Concept of Flying Ad-hoc Network: A Survey

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ABSTRACT : As a large amount of research for mobile ad-hoc networks has been conducted in recent years, new emerging research challenge, aircraft ad-hoc networks, has attracted considerable attention from the research community. These networks aim to construct self-organizing networks with flying aircrafts in the sky instead of typical aircraft-ground- aircraft communications. In recent years, the capabilities and roles of Unmanned Aerial Vehicles (UAVs) have rapidly evolved, and their usage in military and civilian areas is extremely popular as a result of the advances in technology of robotic systems such as processors, sensors, communications, and networking technologies. One of the most important design problems for multi-UAV systems is the communication which is crucial for cooperation and collaboration between the UAVs. Flying Ad-hoc Networks (FANET) can solve this problem easily. In this paper, FANET is surveyed; the main design issues and challenges are introduced. Open research challenges are also discussed.

Keywords: FANET, MANET, VANET, UAV,

1.INTRODUCTION.

As we know that there is a rapid change in technology advancement on electronic, sensor and communication technologies, it has been possible to produce unmanned aerial vehicle (UAV) systems, which can fly autonomously or can be operated remotely without carrying any human personnel. Because of their various property like versatility, flexibility, easy installation and relatively small operating expenses, the usage of UAVs promises new ways for both military and civilian applications, such as search and destroy operations , border surveillance , managing wildfire , relay for ad hoc networks , wind estimation , disaster monitoring , remote sensing and traffic monitoring . Although single-UAV systems have been in use for decades, instead of developing and operating one large UAV, using a group of small UAVs has many advantages. However, multi-UAV systems have also unique challenges and one of the most prominent design problems is communication. In this paper, Flying Ad-Hoc Network (FANET), which is basically ad hoc network between Flying nodes (specially UAV's), is surveyed as a new network family. It is useful in the case of multi UAV's. Although there are several advantages of multi-UAV systems, when compared to single-UAV systems, it has also unique challenges, such as communication. In a single- UAV system, a ground base or a satellite is used for communication. It is also possible to establish a communication link between the UAV and an airborne control system. In all cases, single-UAV communication is established between the UAV and the infrastructure. While the number of UAVs increases in unmanned aerial systems, designing efficient network architectures emerges as a vital issue to solve. As in a single UAV system, UAVs can also be linked to a ground base or to a satellite in a multi-UAV system. There may be variants of this star topology based solution. While some UAVs communicate with a ground base, the others can communicate with satellite/s. In this approach, UAV-to-UAV communication is also realized through the infrastructure. There are several design problems with this infrastructure based approach. First of all, each UAV must be equipped with an expensive and complicated hardware to communicate with a ground base or a satellite. Another handicap about this network structure is the reliability of the communication. Because of the dynamic environmental conditions, node movements and terrain structures, UAVs may not maintain its communication link. Another problem is the range restriction between the UAVs and the ground base. If a UAV is outside the coverage of the ground base, it becomes disconnected. An alternative communication solution for multi-UAV systems is to establish an ad hoc network between UAVs, which is called FANET. While only a subset of UAVs can communicate with the ground base or satellite, all UAVs constitute an ad hoc network. In this way, the UAVs can communicate with each other and the ground base.

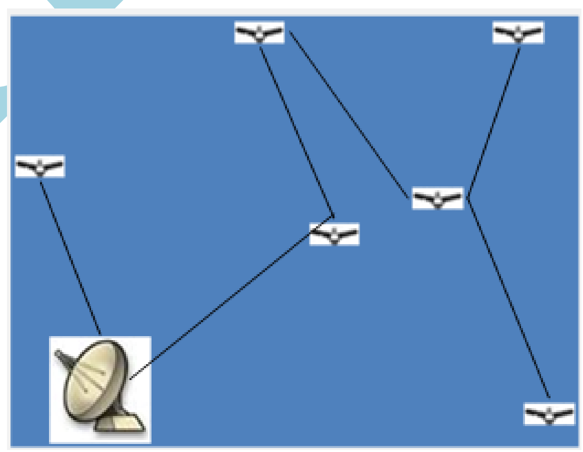


Fig. 1 FANET Scenario describing the extend scalability

II. FANET APPLICATION SCENARIOS

1. Extending the scalability of multi-UAV operations

If a multi-UAV communication network is established fully based on an infrastructure, such as a satellite or a ground base, the operation area is limited to the communication coverage of the infrastructure. If a UAV cannot communicate with the infrastructure, it cannot operate. On the other hand, FANET is based on the UAV-to-UAV data links instead of UAV-to-infrastructure data links, and it can extend the coverage of the operation. Even if a FANET node cannot establish a communication link with the infrastructure, it can still operate by communicating through the other UAVs. This scenario is illustrated in Fig. 1. There are several FANET designs developed for extending the scalability of multi-UAV applications. In [19], a FANET design was proposed for the range extension of multi UAV systems. It was stated that forming a link chain of UAVs by utilizing multi-hop communication can extend the operation area. It should be noticed that the terrain also affects the communication coverage of the infrastructure. There may be some obstacles on the terrain, such as mountains, walls or buildings, and these obstacles may block the signals of the infrastructures. Especially in urban areas, buildings and constructions block the radio signals between the ground base and UAVs. FANET can also help to operate behind the obstacles, and it can extend the scalability of multi-UAV applications [20] .

2. Reliable multi-UAV communication

In most of the cases, multi-UAV systems operate in a highly dynamic environment. The conditions at the beginning of a mission may change during the operation. If there is no opportunity to establish an ad hoc network, all UAVs must be connected to an infrastructure. However, during the operation, because of the weather condition changes, some of the UAVs may be disconnected. If the multi-UAV system can support FANET architecture, it can maintain the connectivity through the other UAVs. This connectivity feature enhances the reliability of the multi-UAV systems [16].

3. UAV swarms

Small UAVs are very light and have limited payload capacity. In spite of their restricted capabilities, the swarm behavior of multiple small UAVs can accomplish complex missions [21]. Swarm behavior of UAVs requires coordinated functions, and UAVs must communicate with each other to achieve the coordination. However, because of the limited payloads of small UAVs, it may not be possible to carry heavy UAV-to-infrastructure communication hardware. FANET, which needs relatively lighter and cheaper hardware, can be used to establish a network between small UAVs. By the help of the FANET architectures, swarm UAVs can prevent themselves from collisions, and the coordination between UAVs can be realized to complete the mission successfully. In [22], Cooperative Autonomous Reconfigur able UAV Swarm (CARUS) is proposed with FANET communication architecture. The objective of CARUS is the surveillance of a given set of points. Each UAV operates in an autonomous manner, and the decisions are taken by each UAV in the air rather than on the ground. Ben-Asher et al. have introduced a distributed decision and control mechanism for multi- UAV systems using FANET [23].In [24], a FANET based UAV swarm architecture is proposed to convey UAVs to a target location with cooperative decision-making. Quaritsch et al. have developed another FANET based UAV swarm application for disaster management [25]. During a disaster situation, rescue teams cannot rely on fixed infrastructures. The aim of the project is to provide quick and accurate information from the affected area.

4. FANET to decrease payload and cost

The payload capacity problem is not valid only for small UAVs. Even High Altitude Low Endurance (HALE) UAVs must consider payload weights. The lighter payload means the higher altitude and the longer endurance [16]. If the communication architecture of a multi-UAV system is fully based on UAV-to-infrastructure communication links, each UAV must carry relatively heavier communication hardware. However, if it uses FANET, only a subset of UAVs use UAV-to-infrastructure communication link, and the other UAVs can operate with FANET, which needs lighter communication hardware in many cases. In this way, FANET can extend the endurance of the multi-UAV system.

III.DIFFERENCES BETWEEN FANET AND THE EXISTING AD-HOC NETWORKS

Wireless ad hoc networks are classified according to their utilization, deployment, communication and mission objectives. By definition, FANET is a form of MANET, and there are many common design considerations for MANET and FANET. In addition to this, FANET can also be classified as a subset of VANET, which is also a subgroup of MANET. As an emerging research area, FANET shares common characteristics with these networks, and it also has several unique design challenges. In this subsection, the differences between FANET and the existing wireless ad hoc networks are explained in a detailed manner.

1. Node mobility Node mobility related issues are the most notable difference between FANET and the other ad hoc networks. MANET node movement is relatively slow when it is compared to VANET. In FANET, the node’s mobility degree is much higher than in the VANET and MANET. According to [16], a UAV has a speed of 30–460 km/h, and this situation results in several challenging communication design problems [33].

2. Node density Node density can be defined as the average number of nodes in a unit area. FANET nodes are generally scattered in the sky, and the distance between UAVs can be several kilometers even for small multi-UAV systems [37]. As a result of this, FANET node density is much lower than in the MANET and VANET.

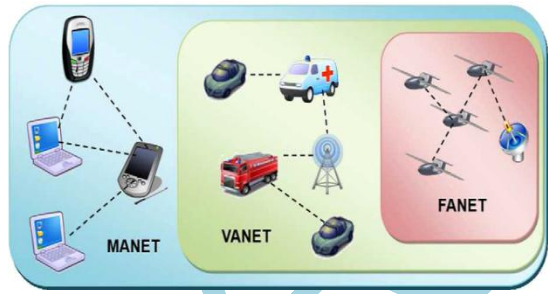
3. Topology change Depending on the higher mobility degree, FANET topology also changes more frequently than MANET and VANET topology. In addition to the mobility of FANET nodes, UAV platform failures also affect the network topology. When a UAV fails, the links that the UAV has been involved in also fail, and it results in a topology update. As in the UAV failures, UAV injections also conclude a topology update. Another factor that affects the FANET topology is the link outages. Because of the UAV movements and variations of FANET node distances, link quality changes very rapidly, and it also causes link outages and topology changes [38] .

4. Radio propagation model Differences between FANET and the other ad hoc network operating environments affect the radio propagation characteristics. MANET and VANET nodes are remarkably close to the ground, and in many cases, there is no line-of-sight between the sender and the receiver. Therefore, radio signals are mostly affected by the geographical structure of the terrain. However, FANET nodes can be far away from the ground and in most of the cases, there is a line-of-sight between UAVs.

5. Power consumption and network lifetime Network lifetime is a key design issue for MANETs, which especially consist of battery-powered computing devices. Developing energy efficient communication protocols is the goal of efforts to increase the network lifetime. Especially, while the battery-powered computing devices are getting smaller in MANETs, system developers have to pay more attention to the energy efficient communication protocols to prolong the lifetime of the network. However, FANET communication hardware is powered by the energy source of the UAV. This means FANET communication hardware has no practical power resource problem as in MANET. In this case, FANET designs may not be power sensitive, unlike most of the MANET applications. However, it must be stated that power consumption still can be a design problem for mini UAVs [39].

6. Computational power In ad hoc network concept, the nodes can act as routers. Therefore, they must have certain computation capabilities to process incoming data in real-time. Generally, MANET nodes are battery powered small computers such as laptops, PDAs and smart phones. Because of the size and energy constraints, the nodes have only limited computational power. On the other hand, both in VANETs and FANETs, application specific devices with high computational power can be used. Most of the UAVs have enough energy and space to include high computational power. The only limitation about the computational power is the weight. By the help of the hardware miniaturization tendency, it is possible to put powerful computation hardware in UAV platforms. However, the size and weight limitation can still constitute serious constraints for mini UAVs, that have very limited payload capacity.

7. Localization Accurate geospatial localization is at the core of mobile and cooperative ad hoc networks [40]. Existing localization methods include global positioning system (GPS), beacon (or anchor) nodes, and proximity-based localization [41]. In MANET, GPS is generally used to receive the coordinates of a mobile communication terminal, and most of the time, GPS is sufficient to determine the location of the nodes. When GPS is not available, such as in dense foliage areas, beacon nodes or proximity-based techniques can also be used. In VANET, for a navigation-grade GPS receiver, there is about 10–15 m accuracy, which can be acceptable for route guidance. However, it is not sufficient for cooperative safety applications, such as collision warnings for cars. Some researchers use assisted GPS (AGPS) or differential GPS (DGPS) by using some type of ground-based reference stations for range corrections with accuracy about 10 cm [42,43]. Because of the high speed and different mobility models of multi-UAV systems, FANET needs highly accurate localization data with smaller time intervals. GPS provides position information at one-second interval, and it may not be sufficient for certain FANET protocols. In this case, each UAV must be equipped with a GPS and an inertial measurement unit (IMU) to offer the position to the other UAVs at any time. IMU can be calibrated by the GPS signal, and thus, it can provide the position of the UAV at a quicker rate [44,45] . Because of the above-mentioned differences between FANET, MANET and VANET; we prefer to investigate FANET as a separate ad hoc network family.



IV.COMMUNICATION PROTOCOLS FOR FANETS

In the literature [46, 47], many routing protocols exists in wireless and ad-hoc networks such as precomputed routing, dynamic source routing, on-demand routing, cluster based routing, flooding, etc. Due to a shortage of energy, to increase the FANET operation time, there are some needs to decrease transmitting power by sending a message to closer nodes (UAVs) and by using multi-hop routing between the sender and receiver nodes over highly mobile UAVs as relay nodes. FANET is a subclass of VANET and MANET; therefore, firstly typical MANET routing protocols are preferred and tested for FANET. Due to the UAV-specific issues, such as quick changes in link quality, most of these protocols are not directly applicable for FANET. Therefore, to adopt this new networking model, both some specific ad-hoc networking protocols have been implemented and some previous ones have been modified in the literature. These protocols can be categorized in four main classes;

• **Static protocols** have static routing tables there is no need to refresh these tables.

• **Proactive protocols**, also known as table driven protocols, are periodically refreshed routing tables.

• **Reactive protocols**, also called on-demand protocols, discover paths for messages on demand.

• **Hybrid protocols** use both proactive and reactive protocols. By using these routing protocols, a FANET can dynamically discover new routes between communicating nodes, and this network may allow addition and subtraction of UAV nodes dynamically.

1.Static Routing Protocols

In static routing protocol, a routing table is computed and loaded to UAV nodes before a mission, and cannot be updated during the operation; therefore, it is static. In this type networking model, UAVs typically have a constant/fixed topology [48]. Each node can communicate with a few numbers of UAVs or ground stations, and it only stores their information. In case of a failure (of a UAV or ground station), for updating the tables, it is necessary to wait the end of the mission. Therefore, they are not fault tolerant and appropriate for dynamic environments.

2.ProactiveRouting Protocols Proactive routing protocols (PRP) use tables to store all the routing information of each other's node or nodes of a specific region in the network. Various table-driven protocols can be used in FANET, and they differ in the way of update mechanism of the routing table when the topology changes. The main advantage of proactive routing is that it contains the latest information of the routes; therefore, it is easy to select a path from the sender to the receiver, and there is no need to wait. However, there are some explicit disadvantages. Firstly, due to the need of a lot of message exchanges between nodes, PRPs cannot efficiently use bandwidth, which is a limited communication resource of FANET; therefore, PRPs are not suitable for highly mobile and/or larger networks. Secondly, it shows a slow reaction, when the topology is changed, or a failure is occurred. Two main protocols are widely used in VANETs: Optimized Link State Routing (OLSR) and Destination Sequenced Distance Vector (DSDV) protocols.

3. Reactive Routing Protocols Reactive Routing Protocol (RRP) is known as on demand routing protocol, which means if there is no communication between two nodes, there is no need to store (or to try to store) a route between them. RRP is designed to overcome the overhead problem of PRP. In RRP, a route between communicating nodes is determined according to the demand from the source node. There are two different messages in this routing model: Route Request messages and Route Reply messages. Route Request messages are produced and dispatched by flooding to the network by the source node, and the destination node replies to this message with a Route Reply message. By receiving a Route Reply message the communication begins. As a result, each node maintains only the routes that are currently in use. There is no periodic messaging in this protocol; therefore, RRP is bandwidth-efficient. On the other hand, the procedure of finding routes can take a long time; therefore, high latency may appear during the route finding process.

4.Hybrid Routing Protocols Hybrid routing protocol (HRP) is a combination of previous protocols, and is presented to overcome their shortcomings. By using HRP, the large latency of the initial route discovery process in reactive routing protocols can be decreased and the overhead of control messages in proactive routing protocols can be reduced. It is especially suitable for large networks, and a network is divided into a number of zones where intra-zone routing is performed with the proactive approach while inner-zone routing is done using the reactive approach.

V.OPEN ISSUES AND CHALLENGES

A FANET is somewhat different from traditional MANETs and VANETs; however, the fundamental idea is the same: having mobile nodes and networking in an ad-hoc manner. Hence, in a FANET, some challenges are valid as in a VANET while facing with additional challenges. Although, many researches have been performed to increase the efficiency of network with flying nodes, there are still many unsolved problems, which should be explored in future works:

(1) National Regulations: UAVs are increasingly used in many application areas, and they get their places in the modern information age. While UAVs increasingly become a part of each country's national airspace system, most of countries' current air regulations do not allow controlled UAV operations in civil airspace. This can be seen as the biggest current barrier to the development of UASs in civilian areas. Therefore, there is a serious need to define distinctive rules and regulations to integrate UAV flights into the national airspace.

(2) Routing: In a FANET, due to the fast movement of UAVs, network topology can change quickly. Data routing between UAVs faces a serious challenge, which is different from low mobility environment. The routing protocols should be able to update routing tables dynamically according to topology changes .Most of previous routing algorithms in MANET are partly fail to provide a reliable communication between UAVs. Therefore, there is a need of developing new routing algorithms and networking model for constructing a flexible and responsive integration model.

(3) Path Planning: In a large-scale mission area and multi-UAV operation, cooperation and coordination between UAVs are not only desirable but also crucial feature to increase efficiency. In the operation theatre, there can be some dynamic changes like addition/ removal of UAVs, physical static obstacles, dynamic threats (such as mobile radars), etc. In such cases, each UAV has to change its previous path, and new ones should be re-calculated dynamically. Thus, new algorithms/methods in dynamic path planning are required to coordinate the fleets of UAVs.

(4) Quality of Service (QoS): A FANET can be used for many types of applications, and it transports different types of data, which include GPS locations, streaming video/voice, images, simple text messages, etc. FANET need to support some service qualities to satisfy a set of predetermined service performance constraints like delay, bandwidth, jitter, packet loss, etc. Defining a comprehensive frame work for QoS enabled middleware is a crucial challenge that should be overcome due to the highly mobile and dynamic structure of FANET.

(5) Integration with a Global Information Grid (GIG): GIG is a worldwide surveillance network and computer system intended to provide Internet-like capability that allows anyone connected to the system to collaborate with other users and to get process and transmit information anytime and anywhere in the world. A FANET should connect to future Information Grids as one of the main information platforms to increase efficiency of a UAS by using a UAV's communication packages, equipment suites, sensors, etc.

(6) Coordination of UAVs and manned aircrafts:
It is inevitable that, in the future, flights of UAVs with other manned aircraft are likely to increase. This coordination will enable the destruction of enemy aircraft with minimal losses. At the same time, these UAVs can be used as electronic jammers and for real time video reconnaissance in enemy

areas. Therefore, the collaboration of UAVs and manned aircraft should be in a networked environment.

(7) Standardize FANETs: A FANET uses various wireless communication bands such as VHF, UHF, L-Band, C-band, Ku-Band, etc. These bands also used in different application areas like GSM networks, satellite communication, etc. To reduce the frequency congestion problem, there is a need to standardize these communications bands, signal modulation and multiplexing models.

(8) UAV mobility and placement: Mini-UAVs are smaller in size and can carry limited payloads, like a single radar, infrared camera, thermal camera, image sensor, etc. If there is a need to use different sensors, they should be loaded on different UAVs, e.g., one UAV can be loaded with an infrared camera, while another UAV is equipped with a high-resolution camera. This allows multiple images to be taken from the same area, which can be hundreds and thousands of square meters. There is an open issue in this topic to optimize the UAV placement to reduce energy consumption while increasing the taken information.

VI.CONCLUSION

In this paper we describe about the Flying Ad-hoc Network (FANET). We described the most challenging task i.e. communication between the multi- UAV's. We formally define FANET and present several FANET application scenarios. We also discuss the differences between FANET and other ad-hoc network types in terms of mobility, node density, topology change, radio propagation model, power consumption, computational power and localization.

VII.FUTURE SCOPE

This approach will really help to the people in research area of Ad-hoc Networks. It will spread the awareness among the scholars about the FANET

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