Review of Flying Ad-hoc Networks (FANETs)

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Abstract— As a result of recent advances in processors, sensors, communications, and networking technologies, the roles and capabilities of Unmanned Aerial Vehicles (UAVs) have evolved rapidly, and their usage in military and civilian areas has become commonplace. The focus is now changing from the use of one large UAV to that of multiple UAVs that can coordinate to achieve high-level goals. Using the concept of Mobile Ad-hoc Networks (MANETs), new networking paradigms like Flying Ad-hoc Networks (FANETs) have evolved to tackle high mobility and fast topology change.

This paper focuses on Static Routing protocols, namely, LCAD, multi-level hierarchical routing and data centric routing. The mobility models employed for FANETs are also addressed. Finally, the future scope of this technology is highlighted.

Index Terms*-UAVs, FANET, Static Routing, SGN, DGN, Mobility Models*

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I. INTRODUCTION

Ad-hoc networks are decentralized type of wireless networks. They do not rely on a pre-existing infrastructure, such as access points in infrastructure wireless networks or routers in wired networks. Owing to this decentralized nature of wireless ad-hoc networks, they are suitable for a variety of applications and may improve the scalability of networks as compared to wireless managed networks. Wireless ad-hoc networks can be further classified by their application into three broad categories:

Mobile ad hoc networks (MANETs)

MANETs are self-configuring, infrastructure-less wireless networks of mobile devices.

Vehicular ad hoc networks (VANETs)

VANETs are a type of mobile ad-hoc network used for communication between vehicles and other roadside equipment.

Flying Ad-hoc Networks (FANETs)

FANETs are a special case of VANETs characterized by a high degree of mobility. And frequent topology change.
Fig. 1 shows various ad-hoc networks.

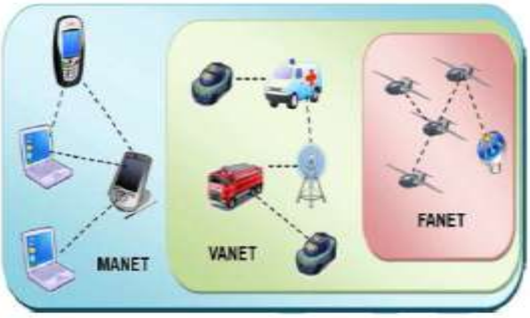

Figure 1. Various Ad-hoc Networks

A. Comparison of FANET with Existing Ad-hoc Networks

TABLE 1. Comparison of FANET with existing Ad-hoc Networks

	FANET	**MANET/VANET**
1.	High degree of node mobility	Medium to low node mobility
2.	Low node density	Higher node density
3.	Rapid topology change	Slow and steady topology change
4.	High above ground level; LoS accessible in most cases.	Close to the ground; no LoS between sender and receiver in most cases.
5.	Computational power of nodes is very large.	Computational power of nodes is average/limited.
6.	GPS, AGPS, DGPS, IMU used to provide geospatial localization.	GPS sufficient to provide accurate geospatial localization.

II. FANET ROUTING PROTOCOLS

FANET routing protocols are categorized into four main classes;

- **Static** protocols have fixed routing tables there is no need to refresh these tables.
- **Proactive** protocols, or table driven protocols, have routing tables that are periodically refreshed.
- **Reactive** protocols, or on-demand protocols, dynamically discover paths for messages on demand.
- **Hybrid** protocols are a combination of proactive and reactive protocols.

Static Routing Protocols

In static routing protocol, a routing table is computed and loaded onto UAV nodes before a mission, and cannot be updated during operation; hence the term static. In this type of networking model, UAVs have a fixed topology. Each node communicates with a certain number of other UAVs or ground stations, and stores only their information. In case of failure (of a UAV or ground station), it is necessary to wait till the end of the mission to update tables. Therefore, they are not fault tolerant and appropriate for dynamic environments.

A. Load Carry and Deliver (LCAD) Routing

This is FANET's first routing model. In this, data is loaded from the source ground node (SGN) by UAV; and carries data when flying; and lastly delivers to ground station i.e. destination ground node (DGN). In Fig.2, a single source and destination node is considered and multiple source and destination nodes can be implemented. Although the LCAD paradigm incurs a longer data delivery delay as compared to conventional store-and-forward, LCAD does have a number of advantages. First, LCAD can achieve high throughput performance by making sure that communication between UAVs and the source/destination ground nodes is free of interference from other nodes within a networking system. Second, LCAD can scale its throughput by using multiple relaying UAVs in a pipelined fashion for data delivery. For these reasons, LCAD is attractive for delay-tolerant applications that demand high networking bandwidth, e.g., for bulk data transfer.

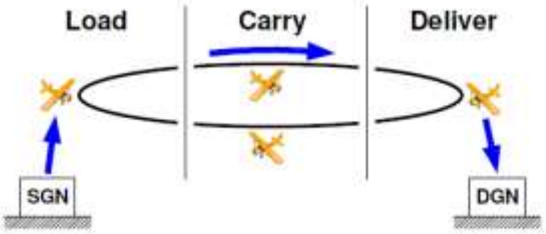

Figure 2. Load Carry and Deliver Routing

Assume a fixed data transmission rate and fixed transmission power in the following analysis leading towards a throughput-maximizing framework. Important design decisions in LCAD networking model include time allocation for each stage, as well as the design of the UAV trajectory.

For a UAV that flies cyclically along the same path, for e.g., the oval-shaped flight path shown in Fig. 2, the achieved long-term throughput T can be expressed as Pkt_{dlvd}/T_{cycle}, where, Pkt_{dlvd} denotes the total number of packets delivered by the UAV to DGN in one cycle, and T_{cycle} gives the flight time per cycle. T_{cycle} can be deco*mposed into T_{load}, T_{carry}, and $T_{deliver}$, each of which refers to the time that a UAV spends in the respective LCAD stages. T_{idle} can be used to denote to the time spent on the return leg from destination to source.

The first necessary condition for achieving maximal throughput is that T_{carry} must include only the time during which the UAV is out of communication range of either the SGN or DGN. Otherwise, the system is wasting transmission opportunities[10]. Thus, T_{carry} depends on the UAV speed, the distance between SGN and DGN, and the communication range of the wireless devices used. Let D denote the transit delay budget the application imposes on packet delivery. Transit delay[10] is defined as the amount of time a packet spends in transit through the network i.e., the time between when the packet is first enqueued at SGN and when the packet is delivered to DGN. The worst case transit delay equals $T_{cycle}+T_{carry}-T_{idle}$, experienced by the first packet after the load stage. So, the combined time allocated for load and deliver stages must satisfy the condition:

$$T_{load} + T_{deliver} < D - 2T_{carry} + T_{idle}. \qquad (1)$$

The second necessary condition[10] for achieving maximal throughput is that the load stage should not overrun or underrun the subsequent delivery stage. In either of the two cases, the time for the two stages could have been better allocated. Therefore, (2) arises.

$$T_{load} = T_{deliver} = (T_{cycle}-T_{carry})/2 \qquad (2)$$

B. Multi-level Hierarchical Routing

In order to operate in different areas, UAV networks are grouped in a hierarchical fashion. In order to initialize functions to a group in a different manner, each group has a cluster head by which it is connected to upper or lower layers. Cluster head should have direct transmission to other UAVs which are within the cluster to broadcast and control information to other UAVs. This model is used in swarms, in large mission areas and in UAV networks. Fig. 3 shows multi-level hierarchical routing.

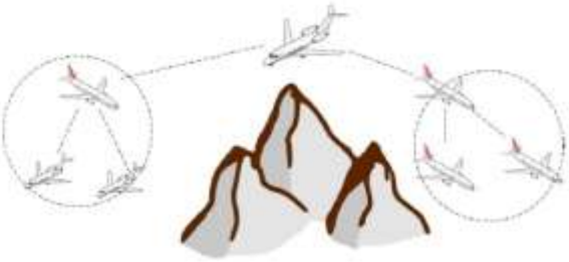

Figure 3. Multi-level Hierarchical Routing in FANETs

C. Data Centric Routing

Wireless communication in UAVs causes one-to-one data transmission to be preferred over one-to-many data transmission. When a number of nodes are requesting for data and distribution takes place on the on-demand algorithm, data centric routing is a promising paradigm and can be adapted for FANET. Rather than using IDs of sender or receiver nodes, the request and collection of data is based on data distribution. This model is used in clusters[7].

In this model, the subscription message is broadcasted by a consumer node in the form of queries to get the required data from the required area. The producer node decides which data are needed to be published and initializes the broadcast. When data reaches the UAV which is published, it will check for the messages which were subscribed and then forwarded based on it. Routing is based on data content and data needs. Data aggregation algorithm is used for energy efficiency in broadcasting data. Network load increases when collection and broadcasting of messages is added, due to elimination of redundancy during data transmission. By using this model, efficiency is increased. Three coupling dimensions are performed in this type of routing;

Space coupling is that ID's of the other party is not known during communication between them.

Time decoupling In this, the parties who are communicating at the same time need not be online.

Flow decoupling: In this, **t**he process of sending messages cannot be blocked by a third party.

Data centric routing model used in FANETs is depicted in Fig. 4.

Figure 4. Data Centric Routing in FANET

III. MOBILITY MODELS

A mobility model represents movement of nodes and how their location, velocity and acceleration change over time. Mobility models are used to create a realistic simulation environment. Following are three Mobility Models commonly employed in FANETs.

A. Random Waypoint Mobility Model (RWMM)

The Random Waypoint Mobility Model[1] includes pause times between changes in direction and/or speed of the UAV nodes. In all the random based mobility models, UAV nodes are set free to move randomly in any direction within the simulation area. It can be said that nodes are free to select their destination, speed and direction independent of the neighbouring nodes. UAVs decide on one of three actions: going straight, turning left or right, according to fixed probabilities. So far, random waypoint model was used as a synthetic one for mobility in most of simulation scenarios. However, it is not suitable for aircrafts because aircrafts do not change their direction or mobility speed rapidly at a time. Fig. 5 shows the travelling pattern of a node in Random Waypoint Model. Zig-zag trajectories are a common problem with this model.

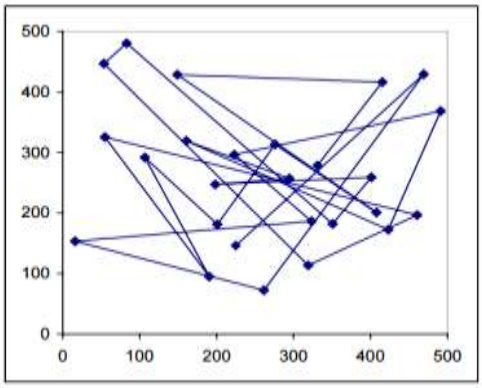

Figure 5. Travelling pattern of a node in RWMM

B. Gauss-Markov Mobility Model

Gauss Markov mobility model is used to simulate UAV behaviour in a swarm. The size of simulation area is variable. Node position is always directed by its previous position. The path of a drone is determined by the memory of the model. In this model, each node is initialized with a speed and a direction. After fixed intervals of time movement occurs to update the speed and direction of each node. In other words, the values of speed and direction at the nth instance of time are calculated based on the values of speed and direction at the (n-1)th instance and a random variable. As depicted in Fig.6, the nodes move according to previous node position. Here, the velocity of a node at time n is given by (3).

$$v_n = \alpha v_{n-1} + (1-\alpha)\mu + \sqrt{1-\alpha^2} * x_{n-1} \qquad (3)$$

Where, α is the tuning parameter used to vary the randomness, μ is a constant representing the mean value of Vn as n → ∞ , and n−1 x is a random variable from a Gaussian distribution. Completely random values are obtained by setting α = 0[12] and linear motion is obtained by setting α = 1[12]. Intermediate levels of randomness may be obtained by varying α between 0 and 1. Further, the displacement of a node is given by (4).

$$S_n = \sum_{i=0}^{n-1} v_i \qquad (4)$$

This model allows the study of individual node movements

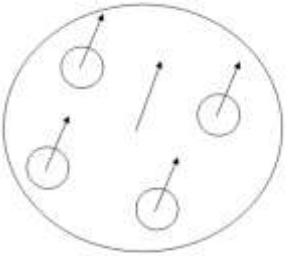

Figure 6. Gauss-Markov Mobility Model

C. Paparazzi Mobility Model (PPRZM)

According to Paparazzi experts, UAVs can have five possible movements:

Stay-At: the UAV hovers over a fixed position (Figure 7a);

Way-Point: the UAV follows a straight path to a destination position (Figure 7b);

Eight: the aircraft trajectory has the «8» form around two fixed position (Figure 7c);

Scan: the UAV performs a scan of an area defined by two points along the round-trip trajectory (Figure 7d);

Oval: a shifted round-trip between two points with a turnaround once each point is passed (Figure 7e).

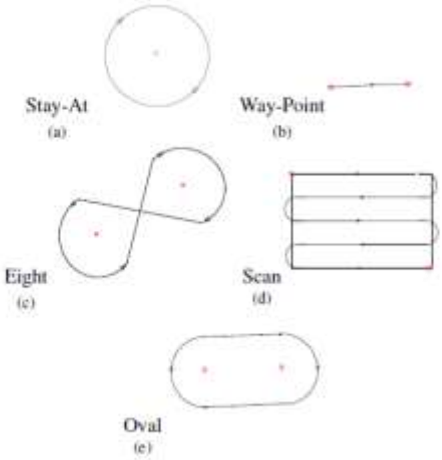

Figure 7. Paparazzi UAV Movements

Each UAV chooses a movement type and fixes its characteristics:

Location: the center positions for Eight, Oval and Stay-At movements or the starting and the ending positions for Way-Point and Scan movements;

Speed: is a uniform random value between 15 m/s and 25 m/s.

Thus, UAVs are assigned a specific position through a Way-Point movement, then it follows a well-defined path according to the movement chosen. The altitude of each aircraft is fixed randomly at the beginning. Once reached, it remains constant till the end of the simulation. All of these movements have different probabilities to occur. According to Paparazzi experts, Stay-At, Oval, and Scan are the movements the most produced during a mission flight. Therefore, probabilities used were fixed as follow:

Stay-At, Oval, and Scan probabilities are equal to 30% for each movement;

Eight and Way-Point probabilities are equal to 5% for each movement.

Unmanned Aerial Vehicles play a promising role in a large operation zone with complicated missions. For regions that are reasonably isolated from the ground, UAVs require cooperation with one another and need a quick and easy deploying network system. Multi-UAV systems reduce the operation accomplishment time and increase reliability of the system for airborne operations when compared to a single-UAV system. To apply networking in non-LOS, urban, noisy environments, multi-UAV systems are very effective and accurate.

Ongoing research work is aimed at integrating FANETs with future Information Grids to serve as a main information platform as well as coordination of UAVs and manned aircrafts for security reasons.

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