Flying Ad-Hoc Networks: Routing Protocols, Mobility Models, Issues

Muneer Bani Yassein and "Nour Alhuda" Damer
Jordan University of Science and Technology, Department of Computer Science
Irbid, 22110, Jordan

***Abstract*—Flying Ad-Hoc Networks (FANETs) is a group of Unmanned Air Vehicles (UAVs) which completed their work without human intervention. There are some problems in this kind of networks: the first one is the communication between (UAVs). Various routing protocols introduced classified into three categories, static, proactive, reactive routing protocols in order to solve this problem. The second problem is the network design, which depends on the network mobility, in which is the process of cooperation and collaboration between the UAV. Mobility model of FANET is introduced in order to solve this problem. In Mobility Model, the path and speed variations of the UAV and represents their position are defined. As of today, Random Way Point Model is utilized as manufactured one for Mobility in the greater part of recreation situations. The Arbitrary Way Point model is not relevant for the UAV in light of the fact that UAV do not alter their course and versatility, speed quickly at one time because of this reason, we consider more practical models, called Semi-Random Circular Movement (SRCM) Mobility Model. Also, we consider different portability models, Mission Plan-Based (MPB) Mobility Model, Pheromone-Based Model. Moreover, Paparazzi Mobility Model (PPRZM). This paper presented and discussed the main routing protocols and main mobility models used to solve the communication, cooperation, and collaboration in FANET networks.**

Keywords*—FANET; Ad-hoc Network; UAVs; MANET; Mobility Model; Networking Model

I. Introduction

FANETs (Flying Ad-hoc Networks) is a group of Unmanned Air Vehicle (UAVs) communicating with each other with no need to access point, but at least one of them must be connected to a ground base or satellite [1]. UAVs work without human help, like autopilot. This is because cheaper and small wireless communicating devices, the in recent years, many research fields from academia and industry make attention on FANETs. Now, FANETs are used in various applications such as military and civil applications [1], such as managing wildfire [2] and disaster monitoring [3]. As each type of network has its own specification and using the protocol depends on this specification, it is important to use a reliable protocol for this kind of networks and check their performance using simulation. Two factors affect protocol simulation: the first one is mobility model, and the second one is the communicating traffic pattern, among others. This paper focuses on the routing protocols and mobility models that have been used in the FANET network to solve communication, cooperation and collaboration problem between UAVs.

The rest of this paper is organized as follows. Section II gives literature review of specific ad-hoc network with flying nodes, Section III presents the FANET characteristics, and section IV presents themainrouting protocols used in FANET. Mobility models recently used in the FANETs have been displayed in Section V. Section VI concludes this study.

II. Ad-Hoc Networks with Flying Nodes

FANET are a special case of mobile ad hoc networks (MANETs) [4]. FANET are a network with nodes –UAVs-flying in the sky [1], which can automatically fly without human help. It consists of two parts, ad-hoc network and access point like a satellite or ground base to connect with the network in at least one of them, according to carry the data from one ground base to another. The network that its link is established between each UAV and an access point is not specified as FANET network. Using multi-UAVs in this network family reflects many advantages on this network [5]:

1) Minimize the completion time for a request: when many UAVs processes a request, it will be ready faster than one UAV.

2) Minimize the cost and the maintenance: using small UAVs is cheaper than one big UAV, and the maintenance is lower as well.

3) Increase Scalability: It can maximize the operations done by the network by adding more UAVs to the network dynamically according to the request needs.

4) Increase sustainability: the network can work continuously even if one UAV fails since other UAVs can perform the task.

Since multi-UAVs have many other advantages like the dynamic topology of the network, it still has the problem of communication between UVAs in FANETs. This problem is solved this problem using two types of protocols for communication first one is between the UAVs itself, and the other between the UAV and the access point [4]. In UAVs communication, each UAV communicates with the other UAV directly or using multi-hop communication. In the other kind of communication, the UAV create the connection with an infrastructure like a ground base or satellite to transfer the data.

III. FANETs Characteristics

In FANETs, the node became UAV [1]. The single UAV system cannot create an FANETs network; therefore, it is valid for multi-UAVs systems. On the other hand, it cannot call any multi-UAVs systems FANETs; if each UAV is connected to a base ground or satellite, it does not have a FANETs network. FANETs must contain UAVs which communicate between each other using ad hoc network and at most one of them connect to infrastructure. In MANET and FANETs, there are many common design considerations. In the following points, some FANETs characteristics are displayed in a detailed manner [1]:

1) Node Mobility

In node mobility, the degree is larger than MANET and VANET. The UAV has a speed of 30-460 km/h, and this speed causes the communication problem between UAVs [1].

2) Mobility Models

In many mobility models, the flight plan is predetermined and at each step there is a change, recalculation for the map take place [1]. Other models are using random speed and directions for the UAVs. In section V, Mobility models described in details.

3) Node Density

The average number of UAVs in some area is called Node Density. In FANETs, it must be a sparse density with large distances between them according to the nature of flying [1].

4) Network Topology

In order to the higher mobility, degree, topology changed frequently [1]. The communication between UAVs has also broken frequently; because the higher speed, or if the UAV is out of the range because location changing occurs rapidly. At each UAV connection failure, update processing is needed.

5) Radio Propagation model

Here, according to the nature of the environment in FANETs and the large distances between UAVs. The UAVs uses a line-of-sight between them and with a ground base. In contrast with MANET, it does not use any radio signal between nodes.

6) Power Consumption and network lifetime

Network lifetime is an important issue for the network, which consists of battery-powered computing devices. Communication hardware used in FANETs is powered by UAV energy source itself. In case of this, FANETs designs may not be power sensitive, in contrast with MANET applications. But it stills a problem in mini UAVs [6].

7) Localization

Localization means determining the location for each UAV. According to high speed and frequently change in place, there is a need for highly localization information with small intervals of time. Using GPS, the information about the new locations will be propagated to the network each one second, and this is not sufficient. Therefore, each UAV must be containing a GP and Initial measurement unit to broadcast his location to all UAVs in the network at any time.

IV. ROUTING PROTOCOLS USED IN FANETS

There are many routing protocols used in wireless and ad-hoc networks [7, 8], such as flooding, dynamic source routing, and pre-computed routing. But due to the characteristics of UAVs like speed and rapid changes in links between nodes, these protocols need to be modified and the others will be established to adopt this network issues. Using the following protocols, FANETs network has the property of dynamic adding nodes and deleting nodes from the network due to their needs. These protocols can be viewed as four main classes [5].

1) Static protocols: They contain a routing table that is not edited at any time.

2) Proactive protocols: It contains a routing table for each node that is refreshed periodically.

3) Reactive Protocols: It is called on-demand routing protocol, which fills the routing tables when there is a need to send data and the path is not known.

4) Hybrid Protocols: It takes advantages from proactive and reactive protocols.

STATIC ROUTING PROTOCOLS

In this kind of routing protocol, firstly the information for UAVs is computed and loaded to each UAV. It cannot be changed during the operation, and the topology of the network must be fixed also [9]. This leads to minimizing the number of communication links between UAVs or between UAV and the ground base. There is no fault tolerance to provide a dynamic environment for the network in case of the failure of some UAVs or access point because they must wait until the end of the mission to fix the failure occurs. Instead of these problems, some routing models are established for FANETs network:

- Load Carry and Deliver Routing (LCAD)[5]

One of the most popular secure routing protocols used in FANETs is LCDR [5]. In this model, communication between UAVs does not occur. This protocol is used to transfer data from a ground base to a ground base using flying UAVs with single hop communication; it is useful to transfer images or videos. Firstly, the data loaded from a source access point to the UAV and the UAV moves to the destination access point to get it the data. In terms of security, this model is secure; because there are no hops during the transfer of data. The time needed to deliver the datafrom the source ground base to the destination ground base depends on the speed of UAV and the distance between the source and destination access points, another suggestion to decrease the transfer time more than one UAV can be used for the same source and destination, or increase the speed of UAVs, and divide the network to smaller LCAD sub-networks. Figure 1 shows LCAD routing technique.

- Multilevel Hierarchical Routing (MLH) [5]

Due to big FANETs, the network consists of UAVs with different attributes; this model organizes the process of sending the data between a ground station and the UAVs [5]. MLH divides the UAVs into clusters; each cluster performs the operations in specific areas, with a cluster head (CH) for each cluster to communicate between other clusters and their access point. This model is useful when UAVs is ordered in different characteristics, and the area of the network is large, and the network has many UAVs. Figure 2 shows MLH routing technique.

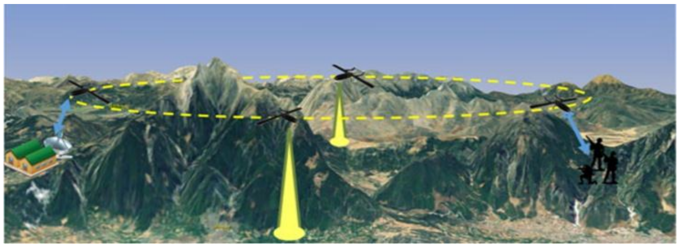

Fig. 1. Load Carry and Deliver Routing [5]

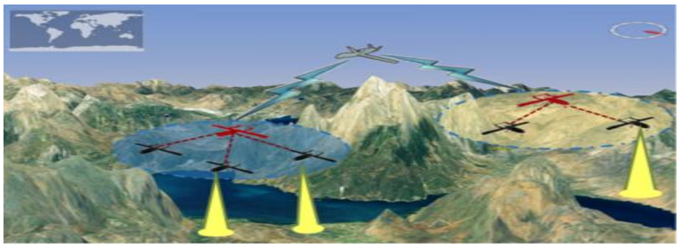

Fig. 2. Multilevel Hierarchical Routing [5]

- Data-Centric Routing (DCR) [5]

This kind of routing protocols used when some data needed by many UAVs in the network, in this case,one-to-many communication are preferred than one to one data transmission [10, 11]. In this routing protocol, the ID for UAVs is not important; here the routing is done with respect to the data, not to the ID of UAVs that requests it. DCR UAVs are divided into clusters and works as follows, when a UAV or a ground station needs data such as (Take a photo for region A if there is more than one tank on the ground), this request will be sent to all UAVs and each one decides if it must collect the data or not, and send the data to other UAVs, Figure 3 shows DCR technique. The disadvantage of this technique is the redundant data sent on the network, but there are advantages of this technique like:

- **Space decoupling** communicating UAVs and ground station does not need to know the ID and the location of each other.
- **Time decoupling** there is no need to be UAVs online all the time.
- **Flow decoupling** in case there is an interaction in the outside, message sending process is not blocked between UAVs.

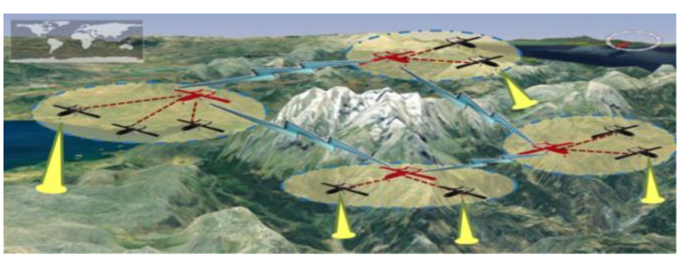

Fig. 3. Data-Centric Routing [5]

PROACTIVE ROUTING PROTOCOLS (PRP)

This technique of routing using a table contains all the information about all nodes in the network, thus each node knows all the things about each other in the network. This technique has one main advantage, the table for each node always has the latest information about the other nodes, but we take in our mind that this technique needs a bandwidth because the overhead of the updated messages for the tables, therefore PRP is not applicable for highly mobile or big networks -FANETs-. Due to the control of bandwidth in FANETs network, some routing protocols in modified version can be used in order to change the topology for the nodes.

- Optimized Link State Routing (DLSR) [12]

In OLSR, each node has the information about their neighbors. Two kinds of messages are used in the network. The first one is hello messages, which is sent periodically to check the connectivity with neighbors in one hop in the communication range, and then each UAV sends another one to hop hello message to the neighbors at another time. The second one is the control messages that issued to refresh the information about the topological order for the network; therefore, each node refreshes its information about paths to all other nodes in the network periodically. In this solution, there is a big overhead. In order to reduce this overhead, Directional Optimize Link State Routing arises (DOLSR) [13].\, in which Multipoint Relay is used. Therefore, when any node needs to broadcast the information to other nodes, it will select an MPR to forward the routing messages. Figure 4 shows MPR model.

The process of selecting the MPR is the most important step in OLSR protocol. [13] Generally speaking, as the MPR can be as small as possible, the overhead will decrease accordingly. To this respect, a new mechanism is proposed for reducing the number of members of MPR. Figure 5 shows a diagram for the proposed DOLSR. At any sending data step, the sender calculates the distance to the destination, then if the distance is greater than the maximum distance that can be achieved using the directional antenna (Dmax/2), DOLSR algorithm will be used in this case or when the Omni-directional antenna cannot achieve the destination. Otherwise, OLSR will be used [13].

- Destination-Sequenced Distance Vector (DSDV)

Using this routing protocol, each UAV must know everything about all other UAVs in the network, but with a small modification [14].The difference between this technique and the simple proactive approach is that this approach uses a sequence number assigned by the destination node in order to eliminate the loop of routing occurred by the changes of the topology for the network. Then each UAV with a higher sequence number is better than the UAV with a lower sequence number. Simplicity and loop-free are the main advantages in Destination-Sequenced Distance Vector routing protocols. However, on the other hand, DSDV has the same drawback of OLSR, the overhead in the network when updating the tables.

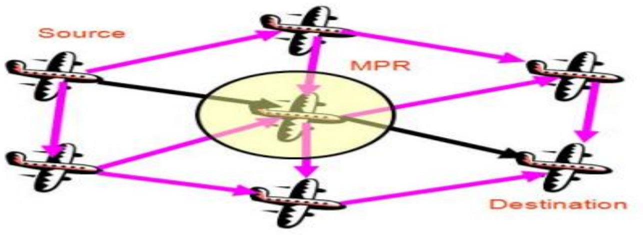

Fig. 4. MPR Model [13]

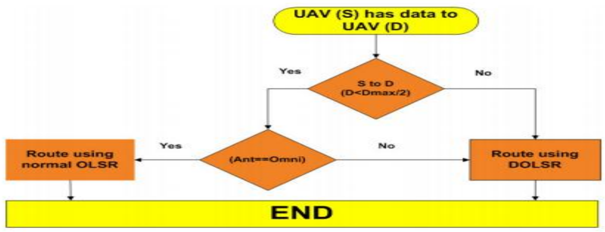

Fig. 5. DOLSR Algorithm [13]

Reactive Routing Protocols

RRP is also called on-demand routing protocol, which means that the path between nodes is established when there is a request [5]. RRP comes up to solve the overhead problem in PRP; there is no need to periodically calculate the paths for each node. In this technique, there are two types of messages which are RouteRequest and Route Reply. RouteRequest is sent from the source node to all neighboring nodes using flooding techniques to scan the path, and each node uses the same strategy until it reaches the destination. The second one is a message generated by the destination node and goes to the source using the unicast technique. In this case, each node saves the current using one path not all paths, and there is no need to refresh all tables in the network.

Bandwidth efficiency is the main advantage to using this technique. On the other hand, it will be slower than PRP because of the time for finding the path.

- Dynamic Source Routing (DSR)[14]

It is a simple RRP used in multi-hop wireless networks [15]. In this technique, each UAV sends data that includes a request ID with the data and then sends the data to avoid any confection that may occur in the media. DSR differs from other routing protocols; each source node saves the path to the destination in the header of the data. A maintenance process needed when some hop failure occurs in the network, if the new route does not found, a new recalculation process will begin to find another path. This routing protocol was implemented by Brown et al. In [16], and they concluded that finding a new route in the UAV network with DSR cannot be easy.

- Ad-hoc On-demand Distance Vector (AODV)

It is a reactive protocol that has some characteristic as DSR with differences in the routing table [17]. DSR, as mentioned above, saves the complete path from each node to any other node in the network, the contrast with AODV that saves one record for each node in the table. The second difference is in the process of sending the data, DSR saves the complete path with the data, but AODV saves just the next hop which maximizes the bandwidth in the network.

AODV protocol has three phases in sending the packets over the network. Any node that needs to send data, the discovery process takes place to discover the path from the source to the destination. This process is useful for loop-free. To maximize the freshness of the paths, it always uses a sequence number at each step that will be refreshed with the inner nodes in the network. When the route is discovered, then the second phase works, which is transmitting the data. In order of network failure, routing maintaining phase takes place to fix the failure or to refresh the ruts in the tables.

In a high mobility network, this congestion increases due to the need to refresh the routes more frequently. Thus, network congestion is an issue with AODV during the route determination phases. To solve this, Time Slotted On-demand Routing (TSOR) arise [18]. To decrease the communication between the UAVs, therefore, the collision during routing will be decreased. TSOR is based on AODV, in addition, to including a time component to the algorithm, as in slotted ALOHA, each UAV have a time-slot can send their data within. The communication occurred between all other nodes in the network not in the neighbor UAVs within the time-slot.

V. Mobility Models Used In FANETs

The mobility of a network depends on two basic parts, nodes location and velocity change in a time [19]. Nodes movement can be described as mathematical equation or simulation. Using simulation environment in mobility modeling gives us more accurate results, and gives solutions to more complex problems. Figure 6 shows some of the Mobility modelings that are used in FANETs network.

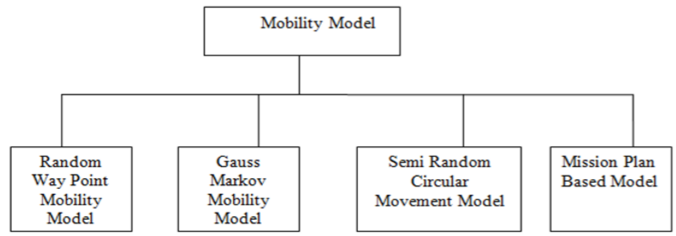

Fig. 6. Some of Mobility Models [23]

- Random Way Point Mobility Model[20]

The time pause between the changes in node direction and speed are included in Random Way Point Mobility Model [20]. UAVs in this Model move in random locations in a specific area, it is free in their movements within the simulation are independently from any other UAVs in the region. In [21] UAVs movements depend on specific probabilities. Because aircraft do not change their direction and speed rapidly and cannot stop in the sky period of time, this model is not suitable for aircraft. RWP is based on three actions: turn right, turn left, and going. Figure 7 shows RWP model.

- Gauss-Markov Mobility Model [19]

GMM model uses one tuning parameter to vary the degree of randomness in the mobility pattern [19]. For ad hoc network protocol simulation, this model has been used [22] and in swarm behavior. Here the simulation area is variation in contrast with RWP Model.

In GMM model, each node is initially set to a specific speed and direction, and then at each period of time, the movement will update the direction and the speed for the UAVs. The speed and direction are calculated based on the last position in order to the high velocity, as shown in Figure 8.

- Semi-Random Circular Movement Model [23]

This model is developed for the UAVs which their moves are in curving manner [19]. This technique is used to simulate UAVs to capture some information about some regions by rotating around the area specified. Thus, each UAV is monitoring part of the area where the object is wanted on it, as shown in Figure 9.

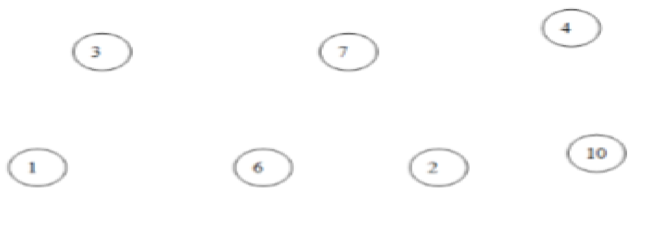

Fig. 7. Random Way Point Mobility Model [23]

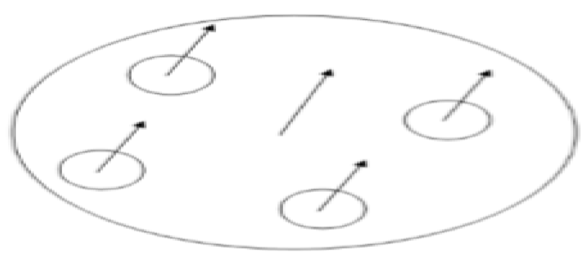

Fig. 8. Gauss-Markov Mobility Model [19]

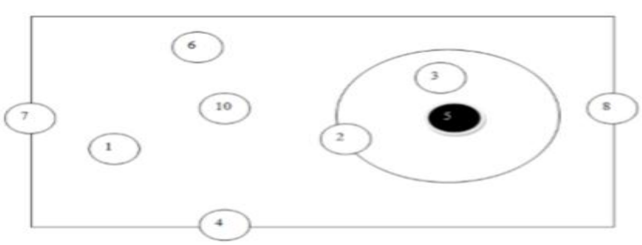

Fig. 9. Semi-Random Circular Movement Model [23]

- Mission Plan-Based Model [23]

In MPB model, the flight plan info is predefined and the aircraft can go ahead with this plan. It implies that the aircraft moves along the planned path each time, wherever the aircraft can reach mission space and the potential target location data is accessible [19], as shown in Figure 10. In the MPB mobility model, when the time is over, the mobility files are created and updated. For every aircraft, beginning and ending purpose are arbitrarily designated whereas rate and flight time are given. If an aircraft reaches the destination before flight time is over, it starts a new flight trip by change its direction and continuous flying.

- Pheromone-based model [20]

Pheromone model takes into account the area specified for each UAV and the pheromones guide UAV developments. Each UAV marks the zone that it checks on the guide, and imparts the pheromone guide to other UAVs. In order to expand the scope, UAVs incline toward the development through the zone with that does not discover yet. It was demonstrated that the utilization of a run of the mill MANET versatility model may bring about an undesirable way gets ready for helpful UAV applications, it was likewise watched that the irregular model is strikingly straightforward; however it prompts common results [25]. However, the pheromone base model has extremely dependable checking properties. With the pheromone show, a pheromone guide is utilized to manage UAVs. The flying machine trade data about their examined territory, and as indicated by what they choose, they turn left, right or proceed. Figure 11 shows PBM.

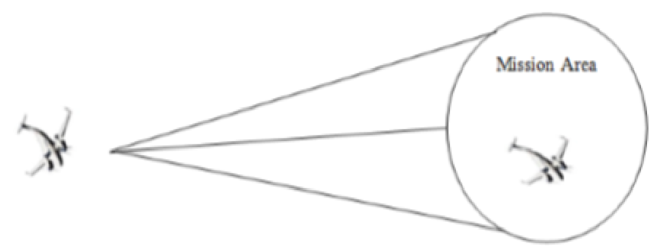

Fig. 10. Mission Plan-Based Model [23]

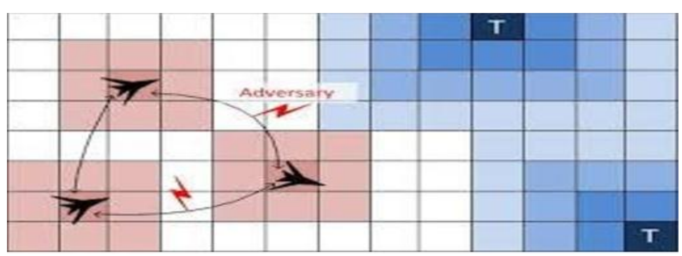

Fig. 11. Pheromone-based model [20]

- Paparazzi mobility model (PPRZM) [20]

The paparazzi portability model is a stochastic versatility demonstrate that the copies paparazzi UAV conduct in light of the state machine. PPRZM has nearer conduct to the genuine follows, and then RWP.PPRZM can be utilized to assess any correspondence, convention with regards to swarms of synergistic UAVs since it bears a practical development situation [20]. As a case in point, it might be utilized to contrast a few steering conventions all together to locate the suitable one for each UAV advertisement tothesystem. In addition, PPRZM can adjust to a mission since it assembles most UAV conceivable development by changing the likelihood of every development sort as required [25].

VI. Conclusion

In this paper, FANETs Literature review has been undertaken, Also, FANETs characteristics have been addressed, Then FANETs routing protocols have been discussed. Moreover, Mobility is the most challenging problem for FANETs. Different mobility models have been discussed that is solvedcommunication problems inside offrequent topology changesin FANETs networks. Furthermore, communication, cooperation, and collaboration are the most challenging design issues for multi-UAV systems. In this paper, ad-hoc networks between UAVs are surveyed as a separate network family, Flying Ad-hoc Networks (FANETs). Mobility models are discussed in details like Random Way Point, Gauss-Markov Mobility, Semi-Random Circular Movement, Mission Plane-Based, Pheromone-Based and Paparazzi Mobility model. Table 1 shows a comparison between routing protocols based on, nature, communication between UAVs and feature.

TABLE I. COMPARISON BETWEEN FANETS ROUTING PROTOCOLS

Routing Protocol	Nature	Communication between UAVs	Feature
Load Carry and Deliver Routing (LCAD)	Static	No, Just between the UAV and ground base	Secure
Multilevel Hierarchical Routing (MLH)	Static	The connection between UAVs in each clusterAnd between clusters and GB by CH	Minimize the overhead.
Data-Centric Routing (DCR)	Static	The connection between UAVs in each clusterAnd between clusters and GB by CH	The ID for UAV does not the matter
Directional Optimized Link State Routing (DOLSR)	Proactive	Not all UAVs. Between the UAV and MPR.	Lower end to end delay
Time Slotted On-demand Routing (TSOR)	Reactive	Yes.	Prevent the collision

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