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Considerations and Open Issues in Flying Ad Hoc Network

Sunil Kr Maakar[1], Yudhvir Singh[2], Rajeshwar Singh[3]

[1]Computer Science and Engineering, IKG PTU, Jalandhar, Punjab (India)

[2]Computer Science and Engineering, MD University, Rohtak, Haryana (India)

[3]Doaba Group of Colleges, Nawashar, Punjab (India)

Abstract: ***With the world transforming into a worldwide town because of innovative headways, computerization in all parts of life is picking up energy. Wireless innovations address the continually expanding requests of versatile and adaptable communication. Wireless ad-hoc networks, which allow communication between devices without the need for any central infrastructure, are gaining significance, particularly for monitoring and surveillance applications. A relatively new research area of ad-hoc networks is flying ad-hoc networks (FANETs), governing the autonomous movement of unmanned aerial vehicles (UAVs). In such network multiple UAVs are permitted to communicate so that an ad-hoc network is built up between them. All UAVs in the network convey UAV-to-UAV communication and just gatherings of UAVs cooperate with the ground station. Moreover, if one of the UAV communication link breaks; there is no connection breakage with the base station because of the ad-hoc network appointed between UAVs. In this paper, flying ad-hoc network are surveyed along with existing routing protocols and mobility models. Along with delineates open research issues with dissecting openings and future work are also discussed.***

Keywords: FANET, VANET, MANET, UAVs, Routing Protocols, Mobility Models

1. Introduction

FANET is the special form of wireless ad hoc networks in which nodes, called unmanned aerial vehicle (UAV) fly in the air and while flying in the air they communicate with each others, transfer the data and signals between each other without any human experts and without any physical connectivity between the nodes [1]. A typical architecture of FANET shown is in Figure 1.

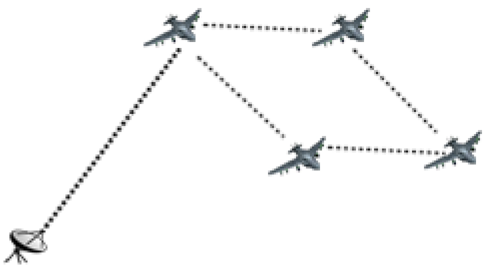

Figure 1: Flying Ad-Hoc Network

Although single-UAV systems have been in use for decades, instead of developing and operating one large UAV, using a group of small UAVs (FANET) has many advantages. Flying

Ad-Hoc Network (FANET), which is basically ad hoc network between UAVs, is surveyed as a new network family. Flying ad hoc networks (FANETs) composed of small unmanned aerial vehicles (UAVs) are flexible, inexpensive and fast to deploy. This makes them a very attractive technology for many civilian and military applications [2].

FANET can be defined as a new form of MANET in which, the nodes are UAVs. According to this definition, single UAV systems cannot form a FANET, which is valid only for multi-UAV systems. On the other hand, not all multi-UAV systems form a FANET. The UAV communication must be realized by the help of an ad hoc network between UAVs. Therefore, if the communication between UAVs fully relies on UAV-to-infrastructure links, it cannot be classified as a FANET.

FANET term immediately reminds that it is a specialized form of MANET and VANET [2]. Therefore, we prefer calling it as Flying Ad-Hoc Network, FANET. FANET can also be classified as a subset of VANET, which is also a subgroup of MANET as shown in Figure 2.

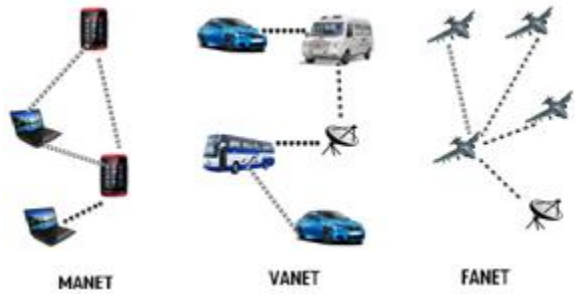

Figure 2: MANET, VANET and FANET

2. Differences between FANET and the Existing Ad-Hoc Networks

In this subsection, the differences between FANET and the existing wireless ad hoc networks are explained in a detailed manner.

2.1 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 [3], a UAV has a speed of 30–460 km/h, and this situation results in several challenging communication design problems [4].

2.2 Mobility Model

MANET nodes move on a certain terrain, VANET nodes move on the highways, and FANET nodes fly in the sky. In some multi-UAV applications, global path plans are preferred. In this case, UAVs move on a predetermined path, and the mobility model is regular. In autonomous multi-UAV systems, the flight plan is not predetermined. Even if a multi-UAV system uses predefined flight plans, because of the environmental changes or mission updates, the flight plan may be recalculated.

2.3 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 [5]. As a result of this, FANET node density is much lower than in the MANET and VANET.

2.4 Topology Change

Depending on the higher mobility degree, FANET topology change more frequently than MANET and VANET topology.

2.5 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 [2].

2.6 Power Consumption and Network Lifetime

Developing energy efficient communication protocols is the goal of efforts to increase the network lifetime. 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.

2.7 Computational Power

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.

2.8 Localization

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 [6]. Where in VANET, for a navigation-grade GPS receiver, there is about 10–15 m accuracy, which can be acceptable for route guidance.

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.

Because of the above-mentioned differences between FANET, MANET and VANET; we prefer to investigate FANET as a separate ad hoc network family. The differences between MANET, VANET and FANET are outlined in Table 1.

Table 1: The comparisons of MANET, VANET and FANET

	MANET	*VANET*	*FANET*
Node Mobility	Low	High	Very High
Mobility Model	Random	Regular	Regular for predetermined paths, but special for autonomous multi-UAV systems
Node Density	Low	High	Very Low
Topology Change	Slow	Fast	Fast
Radio Propagation Model	Close to ground, LoS is not available	Close to ground, LoS is not available	LoS is available for most of the cases
Power Consumption and Network Life Time	Energy Efficient protocols	Not needed	Energy efficiency for mini UAVs, but not needed for small UAVs
Computational Power	Limited	High	High
Localization	GPS	GPS, AGPS, DGPS	GPS, AGPS, DGPS, IMU

3. Routing Protocols

In the literature [7]-[9] many routing protocols exists in wireless and ad-hoc networks such as pre computed routing, dynamic source routing, on demand routing, cluster based routing, flooding, etc. 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 and some previous ones have been studied. These protocols can be categorized in four main classes.

3.1 Static 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 of networking model, UAVs typically have a constant/fixed topology [7]. 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. Examples of Static FANET Protocols include:

- Load Carry and Deliver Routing (LCAP)
- Multi-Level Hierarchical Routing
- Data Centric Routing

3.2 Proactive 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 FANETs:

- Optimized Link State Routing (OLSR)
- Destination-Sequenced Distance Vector (DSDV)

3.3 Reactive 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. 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. The different types of On Demand driven protocols are:

- Ad hoc On Demand Distance Vector (AODV)
- Dynamic Source routing protocol (DSR)

3.4 Hybrid 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. Several hybrids routing protocols have been proposed such as:

- Zone Routing Protocol (ZRP)
- Zone-based Hierarchical Link State (ZHLS)

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.

4. Mobility Models

Mobility models represent the movement of node and how their location, velocity and acceleration change over time. Such models are frequently used for simulation purposes when new communication or navigation techniques are investigated. When evaluating FANET protocols, it is very important to select proper underlying mobility model. We have analyzed those mobility models through which we can take all aspects of real time applications [10]. Few mobility models which can be used in FANET are discussed below in detail.

4.1 Random Way Point Mobility Model

The Random Waypoint Mobility Model includes pause times between changes in direction and/or speed of mobile node. In all the random based mobility models, the UAV nodes are set free to move randomly in any direction within the simulation area. We can say that a node is free to select its destination, speed and direction independent of the neighbor nodes [10]. UAVs decide on their action according to fixed probabilities. Until now, random waypoint model is used as synthetic one for mobility in most of simulation scenarios. However, it is not suitable for aircraft case because aircraft do not change their direction and mobility speed rapidly at one time and cannot stop in the sky.

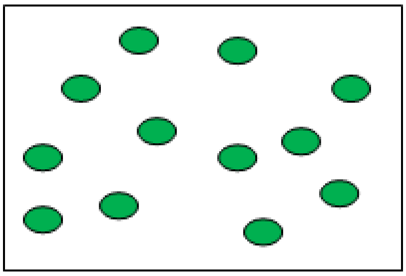

Figure 3: Random Way Point Mobility Model

4.2 Gauss-Markov Mobility Model

Gauss Markov Mobility Model is used to simulate the UAV behaviour in a swarm [11]-[12].GMM use one tuning parameter to vary the degree of randomness in the mobility pattern. The size of simulated area is variable. Node position is always directed by its previous position due to high moving speed. The path of a drone is determined by the memory of the model. In the Gauss-Markov Mobility Model each node is initialized with a speed and direction. By fixed intervals of time movement occurs to updating the speed and direction of each node. To be specific, the value of speed and direction at the nth instance of time is calculated based upon the value of speed and direction at the n - 1st instance and a random variable, as shown in Figure 4.

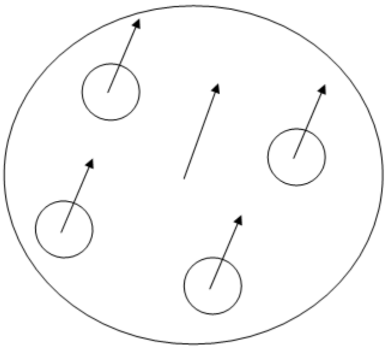

Figure 4: Gauss-Markov Mobility Model

4.3 Semi Random Circular Movement Mobility Model

This mobility model is designed for the circular movement of UAVs. This technique is used to simulate UAVs to capture some information about some regions by rotating around the area specified. Mobility model with hexagon route rather than random waypoint model for unpredicted helper node such as UAVs, their flight plan is not predetermined [13]. In this model at every instant, each aircraft is looking at different place where it chooses the desired object in a square area, as show in Figure 5.

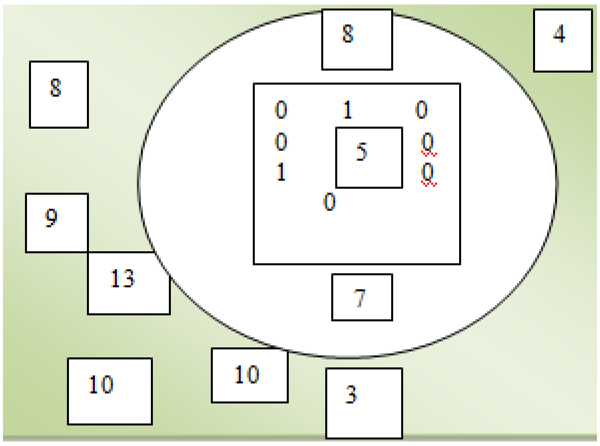

Figure 5: Semi Random Circular Model

4.4 Mission Plan Based Mobility Model

In MPB model, aircraft are already aware of the entire abundant trajectory information which is usually planned in advance. It implies that the aircrafts travel along the predetermined path consistently where potential target location information is available. In the MPB mobility model, when the time is over, the mobility files are created and updated [14].Mission plan based mobility model for aircraft which is supposed to move towards or away from destination. For each aircraft, starting and ending point are randomly selected while velocity and flight time are given. If an aircraft reaches destination before flight time is over, it changes direction to the starting point and continues flight as round trip as shown in Figure 6.

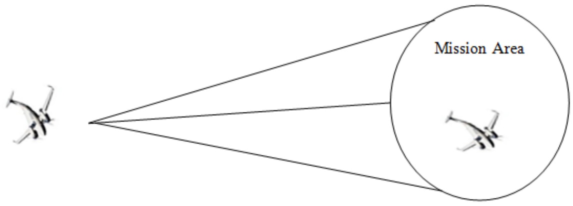

Figure 6: Mission Plan Based Mobility Model

4.5 Paparazzi Mobility Model

According to this model, the UAV have five possible movements:

- Stay-At - UAV hovers over a fixed position.
- Way-point- UAV follows a straight path to a destination position.
- Eight- aircraft trajectory has the 8 form around two fixed position.
- Scan- the UAV performs a scan of an area defined by two points along the round trip trajectories.
- Oval-a shifted round-trip between two points with a turnaround once pass each point [15].

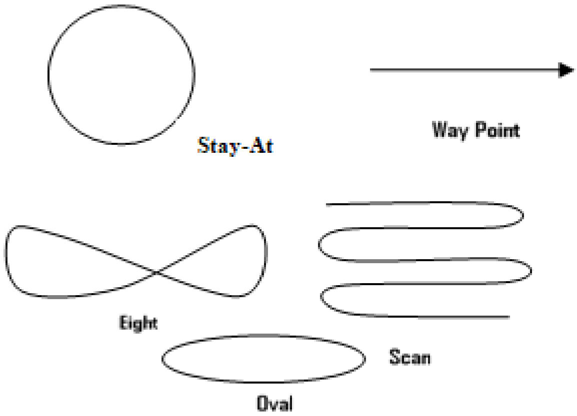

Figure 7: Paparazzi Model

Paparazzi mobility model is a stochastic mobility model that imitates paparazzi UAV behaviour based on the state machine as show in figure 7. PPRZM has closer behaviour to the real traces than RWP. PPRZM can be used to evaluate any communication protocol in the context of swarm of collaborative UAVs since it affords a realistic movement scenario. For instance it may be used to compare several routing protocols in order to find the suitable one for each UAV ad ho network. Moreover, PPRZM can adapt to any type of mission because it groups most UAV possible movement by changing the probability of each movement type as needed.

4.6 Reference Point Group Mobility (RPGM) Model

Group mobility can be used in military battlefield communication. Here, each group has a logical centre (group leader) that determines the group's motion behaviour of UAVs. Initially, each member of the group is uniformly distributed in the neighbourhood of the group leader. Subsequently, at every instant, each node has a speed and direction that is derived by randomly deviating from that of the group leader [16].

Applications: Group mobility can be used in military battlefield communications where the commander and soldiers form a logical group. More applications of RPGM Model are mentioned in [17].

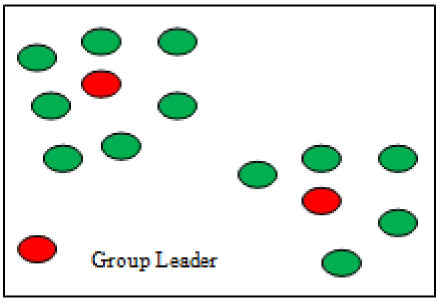

Figure 8: Group Mobility Model

5. 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 [2], [18]:

FANETs along with its special features have several challenges and issues those need to be considered.

5.1 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.

5.2 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.

5.3 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 jitter, packet loss, etc. Defining a comprehensive framework for QoS-enabled middleware is a crucial challenge that should be overcome due to the highly mobile and dynamic structure of FANET.

5.4 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.

5.5 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.

5.6 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.

5.7 UAV 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. Regarding this, UAV placement to reduce energy consumption is still an open issue.

5.8 UAV Mobility Model

Mobility models are one of the features of the simulation environment. They define trajectories and speed variations of the mobile nodes and represent their positions, which generate network topology changes and then communication perturbations since new links will be created and others will be broken. Therefore, the mobility model plays an important role in the evaluation of the flying ad hoc network performance [9]. Regarding this, designing of specific FANET's mobility models for simulation in 3-D are still an open issue.

6. Conclusions

In this paper we have introduced FANET, its routing protocols, mobility models and some of the open issues in the Flying Ad Hoc Network. This paper can serve a guiding path to the researcher to find the open issues and the areas which needs to be researched in the Flying ad hoc network.

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