig. 15 shows the number of received signals of UAV-swarm for the Horizontal line shape is 9, whereas that for the Triangle shape in Fig. 16 is 14. Lastly, for the Vertical line shape in Fig. 17, there are 37 received signals. It is clear that the collecting-signals position within a radius of around 150m from the victim and the Vertical line shape gives us the most significant number of received signals, which makes it the most effective approach in terms of positioning accuracy for the searching operation.

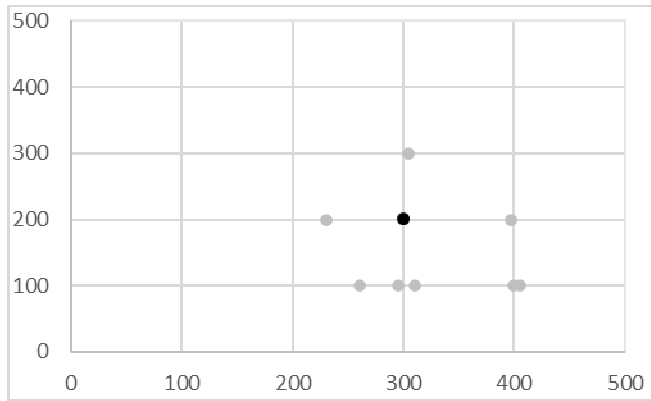


Fig. 15. Coordinates of UAVs, when receiving signals in search used the Horizontal line shape for UAV-swarm

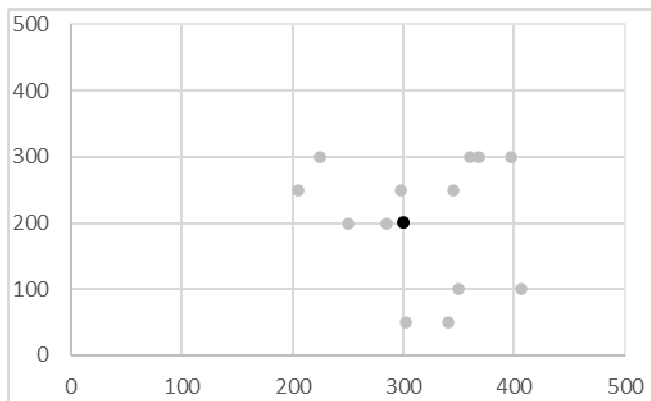


Fig. 16. Coordinates of UAVs, when receiving signals in search used the Triangle shape for UAV-swarm

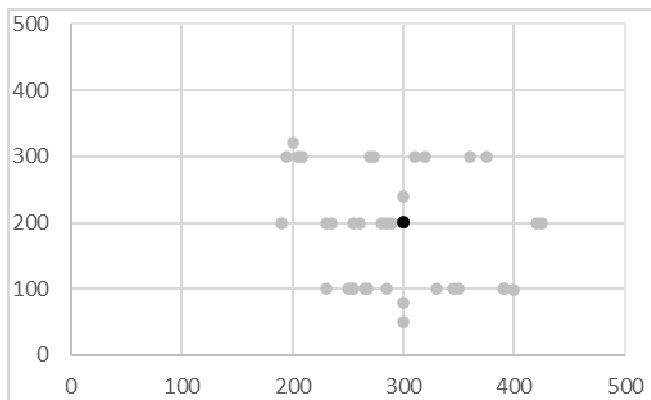


Fig. 17. Coordinates of UAVs, when receiving signals in search used the Vertical line shape for UAV-swarm

Through 50 simulations run for each case, the number of received signals in each case is presented in Fig. 18. This figure shows again that using the Vertical line shape for UAV-swarm, we might receive more signals from the victim's phone. The probability density of the number of received signals for three cases is shown in Fig. 19. There is a higher probability of receiving 20-30 signals using the Vertical line shape, whereas the probability of receiving 5-15 signals is highest by using the Horizontal line shape, and for the Triangle shape, the highest probability of receiving signals is in an interval of 10-17 signals.

The number of received signals is averaged after the whole 50 simulation times. The mean and standard deviation values are shown in Fig. 20. With the results from Fig. 20, the average numbers of received signals in each case are as follows:

- Horizontal line (10 signals with the standard deviation of 3),
- Triangle (13 signals with the standard deviation of 4),
- Vertical line (20 signals with the standard deviation of 5).

Approximately, the ratio of received signals for three cases is as follows (Horizontal line, Triangle, Vertical line) = (1: 1,5: 2). According to Fig. 21, Vertical line and Triangle provide small distance errors (at around 2.2 m with the standard deviation of 0.9 m and 2.1 m with the standard deviation of 1.2 m, respectively). A conclusion that can be extracted from this result is that the positioning method is more accurate when there are more received signals. This is aligned with the statement mentioned above.

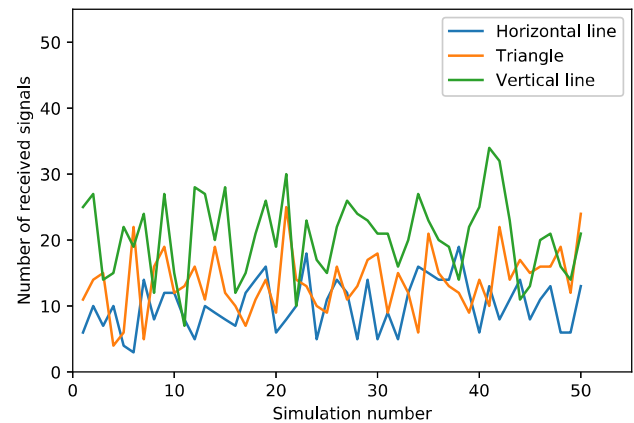


Fig. 18. The number of received signals for UAVs in three cases

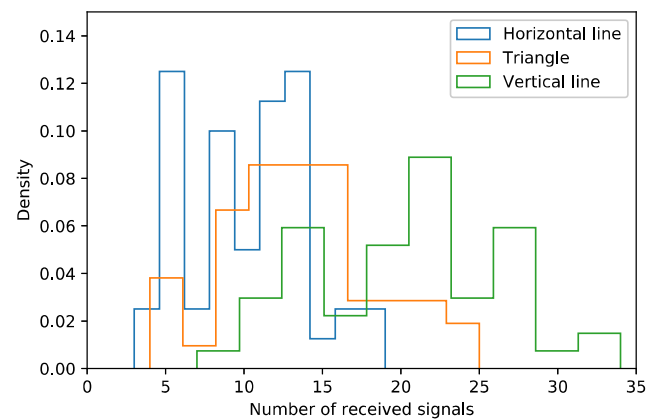


Fig. 19. Density and histogram of the number of received signals for three cases

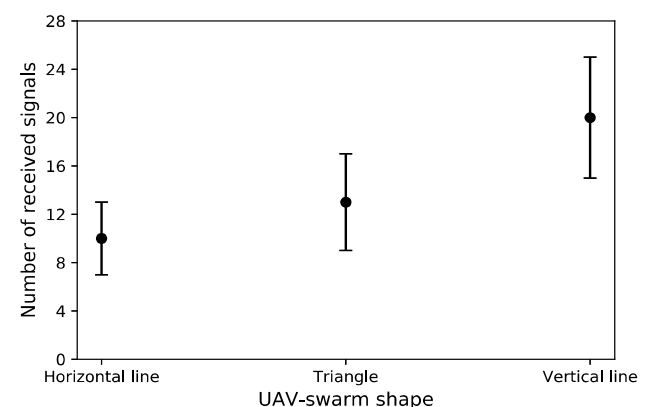


Fig. 20. The average number of received signals for different UAV-swarm shapes

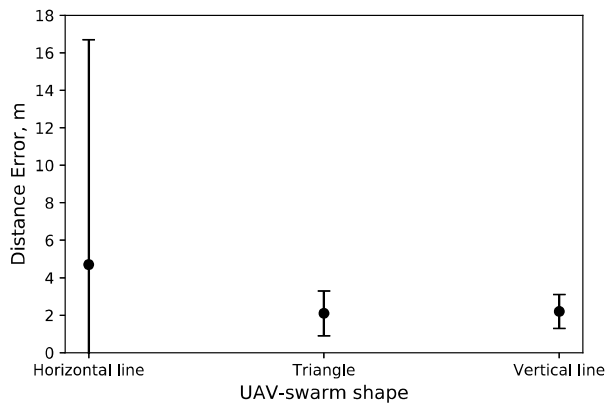


Fig. 21. The distance errors for different UAV-swarm shapes

V. CONCLUSION

In the paper, the method for detecting the coordinates of subscribers by catching the Wi-Fi signals generated from their phones in the absence of infrastructure of networks of communication operators using a flying network for emergencies based on UAV-swarms was proposed. In the flying network for emergencies, UAV-swarms use a new protocol, known as Cluster-based Multichannel MAC IEEE 802.11p protocol, for communication between UAVs and use technology IEEE 802.11n to capture signals. We propose a scheme of searching process of UAV-swarms and study three cases of UAV-swarm structure for searching. The results of experiments show that the Horizontal line shape gives us the shortest scan time while the Vertical line shape is capable of finding the victims with the highest probability. The simulation's results for detecting the coordinates of subscribers show that the probability density of positioning error is much better when there are more signals, which UAV-swarm received from the victim's phone. Besides, the phones' coordinates are determined with less error when more signals are detected, and the positioning error increases when the error of distance measurement increases. In considered three cases, the Vertical line shape provided the best result of positioning methods and continuously received the highest signals.

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