Flying Ad Hoc Networks (FANET) Test Bed Implementation

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***Abstract*—One of the most important design problems for the multi unmanned aerial vehicles systems is communication between UAVs. In a multi-UAV system, the communication between UAVs is provided with all UAVs connecting directly to the ground station via satellite or infrastructure. However, infrastructure or satellite-based communication architectures restrict the capabilities of the multi-UAV systems. Infrastructure or satellite-based communication problems of multi-UAV systems can be solved with ad hoc networks among UAVs. This special ad hoc network structure is called as FANET. In this paper, a FANET test bed implementation study is presented.**

***Keywords*—Multi UAV systems (MUAV), Flying Ad Hoc Networks (FANET), connectivity, test bed implementation.**

I. Introduction

As a result of developments at electronic sensors and communication technologies, the production of unmanned aerial vehicles (UAVs) has become possible. However, the mission capability and flexibility of one large UAV is limited. With the advancement of embedded systems and reduction of micro-electromechanical systems, instead of a single large UAV, the cooperation of multiple small UAVs is ensured. As a result of this, the creation of the systems beyond the capability of a UAV has become possible and this has proved to be very advantageous. Communication is one of the most important problems which has been encountered when trying to ensure the coordination of multi UAVs systems. One of the methods developed to solve the problem of communication between UAVs is Flying Ad Hoc Networks (FANET) [1]. An ad hoc network is a distributed wireless network structure that allows communication among nodes without the need for infrastructure [2]. In this study, studies on the implementation of a FANET network architecture test environment are presented.

As the number of UAVs used in the same systems increase, the design of an efficient network architecture becomes an important problem. The network architecture designs, shown at Figure 1, are developed to solve the communication problem among multiple UAVs [3]. In accordance with Figure 1(a), all UAVs must be attached to only one ground station. However, when this architecture is employed, the operation area is limited to the communication range between UAVs and the ground station. In order to solve the range restriction issue, UAVs can be connected to a satellite instead of a ground station. However, in this case, the cost would be high and the heavy satellite communication hardware would need to be mounted to every single UAVs. On the other hand, this system will not be able to be used in some certain situations, such as extreme weather conditions. Another communication architecture is to use more than one ground station for multi UAV systems, as in Figure 1(c). However multiple ground station architecture will not be suitable for military and disaster application scenarios. Because the infrastructure cannot be trusted in such a situation. Another communication architecture is Flying Ad Hoc Networks, which is shown in Figure 1(d). The employment of this architecture establishes ad hoc network among UAVs and thereby can solve the communication range restriction problem. According to this architecture, while some UAVs communicate with the ground station or via satellite, other UAVs with no direct communication with ground station can employ their communication via FANET structure. The most important advantage of flying ad hoc networks is their ability to provide real-time communication without need of any infrastructure.

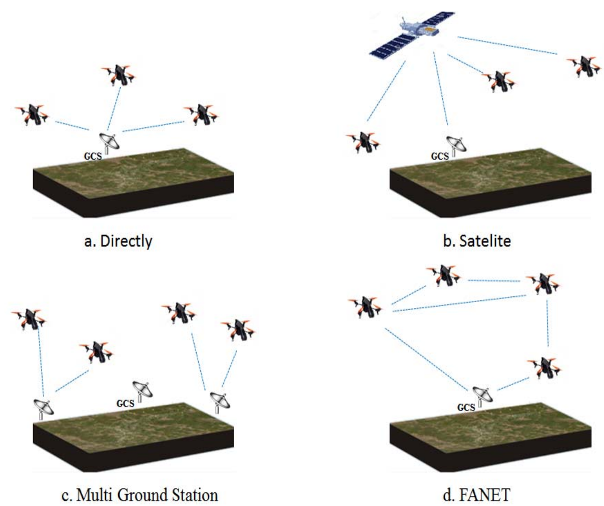

Fig. 1. Multi-UAV communication design architectures.

FANETs are considered as a different ad hoc network structure as opposed MANETs or VANETs due to their unique features [1]. Important differences between current ad hoc networks and FANETs are listed as follows:

- For a typical application, we can consider the node of a MANET as a walking man whereas the node of a VANET as a moving car [1]. But the FANET nodes are UAVs and UAVs can reach much higher speeds. For this reason, FANET nodes move faster than MANET or VANET nodes. Depending on the high mobility, FANET topology can change at a faster pace.
- Communication among nodes is the priority for current ad hoc networks. Nodes at FANETs which ensure communication among UAVs is also important. However, the most important reason to use multi-UAV systems is to collect information from the environment. Therefore as is the case for wireless sensor networks (WSN) as well as, for FANETs, they both relay the collected data to a data center. Most probably, the center is the sink in WSN, and it is the ground station in FANETs. With FANET structure, communication with both between UAV-to-UAV and between the ground station-to-UAV must be provided.
- Distance between UAVs can be longer than the distance between MANET nodes and VANET nodes. This situation also affects the links outages between UAVs.
- For multi UAV systems, lots of different sensors are evident. Each sensor can have a different communication requirement. In this situation FANET should have the flexibility to provide different requirements.

The main motivation of this study is to ensure the realization of a FANET structure, which have gained popularity around the world in recent years [4-6]. This test bed is realized with low cost and easily available hardware, so that all researchers can implement their own FANET test bed with limited budget.

The organization of the paper is as follows. Section 2 covers the application scenarios of the FANETs. The implementation details of FANET test bed is covered in Section 3. Section 4 concludes the paper.

II. Flying Ad Hoc networks

For multi UAV systems, FANET is one of the most effective ways to relay the collected information to the ground station without any infrastructure.

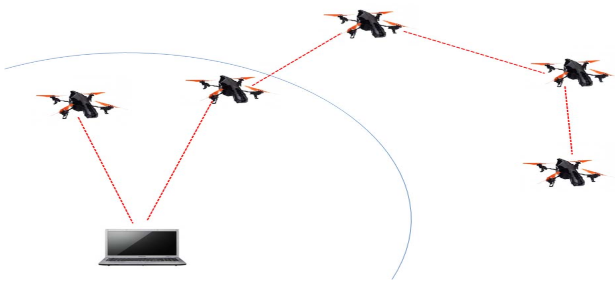

Fig. 2. A FANET scenario to extend the scalability of multi-UAV systems.

As in Figure 2, while some specific UAVs are at the range of the ground station, FANET is used to communicate with other UAVs which are not at the ground station. As a result of this all the UAVs including the ones which are out of the communication range can transmit information to the ground station at any time. Four examples of FANET usage scenarios are presented below.

A. Relaxing the Communication range Restriction

In multi-UAV systems, all UAVs in the system can be connected to a single ground station. However in this case the operation field is limited to the communication range of UAVs with ground station. Also with FANETs, the range of the formed structure is not limited to the range of the ground station due to the fact that UAVs that cannot establish a direct link with the ground station but can communicate with the UAV ground station via other UAVs.

B. Reliable Communication in Multi UAV Systems

UAV systems can operate in highly dynamic environments. For example, a task may change during operation and also a connection between the ground station and a UAV may be interrupted during operation due to the adverse weather conditions. As shown in Figure 3, connection between disconnected UAV from the ground station and other UAVs is maintained if the multi-UAV systems architecture supports FANET. Reliability of the multi-UAV systems is increased with such connectivity [1].

C. Coordination of Multi UAV Systems

Small and mini UAVs are very lightweight and they have low payload capacity. Despite the limited capabilities of single UAV, more complex tasks can be performed by multi-UAV systems. Collaborative actions of UAVs require continuous communication with each other. However, due to the limited load capacity of the UAVs, they may not be able to carry heavy communication hardware to enable communication between the UAV and the ground station. FANET architecture can be used to establish a connection between the mini-UAVs with lighter and cheaper hardware. Collision can be avoided and also FANET architecture can provide coordination between UAVs in order to complete the mission successfully.

D. Reduced Payload and Cost with FANET

Payload problem is not only valid for small UAVs. At the same time, in high-altitude and low-endurance UAVs, payload is extremely important. Less payload means higher altitude and longer endurance [7]. If the communication architecture of the multi-UAV systems will be based on completely ground station and UAV, UAVs must carry a relatively heavier communication hardware for communication.

If FANET is used in multi-UAV systems, connections are established between a specific UAV and the UAV ground station and other UAVs are also able to communicate with each other through FANET. When FANET is used in this way, the durability of multi-UAV systems can be increased.

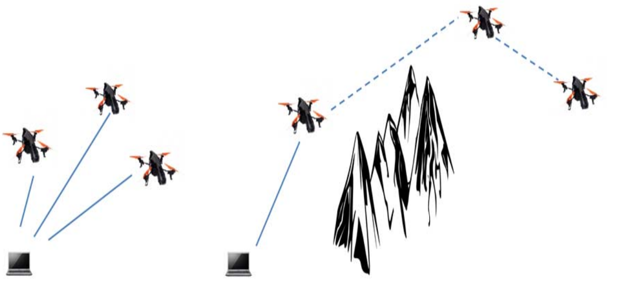

Fig. 3. A FANET application scenario for reliable multi-UAV communication network.

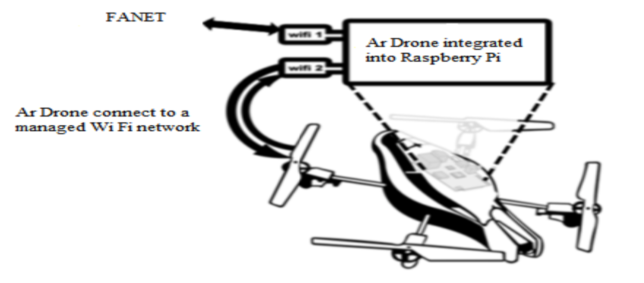

Fig. 4. The representation of FANET test bed implementation with Ar.Drone and Raspberry Pi.

III. Implementation of Flying Ad Hoc Network

The main objective of this study is to realize the implementation of a low-cost test bed for FANETs. Due to its low cost, easy deployment and ease of structural development, Ar.Drone 2.0 is used as the UAV platform [8]. Ar.Drone can be controlled by a 802.11 connection.

Connection to Ar.Drone can be established through the its wireless network module. However, this module does not support the ad hoc network structure, and it cannot be used for establishing an ad hoc network between UAVs. In order to operate an ad hoc network between Ar.Drones, a light weight and low cost computational unit must be mounted on top of the Ar.Drone. Ad hoc network can be formed by Raspberry Pi Model B that possesses have these features. Raspberry Pi model B which has dimensions of 85mmx54mmx17mm and a weight of 45 gr. is a mini single-board computer [9]. It can be easily mounted on Ar.Drone due to its small size and light weight. Raspberry Pi Model B can work with 3.3V or 5V and can use Ar.Drone's battery directly. Unfortunately, Raspberry Pi Model B does not have the hardware to support wireless communication. However, the wireless network card can be added to the USB port in order to support Wi-Fi. The Wi-Fi dongle which is added to Raspberry Pi is used to establish ad hoc networking. An ad hoc network structure can operate on Raspberry Pi with some additional software and Raspberry Pi is only run on ARM-compiled software because it has a ARM-based processor. Therefore, FANET structure is created by the Byzantium operating system installed on the Raspberry Pi operating system to create ad hoc networks on Raspberry Pi [10]. With this developed structure, communications between Ar.Drones that are not connected directly to the ground station are provided by FANET created with Raspberry Pi.

On the other hand, controlling Ar.Drone is another problem that must be handled. If Ar.Drone is controlled with a direct Wi-Fi connection to a central station (like a laptop or tablet), the resulting structure cannot be used as FANET test bed. UAVs in a FANET test bed can be controlled even if they are out of the communication range between ground base and the UAVs. Fortunately, Parrot, which is the producer of Ar.Drone, supply an open APIs to develop custom software. We use an open source code that can be run on Raspberry Pi to control Ar.Drones. We prefer NodeJs based open source Ar.Drone control software [11]. NodeJs begun to develop in 2009 and is a registered trademark of the Joyent company. NodeJs is a platform that is built on high-performance JavaScript engine. For the waypoint based scenario performed in the test environment, we used code fragments that written by Andrew Nesbitt in NodeJs language [12]. However, it was found to operate unstably through tests and experiments. Necessary corrections are performed in the code.

Controlling Ar.Drone is only possible through its Wi-Fi connection. Control instructions are generated with its controlling device (probably a laptop or tablet) and the instructions are sent to Ar.Drone with a UDP connection. In our FANET test bed, control instructions are generated by Raspberry Pi. However, they must be sent with a Wi-Fi connection. As previouslystated, we used one Wi-Fi dongle for ad hoc network establishment between UAVs, and Ar.Drone Wi-Fi does not support ad hoc mode. It concludes that we need one more Wi-Fi connection in Raspberry Pi. The second Wi-Fi connection is only used for controlling Ar.Drone so that it can visit predefined waypoints.

The representation of the developed FANET test bed is presented in Figure 4 and have carried out are presented in Figure 5. Raspberry Pi is mounted on top of Ar.Drone. Flight Recorder is also connected to the system so that it can provide location information of the UAV [13]. Raspberry Pi has two separate Wi-Fi connections. While one Wi-Fi is used to establish ad hoc network between the other Raspberry Pi systems, the second Wi-Fi connection is used to send control instructions generated by Raspberry Pi.

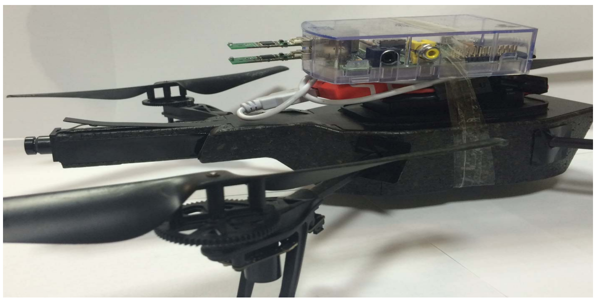

Fig. 5. The structure formed by an Ar.Drone and a Raspberry Pi.

IV. Conclusion

Multi UAVs which small and inexpensive UAV systems have great importance to fulfillment of the complex mission that can do the largest UAVs. Many different designs have been proposed to resolve the communication problem which one of the most important design problem of multi UAV systems, between UAVs. FANET that is capable of solving communication range constraints between UAV and GS without infrastructure is an important solution. In addition, a continuous flow of information through these structures is also ensured. This study presents a cost-effective and easily repeatable test environment implementation to support FANET research studies. In conclusion, it has been demonstrated that the FANET system is a low cost system that can be employed in all universities to realize the test environment.

V. ACKNOWLEDGMENT

This research was supported by The Scientific and Technological Research Council of Turkey (TUBITAK) under Grant 113E565.

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