Design and Simulation of the Hierarchical Tree Topology Based Wireless Drone Networks

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Abstract— **In drone applications, the drone could send data using telemetry devices or radio frequency module which has a limited range. So, there is no interaction between user and drone after a certain range. In this study, a hierarchical tree topology based wireless drone network is designed and presented to overcome range challenge. Proposed network consist of three main parts; Control Center (CC), Master Drone (MD) and Slave Drones (SDs). The CC as a network manager communicates with just MD via telemetry devices. SDs are explorer drones for the search and rescue application. The data transfer between CC and SDs is provided by MD which is explorer like SDs. This paper clearly shows that the enhancement of the communication range is possible with such this approach. Also the designed drone networks are simulated using V-REP (Virtual Robot Experimentation Platform). According to the simulation results, the proposed drone network system operates quickly, and finds the target in 5 minutes, which classical system not find in 10 minutes. The proposed model clearly shows that an application using a drone is completed in a shorter time with the drone swarm well organized.**

Keywords—Drone; Drone Communication; Wireless Drone Networks; Drone Simulation.

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), also commonly known as drones, are small aircraft that are controlled remotely or autonomous [1]. First of all UAVs have been used for military purpose, such as combat and surveillance [2]. Drones are a special kind of UAVs that are especially popular for photography and video application [1] [3]. After the 90's, thanks to the advances in microelectronic technology, the size and weight of UAV have diminished. The diminished size and lower cost have allowed to expand the drone application areas.

Nowadays, drones have many new roles in the public and private sectors, in the fields of trade, environment, agriculture and surveillance [4]. Murugan et al. have worked on drone applications for better agricultural productivity and food management [5]. Reinecke and Prinsloo have used drones for for maximizing their harvest by early detecting pests and water shortages [6]. Pulver and Wei have emphasized on that UAVs are increasingly proposed for medical implementation due to their potential to transport medical supplies quickly and efficiently [7]. Bravo et al. have designed a drone that carries a first aid kit (bandages, alcohol, cotton, gauze, water, and other emergency and survival products) and has real-time audio and video communications capabilities [8]. The drones could be used in numerous mission that are simply too dangerous such as exploration or toxic waste cleanup. Dunnington and Nakagawa have used drone mounted with gas sensors for detecting underground coal fire [9]. The UAVs have also used for Railway infrastructure monitoring [10]. The indoor mapping and outdoor navigation could be done easy with mini aircrafts [11]-[14]. Dilan et al. have demonstrated that that drones can be very useful in search and rescue operations.

The UAVs like drones are being used in specific tasks such as sensing, tracking, transport, safety, search and rescue. In general, the drones just collect raw information about environment periodically and send data to control center. The control center is the management place that operates drone and process the data. The disadvantages of communication between center and drone are follows;

- Drones have a limited battery energy and finite flight time whereas it is expected to operate for up to 10-15 minutes. So, the drone should find the target and communicate with center in its limited flight time.
- Drone and center are using communication module such as RF (radio frequency), Bluetooth and Wi-Fi (Wireless Fidelity). There are communication range between center and drone. If the drone is out of the coverage area, drones can not interact with center.
- The communication between drone and control center needs to be quickly adapted to changes in the distance.

In this paper, we address a search and rescue scenario where drones are deployed to monitor events on a large area, and transmit data to control center. To overcome the difficulties given above the networks and hierarchical tree topology is proposed. The aim of the networks is that ensure maximum performance with minimum energy consumption.

In the remainder of this work, hierarchical tree topology, drone network, protocol description and used data transmit model are explained in Section 2, simulation of the drone networks for search and rescue scenario is described in Section 3, Section 4 which is final section shows the results of this study and concludes our work.

II. System Design

The proposed drone network system consists of three main parts; the slave drones (SDs), the master drone (MD) and the control center (CC). The system model can be considered as a Wireless Drone Network (WDN) architecture with hierarchical tree topology as shown in Figure 1.

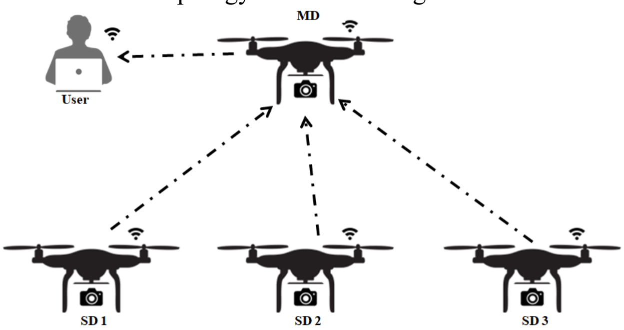

Fig. 1. Wireless Drone Network with hierarchical tree Topology.

For the search and rescue operation, the seek area is first divided into subfield such that each SD can fly whole area in the flight time. The SD can be considered as an explorer of the system. Each SD is responsible for the one subfield and it has to report data to the MD. Operating in large areas could present challenges in communication between SDs and CC. The MD can be considered as a data pathway. The proposed model is based on MD. If MD is out of coverage, the proposed communication model fails. In this study, MD's flight boundaries are set so that the MD does not reach the coverage area.

The data from the each subfield is transmitted to CC via MD. Thanks to MD, drones can set up temporary secure communication networks. To increasement the trustworthy, the data is controlled in two place; MD and CC where the place is respectively middle and end of the communications path. MD also coordinates and positions SDs. CC allows the user to monitor and analyze the drone parameters like battery information, coordinates and sensor data.

Fig. 2. The image of the drone used in this project.

In this study, a periodic transmission model is used. In the periodic transmission model, data transmission from the SDs was performed every 5 seconds. The results of the periodic submission model ensure that all changes in the physical environment are observed.

The communication package consist of Drone ID, password, coordinates, sensor values and CRC test function result as shown Figure 3. Each drone has a specific ID number. Each datapath between SDs and MD has its own unique password. The drones that use a datapath have to add the datapath's password to the data packet. MD checks the password field before processing the incoming data. If the incoming password is the same as the password of the data path, data transmission is performed. The coordinates of the each drone is the necessary and most significant information for the coordinate the whole network. The data transmitted by the transmitter to the network are checked with the cyclic redundancy check (CRC) to determine whether the receiver received the same data from the network. In the CRC method, the data is processed through a predetermined function such as addition, subtraction, deconvolution before the transmission. The function results are written in the CRC field of the resulting packet structure. The receiver applies the same function without receiving the data and compares it with the value of the resultant CRC field. If the calculated CRC and received CRC is the same, it indicates that the data is transmitted without errors from SD to CC [15].

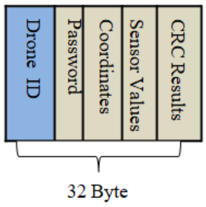

Fig. 3. The communication package of the SD.

In this work, nRF24L01 RF transmitter receiver module is used for wireless data transfer between SDs and MD. The nRF24L01 module has a working frequency of 2.4 GHz. In the case of using without using the antenna, the open field communication is between 20-200 meters, while the distance with antennas is 250-900 meters. It can transfer data to 125 different channels [16].

Physical Layer	Raspberry Pi 3
	NRF24L01 RF Module
MAC Layer	CSMA/CA
	ACK
	Channel Change

Fig. 4. The protocol description.

As shown in Figure 4, the protocol used is divided into the physical layer and MAC layer. The network structure designed in this study can be thought of as wireless sensor networks. In wireless sensor applications, it is important to reduce the energy consumption of the nodes to the minimum, just like in the drones. In order to minimize the energy consumption of the nodes in wireless sensor network applications, it is necessary to focus on the design of MAC layer protocol [17]. In the MAC sublayer, the channel accesses and packet transmissions of the nodes are controlled. The MAC layer protocols are examined in two groups: time based and competition based [18].

For n drones in a hierarchical tree network, the calculation of the necessary channel number can be shown as follows;

$$Channel\ Number = n \quad (1)$$

The competition based model is used for the proposed network. Carrier Sensing Multiple Access (CSMA) technique is used for channel access. With CSMA, a node listens to the communication channel before sending the packet to the network, and sends packets to the network if the channel is not being used by another node [19]. The main disadvantage of the CSMA technique is that some nodes can not detect the packet transmission. This problem causes multiple nodes to send packets at the same time and cause collision problem [20]. To solve this problem, collision avoidance carrier sensitive multiple access (CSMA / CA) technique has been developed [21].

In our proposed model, channel accesses and packet transmissions of the drones are controlled by the CSMA / CA technique as shown in Figure 5.

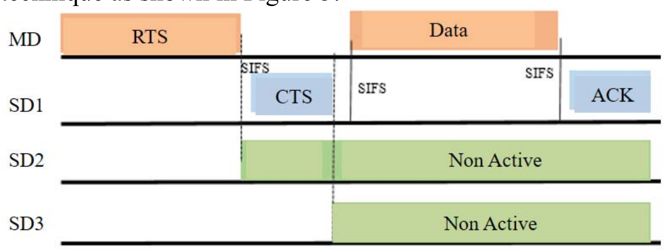

Fig. 5. The CSMA / CA technique.

For our scenario, The SD1 sends RTS (Request to Send) signal to MD inquire whether the channel is available for the data transfer. If MD is available, CTS (Clear to Send) signal is sent and data transfer between drones is started. After the data transfer is completed, the ACK (Acknowledgement) signal is sent from the receiver to the transmitter.

As shown in Figure 5, the SDs compete for the channel access. As a result of the competition, the drone which receives the CTS signal from the MD starts data transmission. Meanwhile, the other drones delay the communication for a certain period of time because of the channel is busy. At the end of this period, the channel will re-listen and if the channel is ready to communicate, a new competitive process will start.

In this study, 2 different channels are used for data transfer between SDs and MD and between MD-CC.

III. Simulation Overview

For the simulation of the drone networks, it is important that the simulation infrastructure must allow the placement and testing of the same topology that is to be eventually placed on the field [22]. V-REP, a well-known framework for robot software development, fast algorithm development, factory automation simulations, fast prototyping and verification, remote monitoring, have used for the proposed protocol and topology. The network control can be described in Algorithm 1.

Algorithm 1. The pseudocode of the Control Method

Step 1	CC assigns MD and SDs.
Step 2	MD gets position data of each SDs.
Step 3	MD sends SDs coordinate data to CC.
Step 4	CC calculate the each drones pathway.
Step 5	CC sends pathway data to the MD.
Step 6	MD sends pathway data to SDs.
Step 7	MD and SDs start the search operation on own pathways.
Step 8	If the target is not found go to step 2.
Step 9	MD gets coordinates of the target and transmit to CC.

As shown Figure 6, the seek area is first divided into 100 square parts. The Wi-Fi communication zone contains about 55 parts which are equal to control range 1.5 kilometers. It means that it is possible the communication between drone and user if the drone is in the blue circle as shown Figure 6. If the drone is the out of the blue circle, there is no interaction between user and drone. That's why communication distance needs to be increased. The increased communication distance (CD) can be shown as follows:

$$CD = \pi(r + \textstyle\sum_{i=0}^{n} Ri)^2 \quad (2)$$

in which r is the telemetry range, n drone number, R_i is the communication distance of the i.th drone.

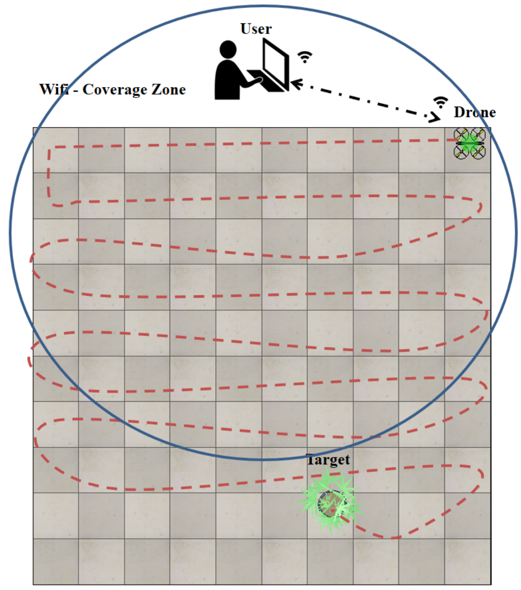

Fig. 6. The seek area of implentation.

On the other hand, the seek area is set to a flight time of 15 minutes. It means, drones can fly whole are just 15 minutes. According to the simulation result, the target is found by a drone in about 12 minutes. The calculation of flight times used in the simulation is as follows;

$$Flight\ time = \frac{m * X}{V} \quad (3)$$

in which m is subfield number, X is the dimension of the each subarea and V is the velocity of the each drone.

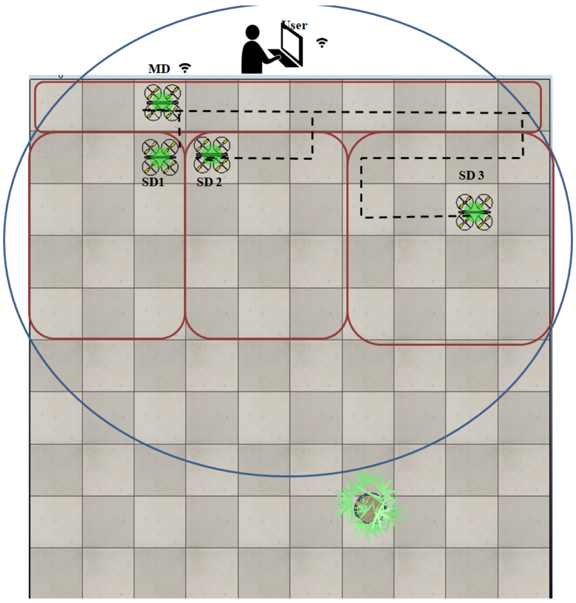

Fig. 7. The first subfields generated by user.

As shown Figure 7, the user generates subfield for the each drone as. During the generating subfield process, user can consider drone properties such as acceleration, velocity and dimension.

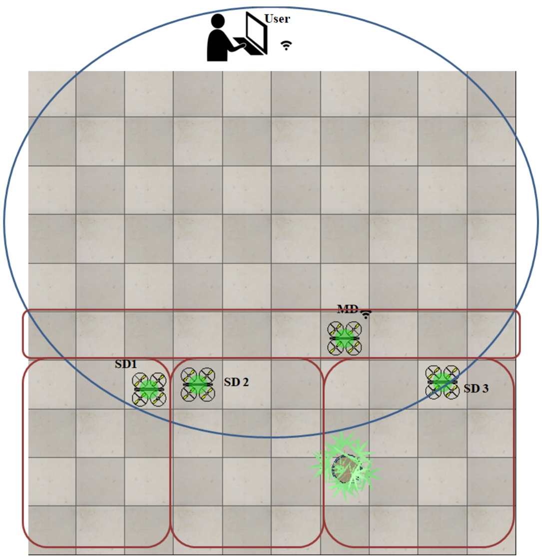

Fig. 8. The second subfields generated by user.

It is important that the subareas do not interfere with each other as shown Figure 8. So after the creating the subareas, user send the coordinates of the each drones to MD. MD forward coordinates information to each SDs.

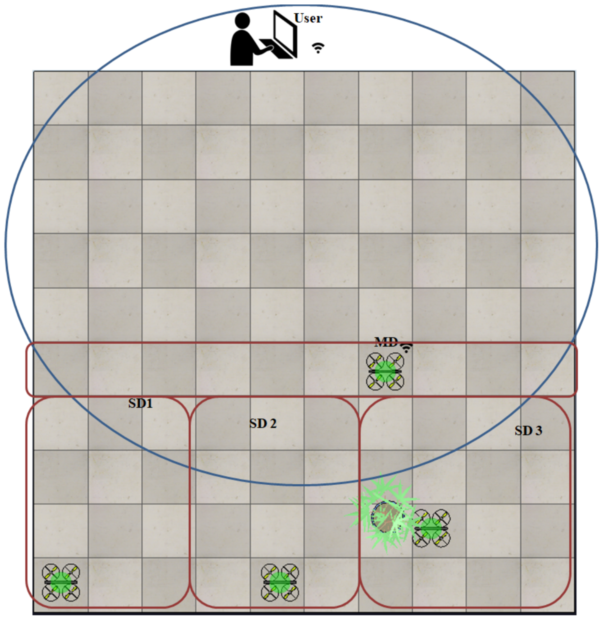

Fig. 9. The target is found.

Search and rescue operations continue until you find the object or finished the whole seek area (Figure 9). Then, SD which is found target send data to a user via MD. If the user approves the information, search and rescue operation is ended.

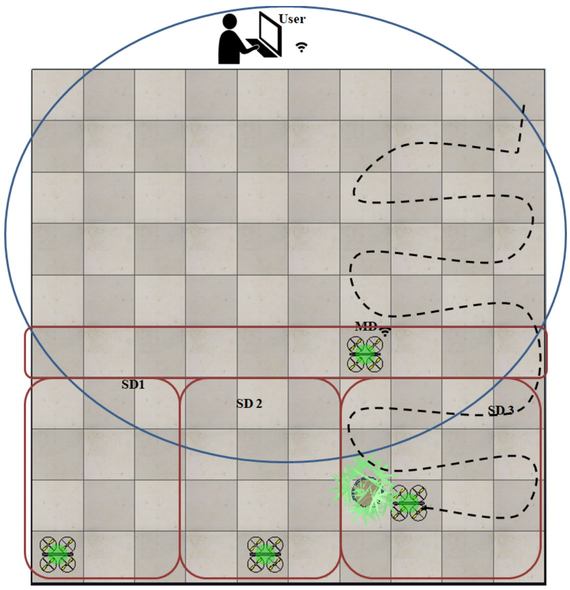

Fig. 10. Drone network application image.

The path the SD3 is used is shown in the Figure 10. According to the simulation result, the target is found by SD3 in about 4,3 minutes.

IV. Results And Conclusion

This paper presented the design and simulation of the hierarchical tree topology based wireless drone networks. The proposed communication schema between drones has been tried by using real drones without lifting off. The simulation works of the proposed design are essential to evaluate to the topology and protocol integration before field trials.

Methods	*Communication Range*	*Communication Range Increasement*	*Communication Type*	*Time*
Classical	1,8 km	✗	RF	12 minutes
Proposed	2,8 km	✓	Wi-Fi, RF	4 minutes

Fig. 11. The results of the proposed and classical methods.

The telemetry circuit is used for the conventional drone communication systems that have a limited range. To increasement of the range, hierarchical tree topology based drone network is proposed. The results show that the enhancement of data transfer range is possible from 1.8 km to 2.8 km. Also, the proposed method is quicker than conventional method for the search and rescue operation as shown Figure 11.

Future work will consider the development of fully automated architecture, in which the MD computes coordinate and creates subareas.

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