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Cooperative decision making using a collection of autonomous quad rotor unmanned aerial vehicle interconnected by a wireless communication network

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Abstract

In recent years, the problem of designing a cooperative communication system to support a swarm of Unmanned Aerial Vehicles (UAVs) is a major research challenge. In this paper, we present a time-effective approach for multiple UAVs conducting a collaborative search algorithm, this approach is targeted for sensing the disaster zone and finding the survivors in most efficient manner. In this respect, we consider a swarm of autonomous quad rotor UAVs that serve as a mobile sensors; communicate through a wireless link and equipped with a sensing devices. We aimed in this approach for the cooperative UAVs to coordinate their actions and behave as an intelligent array of sensors during the searching, detecting, and locating survivors. This approach has the ability to move the UAVs to the required location and finally achieving a cooperative decision making. A simulation of cooperative quadrotor UAVs is implemented using the Optimized Network Engineering Tool (OPNET). We develop a module for each UAV in which it is responsible for searching, detecting, and locating survivors. Moreover, this module is responsible for the wireless communication between the quad rotor UAVs. Performance of a cooperative decision making technique is observed when communication range and number of UAVs are varied. The results indicate that the number of quadrotor UAVs was found to have the greatest impact on the total time that is taken for detecting, and locating survivors. The findings demonstrate that the proposed approach can be used to search a large disaster zone in a very short time.

Keywords: Mobile Ad-Hoc Networks, Quad Rotor Unmanned Aerial Vehicle, Natural Disasters, Cooperative Decision Making.

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1. Introduction

Recently, natural disasters have happened frequently and caused immense suffering and loss of life. As an example, earthquakes and volcanoes have the capability to destroy large area and take life of many people. Those disasters pose a challenge to all countries in the world. Some countries established a series of disaster emergency mechanisms, including a disaster early warning system and information sharing mechanism.

Unfortunately, such mechanisms are not sufficient to dispatch the rescue teams into the disaster area to find the survivors and provide them with the first aids in a short time. Moreover, the response time for some of these mechanisms is too long during a chemical disaster. In our believe, The efficiency of any approach strongly relies on the time to gather the data and send it back to the rescue teams very quickly.

A feasible alternative to mitigate the above difficulties is to use a quad rotor unmanned aerial vehicles. The characteristics of such UAVs make them an attractive choice for communication application [1]. Their small size, which simplifies the take-off and retrieval, presents many advantages in developing a fully functional autonomous UAV. They have the ability to gather and broadcast the information in a short period of time. Implementation of fully decentralized architectures in a UAV may provide higher level of cooperation in mobile Ad-Hoc networks and thus makes them equivalent to low altitude satellites.

An unmanned aerial vehicle can be defined as an aircraft without a human operator, equipped with the necessary sensors and communications systems. They are capable of performing different flight missions in a fully autonomous way. In general, unmanned aerial vehicles can be characterized into the following four categories [2]: fixed-wing flying vehicles, rotor craft, flapping-wing models and other unconventional designs. All have a unique features such as small size and low cost. Among them, a rotor craft or a quad rotor unmanned aerial vehicle is currently the most popular choices for scientific research.

Quad rotor unmanned aerial vehicles are envisioned to be useful during the natural disasters. They are powered by four brushless/brushed motors with fixed pitch blades. Altitude, roll, pitch and yaw motions are controlled by changing the speed of
the motors. Those UAVs are capable for collecting data from multiple points. Moreover, they have the ability to sense the disaster zone and find the survivors in most efficient manner. Quad rotor unmanned aerial vehicle can be equipped with an ultrasound high-speed gas sensor [3]. This sensor is able to detect the concentration of gas with high sensitivity and thus detect the human respiration.

A key requirement for a cooperative decision making in such a quickly changing situation is to automate the operations of the UAVs. During a disaster, two big problems may face the rescue teams: the time limit and the size of the disaster zone. The time period immediately after the disaster has struck is very critical. Moreover, if the size of the disaster zone is large, rescue operations become more difficult with the traditional methods. The best way to facilitate the previous problems is the use of a quad rotor unmanned aerial vehicle, they can be deployed to the disaster areas very quickly; fly close to the area of interest and search for survivors all over the disaster zone in a very short time. In that respect, we propose the use of a quad rotor unmanned aerial vehicle that equipped with a sensing device, GPS receiver and a WiFi technology with the aim of searching for survivors all over the disaster zone in a very short time. The remainder of this paper is organized as follows. In the next section we start with a survey of current research regarding the concept of using UAV swarms for cooperative search mission. In section 3, we discuss the system overview. In section 4, we explain and present our UAV model that is conducting in OPNET simulator. In section 5, we present and discuss the simulation results. Finally, we conclude and discuss future work in section 6.

2. Related Work

A number of studies have been proposed for cooperative search mission that involves several homogeneous UAVs. The authors in [4], [5], [6], and [7] focus on the systematic search for a target in a large area. They gave an overview of a cooperative control strategy for aerial surveillance using fixed wing UAVs. The authors in [8] present a cooperative search system in which a swarm of UAVs search and monitor the ground for enemy targets. They are communicating cooperatively to locate the targets and then send the target’s coordinates to another platform. The authors investigate the effect of the realistic wireless communications upon a group of UAVs conducting a distributed global search algorithm; their results indicated that communication ranges and number of UAVs have a significant impact on the group's ability to search an area for locating targets. Flying UAV over a wireless Ad-Hoc network may help to enhance the rescue operations. In such scenario, the UAV acts as a node and generates, receives, and forwards data packets to the ground station. In [9], the authors introduced an Ad-Hoc wireless mobile network that employs a hierarchical networking architecture. They incorporated the use of unmanned aerial vehicle to enhance the operation of the network, and to achieve a more stable backbone system.

A cooperative network of UAVs has the potential to find survivors using relatively simple rules at an individual level. In [10], the authors present a control strategy for groups of vehicles to move cooperatively in response to a sensed environment. They focus on the gradient climbing missions in which the mobile sensor network seeks out local maxima or minima and adapt its configuration in response to the sensed environment. In [11], the authors present a collaboration algorithm to be used during the execution of a sensing task. They aimed to combine the shared and local information with the goal of minimizing the global cost of the mission under the supervision of a single user. The concept of mobile sensor networks was presented for the purpose of a cooperative search. Recently, a number of studies have been proposed using this technique. As an example, gradient of the field [10], Newton step approximation [12] and Grid cell based search using probability of detection models [7]. Such studies must focus on solving the search problem as quickly as possible, it is also necessary to incorporate the dynamics of the UAVs with the ability of the real sensors.

Impact of wireless communication was investigated upon a swarm of vehicles conducting cooperative search algorithm. The authors in [13] compare two cooperative control algorithms for the aim of searching, detecting and locating mobile RF targets. They summarized their finding as follows: the first algorithm minimizes the total search time, while the second algorithm minimizes the time to localize targets after detection. The authors in [14] also evaluate two cooperative algorithms to search mobile RF targets using multiple VAVs. They used two techniques in their study: Kalman estimation technique and triangulation technique. In [15], the authors present an algorithm for locating a mobile radio frequency (RF) target. They use Kalman filtering technique as [14] did to combine sensor values captured by a swarm of UAVs. They claim that this algorithm has the ability of minimizing the target location error. The results presented in the previous studies [13], [14] and [15] indicate that communication channel must be perfect amongst UAVs to locate the mobile RF targets. Also, communication ranges as well as the number of UAVs have a significant impact on the cooperative search algorithms to search large area.

3. System Overview

The system proposed in this paper includes four, eight and twelve quad rotor UAVs, shared data communication network, sensors and GPS. The data communication network is based on 802.11 standards. The ultrasound high-speed gas sensor [3] is proposed to be used in such systems. This sensor is able to detect the concentration of gas with high sensitivity and thus detect the human respiration. The GPS is responsible for the location of the survivor. Each quad rotor UAV can be viewed as a node equipped with sensor, GPS and 802.11 technologies. We assumed that all quad rotor UAVs are placed over the disaster area and flew at different altitudes. The distance between UAVs will not go beyond 300m. The cooperative decision making systems obtain the position of the survivor via a communication network. The movements of quad rotor UAV is controlled by broadcasting the position of the survivor. As a result, all quad rotor UAV have to move to the new location embedded in the transmitted packet, then they should reposition themselves in a self-organized manner.

As described above, when the model captured sensor values indicating whether a survivor is detected, the quad rotor UAV orbits the survivor and generates a packet including its position. This packet is broadcasted to other UAVs. Upon reception this packet by other UAVs, the mobility model will command the UAVs to move to the captured location and orbiting a survivor to share information and cooperatively locate its position. As the UAVs approach the given location, they will detect the survivor as the first UAV did and broadcast their locations.

If the first UAV captured four packets having the same location, it will send a message to the rescue teams telling them the survivor location.

4. UAV Implementation in OPNET

The node model for each quad rotor UAVs is shown in Fig. 1. This model is slightly different from the original OPNET model. We added two sub modules to the original OPNET model in order to implement our approach: survivor module and mobility module. Those sub modules process and react to the information contained in the packets. Following is a brief description for the functionalities of each module: Source module generates packets in the event of detecting any survivor. Sink module destroys the packet after extracting the location of the survivor and trigger the mobility module to move the UAV to the desired location. Wlan_mac_intf receives packets from the source module, wireless_lan_mac and delivers packets to the sink module and wireless_lan_mac. Wireless_lan_mac is used to implement the MAC layer. Wlan_port_rx0 is responsible for receiving packets from others UAVs. Wlan_port_tx0 is responsible for transmitting packets to others UAVs. Survivor module is responsible for triggering the source module to generate a packet in the event of detecting any survivor. Finally, mobility module is responsible for moving the UAV to the location that is extracting from the received packet.

The function of the wireless_lan_mac is left unchanged. Just we change the retry parameter from seven to two in order to minimize the delay. The source module has been modified to generate packets based on the signal coming from the survivor module. As mentioned above, the functionality of the sink module is to destroy the packets coming from the MAC layer. This module has been also modified to trigger the mobility module to move the UAV to the location embedded in the packet. As soon as all UAVs are moving to a new location, the experienced disaster assistance and rescue team can take one decision regarding the location of the survivor.

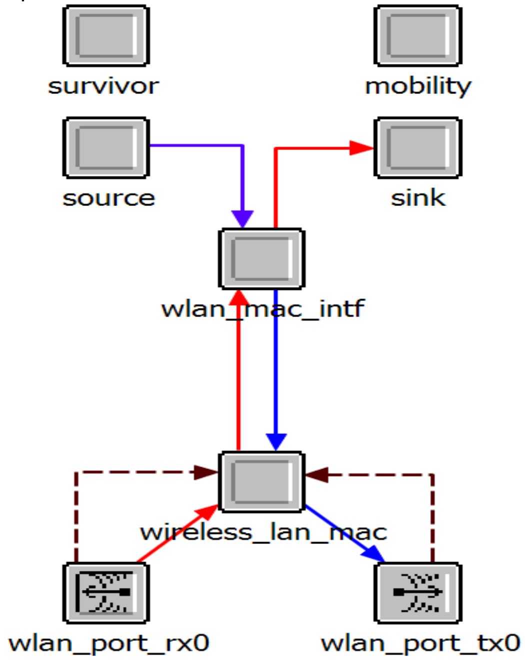

Fig.1. UAV node model.

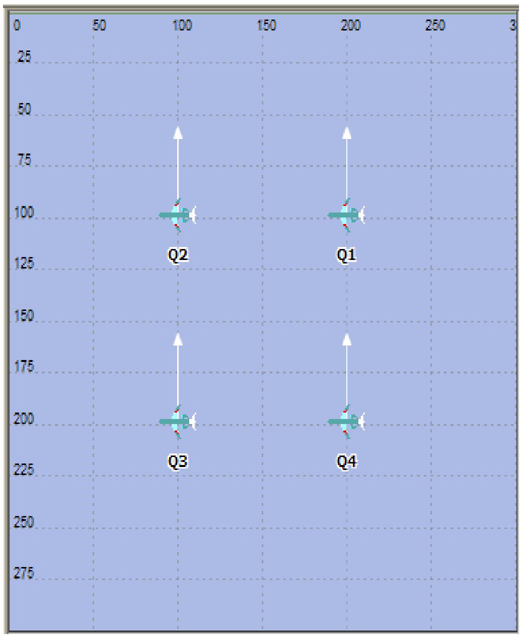

Fig. 2. Simulation scenario for four UAVs.

5. OPNET Simulation Results

In this paper, we present our findings in the form of simulation results. In the near future we will built the hardware and implement our proposed approach. We conduct our simulations under three different scenarios: Four UAVs, eight UAVs and twelve UAVs. In the first scenario, four UAVs are placed in a deployment area of 300

X 300 m. This area is divided into a grid of 12 x 6 cells; thus, each cell has dimensions of 25 x 50 meters as shown in Fig. 2. Each UAV represents anode and transmits packets using a 1mw power level, the data rate is 11Mbps and the simulation period is set to 60 minutes. The packet size is set to 512 bytes and the distribution is exponential. The UAVs are moving in the simulation area according to a random waypoint model with a constant speed of 10 m/sec.

Four metrics are used to evaluate the performance of the proposed approach: Throughput, packet sent, packet received and delay. The number of packets that are successfully received per unit time is the measure of throughput. Generally speaking, the achieved throughput may be low due to highly congested network scenario or due to infrequent use of a network. Based on our previous assumption, the network is used as soon as sensors indicate servitors; thus, throughput in this approach gives an indication of how many survivors are located through the entire area. Combining this data with the number of packets sent or received can give an indication of the effectiveness of our cooperative decision making in reducing the time to locate survivors.

Fig. 3 shows the performance comparison results for throughput against transmission range using four, eight and twelve UAVs. The throughput of the wireless system can be defined as the number of packets received correctly. From the figure, we can see that the maximum throughput is achieved using eight UAVS and not twelve UAVs. The reason for this is due to highly congested network scenario. The common trend in our approach is that the effect of the UAVs number is significantly negative for throughput. Combining this result with what stated before; as the number of UAVs is increased for a fixed network size, the network becomes congested and no meaning for throughput regarding the number of survivors. On the other hand, to validate this assumption, larger network size may result in improving throughput through the use of an efficient routing algorithm.

The next Fig. 4 presents our results regarding the total packets sent using direct transmission to destination. Combining these result with that shown in Fig. 5. The total packets in both directions are higher than the result presented before. Both results indicate that eight UAVs are sufficient for our approach for the area less than 250x 250 m.

Fig. 6 shows the End-to-End delay for different numbers of UAVs. End-to-End delay represents the time interval that is calculated from the instant a packet is generated by the source node to the instant that the packet is received by the destination node. The figure shows that eight UAVs provide smaller End-to-End delays than four and twelve UAVs. The previous results are consistent with what is shown here. Thus, for the proposed area; eight UAVs are capable for searching, detecting, and locating survivors in most efficient manner.

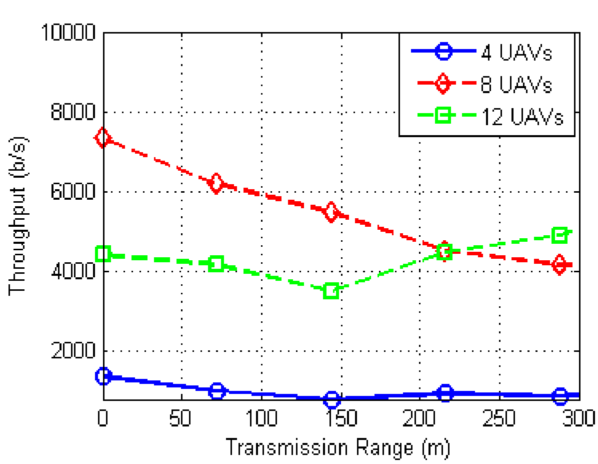

Fig. 3. Throughput vs. transmission range for different UAVs.

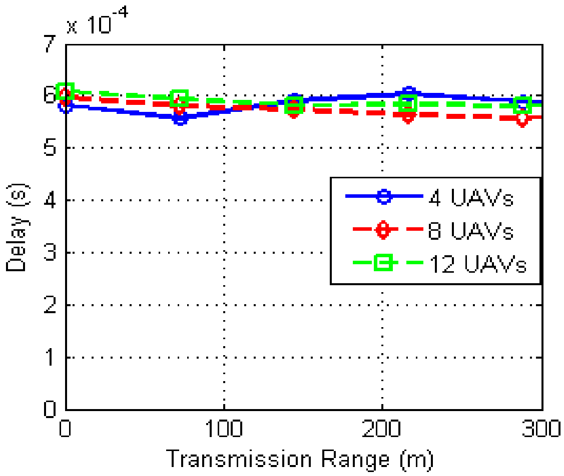

Fig. 4. Traffic sent vs. transmission range for different numbers of numbers of UAVs.

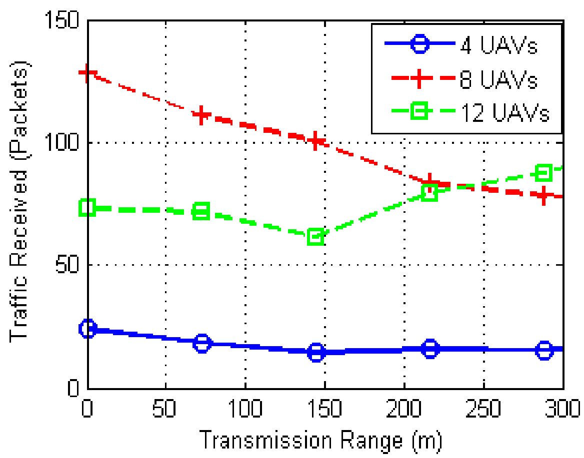

Fig. 5. Traffic received vs. transmission range for different numbers of UAVs.

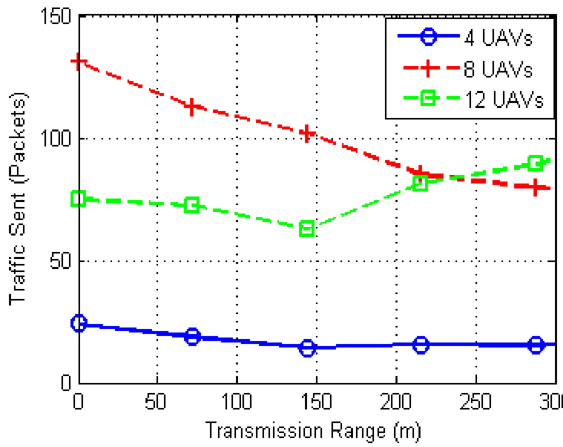

Fig. 6. Delay vs. transmission range for different numbers of UAVs.

6. Conclusion and Future Work

In this paper, we present a time-effective approach for quad rotor UAVs that are conducting a collaborative search algorithm. This approach combines shared and local information to produce an accurate decision regarding the position of the survivor with the goal of minimizing the time for sensing the whole disaster area. Using OPNET simulator, the results demonstrate that quad rotor UAVs can perform a quick search to the disaster area with low latency. Another contribution of this paper is to build the hardware and implements the proposed approach in the near future.

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