A Comprehensive Survey on Communication Protocols for FANET

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Abstract— Flying Ad hoc Network is a collection of small unmanned aerial vehicles (UAV's). In multi-UAV system nodes fly in the air and communicate with each other by creating ad hoc network. If all the nodes are directly connected to the infrastructure than is restrict the capabilities of multi-UAV system. The main Challenge in FANET is routing because of rapidly changing topology, high mobility, and long distance between UAV's. The routing protocols designed for VANET and MANET partially failed in FANET. So this is a new emerging area of research to discover robust protocol for FANET. In this paper we have studied different routing protocols for FANET and how they vary from VANET and MANET.

Key words: FANET, Routing Protocols

I. INTRODUCTION

As a result of the rapid technological advances on ad hoc networks, sensor and communication technologies, it has been possible to construct unmanned aerial vehicle (UAV) systems, which can fly autonomously or can be operated distantly without carrying any human personnel[1]. UAV system started with single unmanned aerial vehicle mainly for surveillance, reconnaissance and monitoring, but with increase in miniature technology deployment of coordinated multi UAV to perform better in group is being developed. In single UAV system the node is connected to infrastructure of satellite directly, which may cause following difficulties

- Each UAV must be occupied with complicated and expensive equipment in order to communicate with infrastructure or satellite.
- The UAV must be in the coverage area of ground base station.
- UAV should maintain communication link continuously.

As shown in the figure 1 these challenges can be resolved by creating ad hoc network among UAV's. This is known as Flying Ad hoc Network (FANET). FANET was basically designed for multi UAV system that has advantages over single UAV systems as follows [1]:

- Cost
- Scalability
- Survivability
- Speed-up
- Small radar cross section

The multi UAV systems are used for Military and civilian applications such as

- Search and destroy operations
- Border surveillance
- Managing wildlife
- Relay for ad hoc networks
- Wind estimation
- Disaster monitoring
- Remote sensing and
- Traffic monitoring

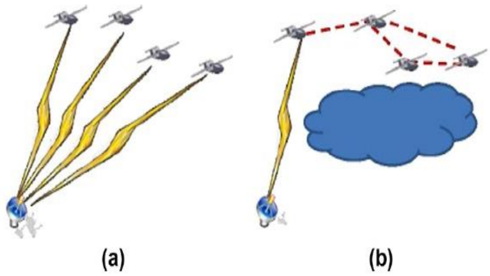

Fig. 1: FANET scenario for multi UAV system

II. CHARACTERISTICS OF FANET

Due to following characteristics, FANET differs from MANET and VANET [2]:

A. Node mobility

In FANET nodes are high speed UAV'S that's why it requires high degree of mobility. The speed of UAV'S may be 30 to 460 km/h

B. Node density

FANET node density is much lower than VANET and MANET. The nodes in FANET are at extensive distance.

C. Topology change

The topology changes rapidly in FANET due to high mobility degree. This may lead to unexpected results of basic routing protocols.

D. Radio propagation model

The MANET and VANET nodes may be on the ground or near the earth but in FANET the nodes appear far from the ground and in most of the cases there is line of site between UAVs which requires radio propagation models to be developed.

E. Power consumption and network lifetime

FANET communication hardware is powered by the energy source of the UAV. So it may not have the power consumption problems as in MANET but still it is the issue to create efficient design model for improved lifetime.

F. Computational power

Most of the UAVs have enough energy and space to include high computational power. The only limitation about the computational power is the weight.

G. Localization

A vital issue of FANET is the localization. Due to high mobility and changing topology, it is important to know the location of each UAV. FANET needs highly accurate location data with less interval of time. For this purpose UAV must equipped with inertial measurement unit (IMU).

III. Classification of Routing Protocols

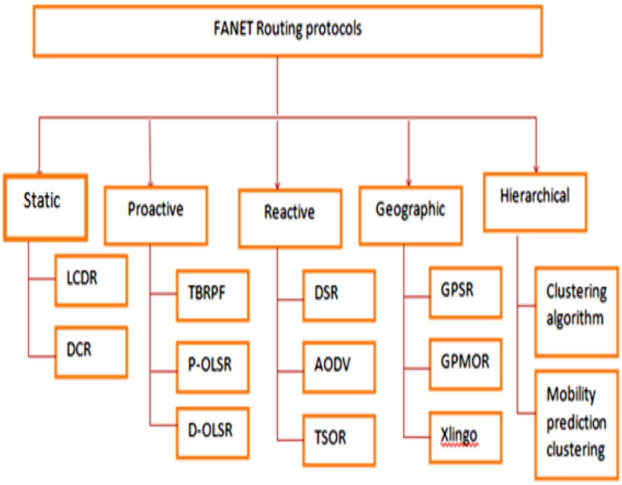

Fig. 2: classification of FANET routing protocols

A. *Static routing protocols*

In static routing protocols, once the routing tables are loaded in the UAV's then during the mission it cannot be changed. It is considered that the network topology will not change. There are limited numbers of nodes that can communicate with each other; it depends on the routing information stored in the tables. In case of failure, it cannot update the table dynamically therefore they are not fault tolerant and not suitable for dynamic networks.

1) *LCDR*

Load Carry and Delivery Routing is one of the first routing models in FANET. In this model, a UAV loads data from a ground node (or gets video image of its path); after that, it carries these important data to the destination by flying; and finally it delivers the data to a destination ground node (such as a military team or a ground control station) [4].

2) *DCR*

Data-centric routing is a hopeful prototype of routing method and can be adapted for FANET. In this model, the consumer node may be the ground node disseminates queries as subscription message in order to collect precise data from a detailed area. The producer node decides which information to publish and starts data dissemination. When published data reach a UAV, it checks the subscription messages on it and forwards these data consequently. Routing is done with respect to the content of data; and if needed, data aggregation algorithms can be used for energy-efficient data dissemination.

B. *Proactive routing protocols*

The proactive routing protocols store routing information in the table called routing table. The table will be updated as the topology changes. The main advantage is that the tables are updated repeatedly so it contains latest routing information that's why there is no need to wait. However, there are some explicit disadvantages. Firstly, PRP protocols cannot efficiently use bandwidth due to continuous message exchange between nodes; therefore, PRPs are not suitable for highly mobile and larger networks. Secondly, it shows a slow response, when the topology is changed, or a failure is occurred [4]. Following protocols are widely used in FANET:

1) *TBRPF*

A protocol called Topology Broadcast based on Reverse Path Forwarding (TBRPF) is developed for efficiently disseminating link state updates [5]. In TBRPF each routing table contains the state of each link. As there is any change in the state of link, it is quickly detected and alternate routes are immediately computed therefore it is suitable for FANET. The process of TBRPF consists of two steps; first, it perform neighbor discovery and second it broadcast link state updates rapidly. TBRPF uses min-hop path spanning trees rooted at the source to send the updates efficiently. The broadcast tree formed by the min-hop paths changes dynamically; is used to travel topology updates using reverse path forwarding. Since the leaves of the broadcast tree rooted at a particular source do not forward updates originating from that source a dramatic reduction in control traffic is achieved compared to link state flooding protocols [5].

2) *P-OLSR*

FANETs are having characteristics of frequent topology change. For this reason the routing protocols for MANET may not be sufficient for FANET. Thus extension to the OLSR protocol is proposed by Stefano Rosati in [6] is P – OLSR i.e. Predictive – OLSR. The key idea of this protocol is to use GPS information available on board and to weigh the expected transmission count (ETX) metric by a factor that takes into account the direction and the relative speed between UAVs.

3) *D-OLSR*

The protocol is known as Directional Optimized Link State Routing protocol (DOLSR). This protocol is based on the Optimized Link State Routing Protocol (OLSR). The protocol focuses on Multi Point relay (MPR) concept which is the most vital feature of this protocol. The UAVs should be equipped with directional antenna in order to implement this protocol. The algorithm is developed that allows DOLSR protocol to minimize the number of multi point relays. With the help of this protocol the number of overhead packets will be reduced and the end to end delay of the network will also be minimized [7].

C. *Reactive routing protocols*

Reactive Routing Protocol (RRP) is known as on demand routing protocol, which means if there is no communication between two nodes, there is no need to store a route between them [4]. RRP is designed to prevail over the overhead problem of proactive protocols. There are two types of messages in this routing model: Route Request messages (RREQ) and Route Reply messages (RREP). The source node generates the Route Request Message and sends over the network then the destination node replies with Route Reply Message. The communication begins after receiving the Route Reply. As a result, each node maintains only the routes that are currently in use. It is bandwidth efficient as there is no periodic messaging in this protocol. Also high latency may appear during the route finding process.

1) *DSR*

The dynamic source routing is a routing technique in which the sender of a packet establish the complete sequence of nodes through which to forward the packet, the sender explicitly lists this route in packet header, recognize each forwarding hop by the address of the next node to which to transmit the packet on its way to the destination host [8].

There are no periodic router advertisements in the protocol. Thus the DSR protocol is capable to adapt rapidly to changes like host movement. If there is no changes occur during some periods then it requires no routing protocol overhead. DSR performs basic two operations: route discovery and route maintenance.

2) AODV

Ad-hoc On-demand Distance Vector Routing is the algorithm in which each mobile host operates as a specialized router and routes are obtained as per on demand bases with little or no dependence on periodic advertisements. It is fairly suitable for dynamic networks. AODV provides loop free routes even while repairing broken links [9]. The protocol does not use the periodic advertisement therefore the demand of bandwidth is less.

3) TSOR

The time Slotted On demand Routing protocol is shown to eradicate collisions due to route determination and therefore enhance quality of service as well as ensure necessary support for formation movement. This protocol is developed to decrease the inner node communication and limit the number of collisions that occur during the route finding process. This protocol is based on the AODV protocol because it has a lower packet delay in tense networks. The method includes a time component to the AODV protocol similar to that of slotted ALOHA protocol [10]. The method sets aside a particular time slot for one node to communicate data to the cluster head (CH). Each node is given communication rights over all other nodes in the assigned time out.

D. Geographical routing protocols

The highly dynamic mobility is the main reason of causing frequently changed topology. It is hard for topology based routing protocols to maintain constant routes and high routing performance. Compared with topology ones, the geographic based protocols concern with the best next hop.

1) GPSR

The Greedy Perimeter Stateless Routing is a novel routing protocol for wireless ad hoc networks that uses the positions of routers and a packet's destination to make packet forwarding decisions. As the name suggest, GPSR makes greedy forwarding decisions using only information about a router's instant neighbors in the network topology. The algorithm works fine until the greedy forwarding is possible; at the position where it is impossible, it recovers by routing around the perimeter of the region. As the protocol keeps state only about the local topology, GPSR scales better in per-router state than shortest path. Under mobility's frequent topology changes, GPSR can use local topology information to find correct new routes quickly.

2) GPMOR

Geographic Position Mobility Oriented Routing (GPMOR) uses Gauss-Markov mobility model to predict the movement of UAVs to eliminate the impact of highly dynamic movement. Then it selects the next hop according to the mobility relationship in addition to Euclidean distance to make more accuracy decision [12].

3) Xlingo

Cross-layer Link quality and Geographical-aware beaconless opportunistic routing protocol (XLinGO) improve the transmission of instantaneous multiple video flows over FANETs by creating and keeping reliable persistent multi-hop routes. XLinGO considers a set of cross-layer and human-related information for routing decisions, as performance metrics and Quality of Experience (QoE) [13].

E. Hierarchical routing protocols

Another set of routing solutions for FANETs is the hierarchical protocols, which are developed to address the network scalability problem. Here, the network consists of a number of clusters in different mission areas. Following hierarchical protocols are used for FANET

1) Clustering algorithm:

In the clustering algorithm the network consists of a number of clusters. Each cluster has a cluster head (CH), and all the nodes in a cluster are within the direct communication range of the CH. As the CH represents the whole cluster, it is directly connected with satellite. CH can also distribute data by broadcasting to its cluster members. This model can produce better performance results when the mission area is large, and the number of UAVs is higher [14].

2) Mobility prediction clustering

Mobility prediction clustering is a cluster formation algorithm developed for FANET. Due to high mobility the clusters may changes frequently so the protocol is used to solve this problem by predicting the cluster updates frequently. It predicts the mobility structures of UAVs by the help of the Trie structure prediction algorithm and link expiration time mobility model [15]. The selection of CH is done by taking the weighted sum of all the models and finding the highest weight. The CH selection scheme can increase the stability of the clusters and the CHs.

Protocol	Feature	Nature	Efficiency
LCDR [16]	load carry and deliver paradigm	Static	High throughput and scale throughput by arranging multiple UAVs in pipeline manner
DCR [1]	Publish subscriber model is used	Static	Used when limited number of UAVs for particular applications
TBRPF[5]	Reverse path forwarding	Proactiv e	Reduce overhead
P-OLSR[6]	Prediction based on GPS informatio n	Proactiv e	Suitable for frequent topology change,outperfor m OLSR
D-OLSR [7]	Based on selection of MPR node, directional antenna	Proactiv e	Lower end to end delay
DSR [8]	Mobility aware	Reactive	More adaptable to dynamic topology of FANET
AODV [9]	On demand routing	Reactive	Suitable for dynamic networks
	Based on AODV	Reactive	Reduced packet collision,

TSOR [10]	dedicated slot to send data		enhanced packet delivery
GPSR [11]	Position based stateless protocol	Position based	Outperform many existing non position based protocol
GMPOR [12]	Based on Gaussian markov mobility model	Position based	Better latency, packet delay ratio position based protocol
Xlingo [13]	Cross layer, position based for multimedia data	Position based	Efficient QOS, reduce packet delay
Clustering algorithm [14]	Divide the nodes into number of clusters then select CH	Cluster based	Increase the stability, guarantee the ability of dynamic networking
Mobility prediction clustering [15]	Predicts the mobility structure frequently	Cluster based	Increase the stability of clusters and CH

Table 1. Routing protocols for FANET

IV. Conclusion and Future Work

The routing protocols for FANET are currently taking more interest of researchers due to their different characteristics. Here we have tried to mention almost maximum number of protocols used for FANET. Since there is a lot of work to do in this particular field and there is a need to find more efficient routing protocols.

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