Flying Ad-Hoc Networks (FANETs): A Review of Communication architectures, and Routing protocols

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***Abstract*—With recent technological progress in the field of electronics, sensors and communication systems, the production of small UAVs (Unmanned Air Vehicles) became possible, which can be used for several military, commercial and civilian applications. However, the capability of a single and small UAV is inadequate. Multiple-UAVs can make a system that is beyond the limitations of a single small UAV. A Flying Ad hoc Networks (FANETs) is such kind of network that consists of a group of small UAVs connected in ad-hoc manner, which are integrated into a team to achieve high level goals. Mobility, lack of central control, self-organizing and ad-hoc nature between the UAVs are the main features of FANETs, which could expand the connectivity and extend the communication range at infrastructure-less area. On one hand, in case of catastrophic situations when ordinary communication infrastructure is not available, FANETs can be used to provide a rapidly deployable, flexible, self-configurable and relatively small operating expenses network; the other hand connecting multiple UAVs in ad-hoc network is a big challenge. This level of coordination requires an appropriate communication architecture and routing protocols that can be set up on highly dynamic flying nodes in order to establish a reliable and robust communication. The main contribution of this paper include the introduction of suitable communication architecture, and an overview of different routing protocols for FANETs. The open research issues of existing routing protocols are also investigated in this paper.**

Keywords—Ad-hoc Network; UAVs; FANETs; Routing

I. Introduction

Thanks to the recent technological advances in electronics, sensors and communication systems, the production of small UAVs (Unmanned Air Vehicles) has paved the way for the conception of low-cost Flying ad-hoc network. Owning to the versatility, flexibility, relatively small operating expensive and easy installation, the usage of FANETs has attracted more attention and importance recently in several military, commercial and civilian applications like disaster management [1], crisis management and hostile environment [2],destroy and search operations [3], border surveillance [4], wildfire management [5], relaying networks [6, 7], estimation of wind [8], civil security [9], agricultural remote sensing [10], traffic monitoring [11]. For example, in case of calamitous situation, when ordinary communication infrastructure collapsed or simply not available, and where it is difficult to install infrastructure in a short amount of time. FANETs can be used to offer an easily deployable and self-configured ad-hoc UAVs network to connect with the rescue crews on the ground. With the assistance of its multi-hop ad-hoc networks schema, FANETs architecture validates that all the UAVs are communicated with each other and to the base station simultaneously without having any pre-defined fixed infrastructure [12].In this way, it can not only deliver the aggregated data to the base station instantly, but also having the capability to share it among the connected UAVs. Moreover, during the operation if some of the UAVs are disconnected due to the weather condition, it can still make their connectivity to the network through the other UAVs. Also, due to the ad-hoc networking among the UAVs, it can solve the complications like short range, network failure and limited guidance which arise in a single UAV system [13]. Even though, such distinctive attributes make FANETs an appropriate solution for different types of scenarios, but they also bring some challenging issues such as communications and networking of the multiple UAVs [14].The speed of a normal UAV ranges from almost 30-460 km/h with movement to 3D-space.As such, the network topology will change rapidly that results connectivity problem [15].

Under these circumstances, choosing an appropriate communication architecture and reliable routing protocols are required to provide robust communication among the UAVs. Particularly, in this paper we explicitly focus on

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communication architectures and routing protocols that are suitable for addressing the communications issues between the UAVs. We compare the characteristics of different communication architectures and routing protocols for networking of the multiple UAVs, and discuss their advantages and disadvantages. The Comparative analysis of our review paper will provide help to network engineers in choosing effective communication architecture and reliable routing protocols for FANETs deployment.

The rest of this paper is organized as follows. Section II introduces various communication architectures for FANETs. In Section III, we provide an extensive review of the existing routing protocols, followed by discussion on open research issues of routing protocols in Section IV. Finally, concluding remarks are presented in Section V.

II. Communication architectures

A communication architecture identifies how information exchange between the base station and a UAV or between the UAVs. In FANETs architecture, UAVs render real-time communication in ad hoc manner that can abolish the need for the infrastructure and it rectifies the communication range constraint [16]. FANETs architecture performs significant role in scenarios where real-time communication and range constraints are main issues, and where it is difficult to provide an infrastructure [17]. In FANETs, as the UAVs connect and detach to the network frequently and, hence, ad hoc network between the UAVs have been found to be the best solution in most cases. Additionally, for quick and robust communication between the UAVs, decentralized communication architecture is more suitable. There are several different communication architectures proposed for multi-UAV systems [18], in which we introduce three communication architectures for FANETs.

A. UAV Ad Hoc Network

In a "UAV ad Hoc network" architecture, all the unmanned air vehicles (UAVs) are connected with each other and the base station autonomously without having a pre-existing communications set-up. In this specific architecture, each and every UAV will be engaged in the data forwarding of the FANETs system. In the UAV Ad-hoc network, a backbone UAV act as a gateway between the ground station and the other UAVs as shown in Fig.1.The gateway UAV carries wireless communication devices capable of operating on both a low power, short range for communication with the UAV and a high power, long range for communicating with the ground station [19]. In this structure, since only backbone UAV is connected with the ground station, due to which the communication range of the network is significantly extended. Additionally, the distance between the multiple UAVs are relatively small, the transceiver device in a UAV will be inexpensive and light-weight, which makes them more appropriate for small sized UAV network. However, in order to maintain connectivity of the network persistent, the mobility pattern such as speed and directions need to be similar for all the connected UAVs in Flying Ad-hoc Networks (FANETs). Hence, this network architecture is best suitable for a group of similar and small size UAVs to pursue persistent operations such as autonomous aerial surveillance mission [20].

B. Multi-Group UAV Ad hoc Network

A multi-group UAV ad hoc network architecture is basically integration of both ad-hoc network and a centralized network. In this network as shown in the Fig.2, multiple UAVs are connected in an ad hoc manner within a group, and the groups are further connected via the backbone UAVs to the ground station in a centralized manner. Intragroup communication is done without involving the ground station, but inter-group communication is performed with the help of the ground station. This type of UAVs network architecture is suitable for cases where large numbers of UAVs are involved in a mission with different flight and communication characteristics. However, due to its semi-centralized nature, this communication architecture is not robust.

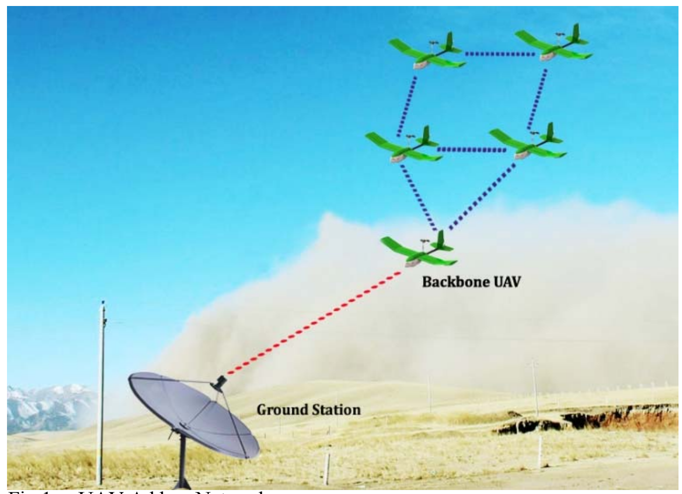

Fig.1. UAV Ad hoc Network

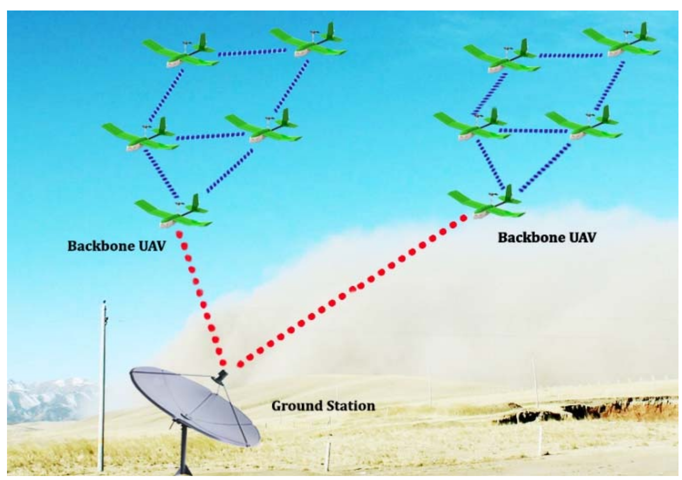

Fig.2. Multi-Group UAV Ad hoc Network

C. Multi-Layer UAV Ad Hoc Network

A multi-layer UAV ad-hoc network is shown in the Fig.3.In this communication architecture multiple group consist of heterogeneous UAVs form an ad-hoc network within an individual group. The lower layer is used for communication between the UAVs and the upper layer is used for communication between the backbone UAVs of all the connected groups and the ground station. The backbone UAV of each group is connected with each other and only one backbone UAV is further directly connected to the ground station. The communication or information exchange between multiple groups does not need to involve or routed through the ground station. The ground station only processes that information that is destined to it, results greatly reduced the communication load and computation on ground station. This communication architecture is best suited for one-to-many UAVs operation. Moreover, this communication architecture is robust because of not having single point of failure. The UAVs hereby are connected with each other through multiple links.

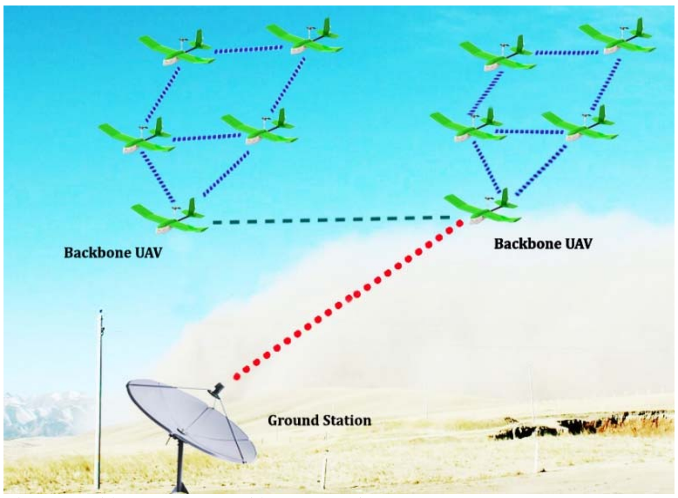

Fig.3. Multi-Layer UAV Ad hoc Network

In summary, a decentralized communication architecture is the most appropriate architecture to connect a team of UAVs [21], while a multi-layer UAV ad hoc network is more suitable for FANETs.

III. Routing PROTOCOLS

The highly dynamic nature of UAVs in FANETs causes abrupt changes in the network topology and hence makes routing among the UAVs a crucial task [22].Considering UAV-to-UAV communication, the routing protocols plays a vital role in reliable end-to-end data transport and less routing overhead makes routing an engaging research topic in the area of FANETs. However, the main challenge to design routing protocols which is suitable to all scenarios and conditions is still under research. In the initial studies and experiments of FANETs, the existing MANET and VANET routing protocols are preferred and investigated for FANETs. However, due to the UAVs specific attributes, such as rapid link quality changes and fast movement in 3D-space , the network routing becomes a crucial task [23] and most of the MANET and VANET routing protocols are not applicable directly for FANETs.Hence to acquire this new ad-hoc networking family some previous ad-hoc networking protocols have been modified and some new one have been proposed for FANETs routing.These routing protocols are classified into following six major categories [24]:

- **i. Static Routing Protocols**
- **ii. Proactive Routing Protocols**
- **iii. Reactive Routing Protocols**
- **iv. Hybrid Routing Protocols**
- **v. Geographic/Position Based Routing Protocols**
- **vi. Hierarchical Routing Protocols**

A. Static Routing Protocols

In static routing protocols, each UAV has a routing table that is not updated during the mission. Static routing protocols are applicable in cases when the topology of the network does not change and where the choices in route selection are limited. Here, each UAV communicate with other the UAVs or the ground station and stores their information only. This leads in reducing the number of communication links. However, in case of a failure for updating the routing table, it is compulsory to wait until the mission is completed. As a result, there protocols are not fault tolerant.

1) Load Carry and Deliver Routing (LCAD)

In Load Carry and Deliver Routing (LCAD) [25, 26] model, a UAV store data from a source ground node, convey these valuable data by flying to a destination ground node as illustrated in Fig. 4. Even though initially in LCAD, a single-source and a single-destination scenario was examined but practically, implementation of multiple-source multiple-destination scenarios can also be possible easily if needed. This routing mechanism is feasible for bulk data transfer and delay-tolerant applications with minimum hops [27].The main objectives of LCAD routing is to maximize throughput and increase the security. However, the main downside of this protocol is, whenever the distance increases between the communicating UAVs, the transmission delay becomes exceptionally large and intolerable. To decrease the transmission delay, multiple UAVs can be used on the same path, where distance among the UAVs must be minimum and speed of UAVs can be increased .And also, LCAD network can be divided into smaller sub-network.


Fig.4. Load Carry and Deliver Routing

2) *Multilevel Hierarchical Routing (MLH)*

Another set of routing solutions for FANETs under static routing is the multilevel hierarchical protocols [28].MLH routing protocol is designed to deal with the network scalability issue. Here, the network can be grouped into a number of clusters designated in different operation areas as illustrated in Fig. 5. Each cluster has a cluster head (CH), which describe the entire cluster and has connections outside cluster as well. It is also possible to assign different tasks to each cluster in the MLH network. All the UAVs in a cluster are within the direct communication range of the CH. The CH is directly or indirectly connected with the upper layer UAVs or satellites. MLH can produce better performance repercussions if the UAVs are arranged in different swarms with large operation area, and multiple UAVs are deployed in the network. However, the most crucial design issue for MLH routing is the cluster information. The high mobility of the UAVs required frequent cluster information, and in this way the mobility prediction clustering address to solve this issue with the prediction of the network topology information by the help of the dictionary Trie structure prediction algorithm [29] and link expiration time mobility model. In this model, the highest weighted UAV among its neighbors is chosen as the cluster head. The CH selection criteria can enhance the stability of the clusters and the Cluster Heads (CHs).Clustering algorithm for UAV networks is presented in [30]. It designate the clusters on the ground first, and then keep updating it during the operation. Ground clustering determines the clustering plan, and then select the CHs based on the geographical information. Moreover, just after the deployment of UAVs, the cluster structure is calibrated according to the mission updates. This routing model can significantly enhance the stability and ensure the artistry of dynamic networking.

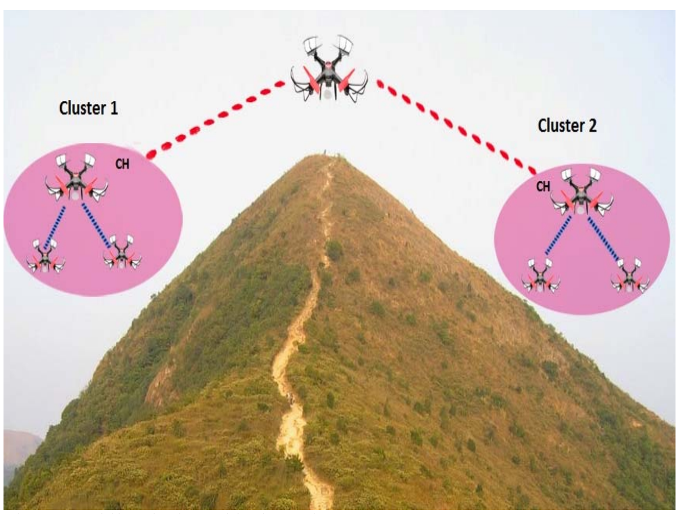

Fig.5. Multilevel Hierarchical Routing

3) *Data Centric Routing(DCR)*

Data-centric routing algorithms implementation on FANETs is also possible, where data is requested and collected with reference to the data characteristics instead of sender or receiver IDs as shown in Fig.6. Apparently, because of the wireless nature of the communication model of UAVs, multicasting can be preferred instead of unicasting. This routing algorithms can be choose when the data request is generated by a number of UAVs, and data distribution is done by on-demand algorithms. DCR can be used in FANETs to provide numerous types of applications on the homogeneous multi-UAV system in order to accumulate explicit data from a specific mission area. Publish-subscribe model is usually valid for this sort of architecture [31, 32]. It connects automatically to the data producers, which are called publishers, with data consumers, called subscribers. The producer node adopts which information need to be published and then starts data dissemination. After reaching the published data to a UAV in the network, it try to find the subscription messages on it and then forwards that data towards the intended UAV. The main benefit of this routing algorithm is that it can only reports the registered contents to the subscribers. Data-centric routing algorithms are decoupled in three dimensions:

•Space decoupling: Communicating UAVs can be anywhere and knowing each other's ID or location is not mandatory.

•Time decoupling: Communicating UAVs are not required to be online simultaneously and data can be forwarded to the subscribers instantly or later.

•Flow decoupling: Data delivery can be accomplished reliably by asynchronous communication structure.

This routing model can be preferred when the number of UAVs are less in the network, and where the UAVs have a predetermined flight-plan, which involves minimum assistance between the clusters

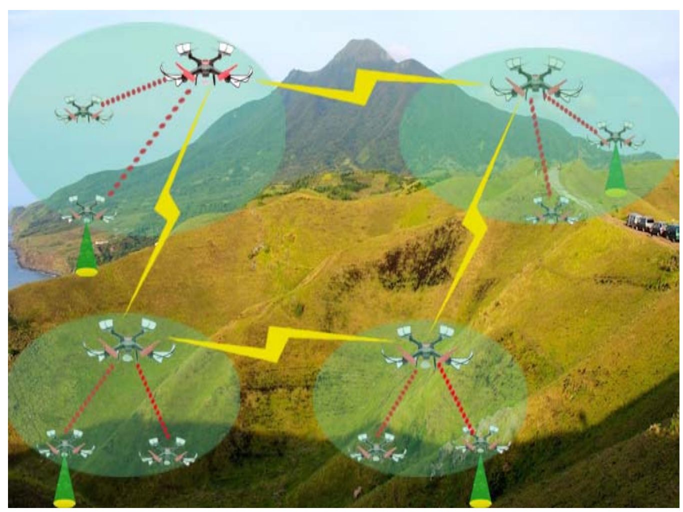
Fig.6. Data Centric Routing

B. *Proactive Routing Protocols*

The proactive routing protocol (PRP) is also known as table. In this type of routing protocol, every node periodically maintains one or more tables indicating the complete topology of the network. Owing to the proactive nature, this routing protocol has advantage of having routes immediately accessible when needed. However, it suffers additional overhead cost because of preserving up-to-date information and as a consequence throughput of the network may be influenced since control messages are sent out unnecessarily even when there is no data traffic. For this reason, proactive routing protocol are not significantly good for highly dynamic mobile and large UAV networks. Second, also for cases when the network topology change or connection failure occurs, these routing protocols shows a slow reaction to failure. There are various routing protocols that fall under this category [33].

1) Destination- Sequenced Distance Vector (DSDV)

It is based on Bellman-Ford algorithm with little modification required by making it more suitable for UAV ad-hoc networks. In DSDV each UAV must distinguish everything about all of the other UAVs connected in the network [34].The routing table here is periodically updated about the entire network with sequence number to avoid routing loops [35].The recently used route with highest sequence number is given preference over on a route with lowest sequence number. The main benefits of DSDV are both the simplicity and the usage of the sequence numbers, which promises the loop free data transmission [36]. However, the main drawback of this routing algorithm is the periodic updating of up-to-date routing table, which creates an overhead to the network.

This protocol is not suitable for highly dynamic networks where topology changes more frequently. Also it support single path routing and does not support multipath routing.

2) Optimized Link State Routing (OLSR)

Routes are continuously stored and updated in tables in OSLR [37]. Hence, whenever a route is required, the protocol determines the route quickly to all possible destinations without any initial delay [38]. With the aim of establishing a communication process between the UAVs in the network running a protocol instance, OLSR uses a unique packet, which comprises of more than one message. OLSR packets can carry three different type of messages, each one for a specific purpose: HELLO message, which is transmit periodically to find connectivity with neighbor, link sensing, and MPR signaling; Topology Control (TC) message, which advertise to maintain link states information and Multiple Interface Declaration (MID) message, which accomplish the multiple interface declaration on a node [39].Therefore, this periodic flooding behavior results in the form of large overhead.

With the use of MPRs mechanism in OLSR, the message overheads can be decreased, and the latency can be improved. Because the MPR UAV can only forward the messages during the flooding process. The sender UAV specifies a set of MPR UAVs so that the MPR UAVs can cover two hop neighbors. A UAV which selects another UAV as a MPR UAV member is called MPR selector of that node.Fig.7 shows the MPR selected by the source UAV. However, the most significant design parameters for OLSR is the number of MPRs, which influences the delay intensely. Apparently, as the number of MPR shrinks, the overhead will reduce consequently. On this way, a new method is suggested for reducing the number of members of MPR. Fig.8 shows a diagram for the suggested DOLSR. For each sending data packets, the sender UAV computes the distance to the receiver UAV, then if the distance is larger than the maximum distance that can be attained by using the directional antenna (Dmax/2), or also if the Omni-directional antenna cannot achieve the destination, the UAV will apply the DOLSR algorithm Otherwise, OLSR will be used usually[40].

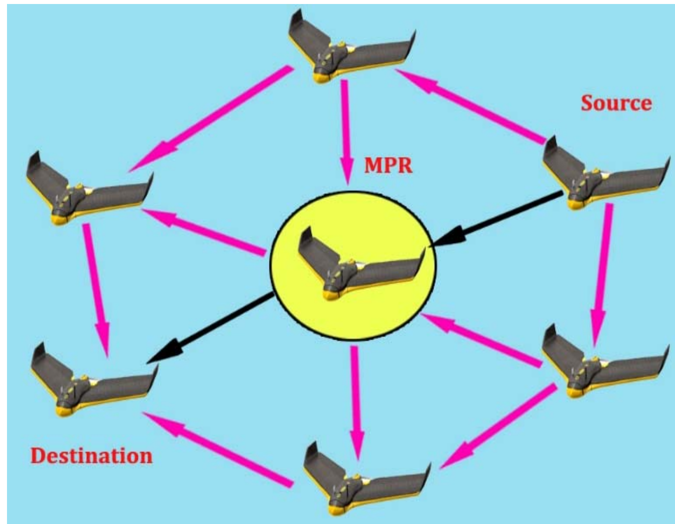

Fig.7. Multipoint Relay (MRP)

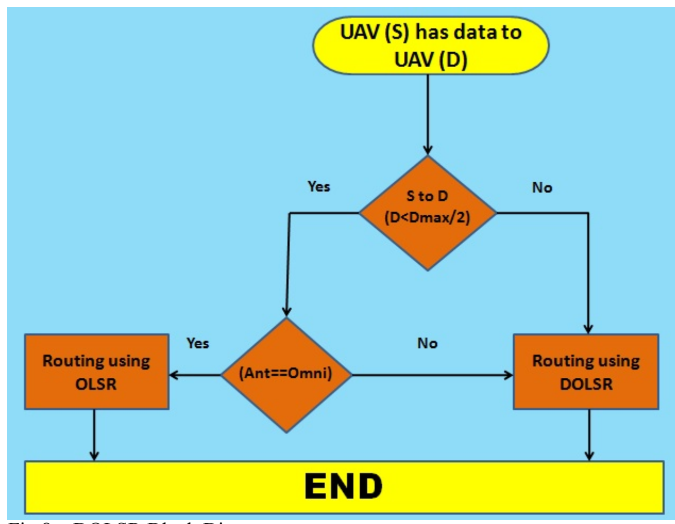

Fig.8. DOLSR Block Diagram

C. Reactive Routing Protocols

The reactive routing protocol (RRP) is also known as on-demand routing protocol, means it discovers or maintains a route on demand. The routing table here is periodically updated, when there is some data to send, if there is no connection between two nodes, there is no need to calculate a route between them. Thus these routing protocols retain the routes only that are presently in use [41],therefore as a consequence it overcome the overhead problem of PRP. In this routing model, there are two types of messages generated: (1) *RouteRequest and (ii) RouteReply* message [36]. *RouteRequest* message is transmit from the source UAV to all adjacent UAVs using flooding mechanism to discover the path, and each UAV uses the same approach until it reaches the destination UAV. While the *RouteReply* message is initiated by the destination UAV and goes to the source UAV using the unicast communication mode. In this routing approach, there is no need to refresh all tables in the network. Reactive routing protocols are bandwidth efficient, because there is no periodic updates. The main shortcoming of RRP is that it takes long time to find the route; as a result high latency may occur in the network during the optimal route finding process.

1) Dynamic Source Routing (DSR)

In [42], Brown et al. developed FANETs test bed with Dynamic Source Routing (DSR) [43] protocol. It allows a network to be self-configuring, self-organizing and without the need for having any available infrastructure.The main objective of choosing DSR is its reactive nature and is mainly used for multi-hop wireless mesh networks. In DSR the source only tries to find a path to a destination in a scenario, whenever it has data to send. Khare et al. stated that DSR is more suitable than proactive methods for FANETs, where the mobility of the UAVs is high, and the topology is not stable [44].Updating a routing table by a proactive methods is not that much optimal due to the high mobility of the UAVs. However, repetitive path finding by reactive method before each packet delivery can also be exhaustive.

2) Ad Hoc On-Demand Distance Vector (AODV)

Ad Hoc On-Demand Distance Vector (AODV) is the enhanced version of both DSDV and DSR routing protocols. It inherits periodic updates from DSDV and hop-to- hop routing from DSR. Due to the reactive behavior, AODV discover a route only when it is desired and does not retain routes to destination that are not active in the communication process [45]. AODV routing protocol comprises of three phases :(i) route discovery (ii) packet transmitting (iii) route maintaining. Whenever a source UAV wishes to send a packet, it first initiates a route discovery operation to detect the location of the intended UAV and then forward packet over a determined route without having a loop during packet transmitting phase. Route maintenance phase take place to restore link failure. This routing protocol uses a sequence number to find an up-to-date optimal route towards the destination. An expiration time is used in order to maximize route's freshness. In this method, intermediate UAVs also update their routing tables. However, network congestion is an issue with AODV due to the high dynamic nature of FANETs system.

3) Time-slotted on-demand Routing

Time-slotted on-demand routing protocol is also proposed in [46] for FANETs. This routing algorithm is basically time-slotted version of Ad-hoc On-demand Distance Vector Routing (AODV) [47]. AODV sends its control packets on random-access mode, whereas time-slotted on-demand protocol practices dedicated time slots in which only one UAV can send data packet. This routing method not only increase the usable bandwidth efficiency, but also avoid the packet collisions and increases the packet delivery ratio.

D. Hybrid Routing Protocols

The Hybrid Routing Protocol (HRB) is a combination of both proactive and reactive routing protocols, taking the best features and to overcome the limitations from both worlds. Reactive routing protocols generally needs extra time to discover route and proactive routing protocols has huge overhead of control messages. These shortcomings can be mitigated by using HRP. Hybrid protocols are especially appropriate for large networks, and is based on the concepts of zones where intra-zone routing is executed with the help of proactive routing and inner-zone routing is achieved using the reactive routing approach.

1) Zone Routing Protocol (ZRP)

This routing algorithm is basically based on the concept of "zones" [48], and is suitable for large network spans and diverse mobility patterns.In this routing approach, each UAV has a different zone, and the zone of neighboring UAVs overlap. The size of the zone is determined by a radius of length "$\mathcal{R}$". "$\mathcal{R}$" is the number of UAVs to the perimeter of the zone.The number of UAVs in the zone can be regulated by adjusting the transmission power of the UAVs.The routing within the zone is called as intra-zone routing. The intra-zone routing uses "proactive routing" approach to maintain the routes. If the source and destination UAVs are available in the same zone, the source UAV can start data communication immediately. The inter-zone routing is responsible for sending data packets to outside of the zone, and it utilizes reactive routing approach to maintain and finding the optimal routes. The delay caused by the route discovery is minimized by using bordercasting [49]. Reply messages are only generated by border UAVs of a zone. The border UAVs then repeat either by selecting inter- or intra-zone routing as required.

2) Temporarily Ordered Routing Algorithm (TORA)

Temporarily Ordered Routing Algorithm (TORA) is a highly adaptive on-demand routing protocol, suitable for multi-hop networks. In this routing approach, each UAVs only update routing information about adjacent UAVs. The key features of using this routing algorithm is to limit the propagation of control message in a highly mobile environment in order to minimize quick reactions to topological changes [50]. It erases invalid routes and searches for new routes in a single-pass of the distributed algorithm. Particularly, TORA uses reactive routing protocols, but it also use proactive approaches in some cases. It construct and maintains a Directed Acyclic Graph (DAG) from the source to destination UAV. There are several routes among these UAVs in DAG. It is preferred for quick computing of new routes in case of disconnected links and for enhancing adaptability [51].TORA is not based on the shortest path algorithm, longer routes are normally used to minimize network overhead. Each UAV has a parameter value known as "height" in DAG, and no two UAVs have the same height value. Data flow from the higher UAVs to lower UAVs like top-down approach. It offers loop-free routing, because of no data flow towards the higher height UAVs. In the route discovery process, this height parameter is returned to the requesting UAV, and in this approach all the intermediate UAVs maintain their routing tables according to the incoming routes and heights information.

E. Geographic/ Position Based Routing Protocols

Position-based routing protocols have been proposed to assume knowledge of the geographical position information of UAVs to supports efficient routing [52]. In this type of protocols, they assume that the source UAV knows about the physical position of the communicating UAVs and sends message to the destination UAVs without route discovery. Generally, each UAV determines its own position with the help of GPS system or any other type of positioning facility. This routing algorithm is primarily inspired by two subjects:

(i) A position facility is normally used by the sender of a packet to locate the physical position of the receiver and (ii) A forwarding approach is used to forward data packets to the intended UAV.

1) Greedy Perimeter Stateless Routing (GPSR)

Greedy Perimeter Stateless Routing (GPSR) [53], which is also a position-based protocol, having better performance comparatively to proactive and reactive routing algorithms. Shirani et al. developed a simulation framework to examine the position-based routing protocols for FANETs [54]. It was shown that "greedy geographic based forwarding routing protocols" are applicable for densely deployed UAVs Network. However, the reliability of the network can be a severe issue in situation of sparse deployments. A combination of other mechanisms, such as face routing, should be used for the applications that target 100% reliability. However, initially for FANETs deployments the existing MANET routing algorithms have tested, in which most are not well suited for FANETs, due to the UAV distinct obstruction such as rapid variation in the link quality and very high mobility of the flying nodes.

2) Geographic Position Mobility Oriented Routing

Geographic Position Mobility Oriented Routing (GPMOR) was presented for FANETs in [55]. The conventional position-based solutions only depend on the location information of the UAVs. However, GPMOR also figure out the movement of UAVs with "Gaussian-Markov mobility model", and it utilizes this data to locate the next hop. It is investigated that this routing mechanism can provide data forwarding effectively with reference to packet delivery ratio and latency.

F. Hierarchical Routing Protocols

In hierarchical routing protocols the ability of choosing proactive and of reactive routing rely on the hierarchical level of the network in which a UAV resides. This specific routing is primarily determined with some proactive planned routes and then helps the request from by triggered nodes through reactive protocol at the lower levels. The main downside of this protocol include complexity and scheme of addressing which response to traffic request and as a repercussion it drape the interconnecting factors.

1) Mobility Prediction Clustering Algorithm(MPCA)

Mobility Prediction Clustering Algorithm(MPCA) proposed for UAV networking [56] based on the attributes of UAVs. It governs on the dictionary of trie-structure prediction algorithm and link expiration time to solve the issues regarding high mobility of the UAVs.The main advantage of this algorithm is to reduce the instability of clustering and improves the network performance.

2) Clustering Algorithm of UAV networking

Clustering algorithm is based to overcome the difficulty of managing out of sight UAVs. In case of multi UAV system, it construct clusters on the ground, and then adjust it in the space to improve the stability and flexibility of near-space clusters [57].

IV. OPEN RESEARCH ISSUES

Due to the fast mobility of UAVs, topology of the network change rapidly in FANETs that constitutes routing issue among the UAVs. Because of this unique FANETs challenge, the existing MANET and VANET routing protocols fail to meet all the FANETs requirements. The routing algorithms and protocols should be sophisticated enough to update routing tables dynamically according to the topological changes. Peer-to-peer network is mandatory for collaborative coordination, congestion control and collision avoidance among the UAVs in FANETs. However, it is also possible to use FANETs in the form of wireless sensor networks to gather information from the environment, which create different traffic pattern. All the data are routed among a limited number of UAVs that are directly connected to an infrastructure. At the same time, developing new routing algorithms are also required that can support peer-to peer networks. In the present time, FANETs is still relatively a new research area, where new routing algorithms instigate and previous ones are modified. Amount of the algorithms is adequate, which can be described by the requirements diversity and the attributes of transmitted data. Data centric routing is an optimistic approach for FANETs. With the support of the publish-subscribe architecture of data centric algorithms, it might be promising to create multi-UAV systems that can validate different application scenarios. To the extent of our understanding, data centric routing algorithm is not examined yet totally. Along with traditional routing algorithm, bio-inspired algorithms (AntHocNet and BeeAdHoc) [58] may also be explored to address routing issues in FANETs.

V. CONCLUSION

FANETs have become an emerging research field, which consists of a group of small UAVs connected in ad-hoc mode. Such networks are distinguished by a high mobility, frequent topology changes and 3D-space movement of the nodes, which constitutes networking issues. In order to overcome such kind of issues, choosing an appropriate communication architecture and reliable routing protocols are mandatory to authenticate robust communication between the UAVs.

In this paper, we first introduced three different decentralized communication architectures, in which we proposed a multi-layer UAV ad hoc network more suitable for FANETs. Subsequently, we investigated various routing protocols along with open research issues.We hope this investigation will help network engineers for FANETs deployment. We also believe that FANETs will be ubiquitous technology in the future.

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