Experimental Analysis on Routing Protocols in Flying Ad Hoc Networks (FANET)

Anna Dieckvoss (1227324)
Department of Computer Science
Lakehead University
adieckvo@lakeheadu.ca

Harika Kudarvalli (0887033)
Department of Computer Science
Lakehead University
hkudarva@lakeheadu.ca

***Abstract*—In recent years, there have been progressive advancement in the field of wireless communication systems. Unmanned Aerial Vehicles have rapidly evolved and being extensively used for military, research and civilian applications. This report gives a brief description on Flying Ad-Hoc Networks (FANET). FANET is a subclass of Mobile Ad-Hoc Networks and made up of a swarm of small flying vehicles enabled with camera, sensor and GPS system. Different types of communication architectures have been explained in this paper. Because of their wireless nature, UAV's are designed to travel long distances. This causes topology issues among UAVs and their base stations which is overcome using topology construction. Multiple UAV's can be connected to make a wider FANET. But this needs dynamic and flexible routing among UAV's. Various routing protocols have been introduced to establish a reliable and robust communication. FANETs are known for their complex architecture which causes multiple technological and social implications in the world of Wireless Communications. The paper includes in-depth research on Flying Ad-Hoc Networks and challenges faced by network scientists. We have also conducted experimental analysis on reactive and proactive routing protocols using NS3 simulation to achieve insights on their performances using evaluation metrics like packet delivery ratio, end - end delay and average throughput.**

***Index Terms*—Wireless Communications, Mobile Ad-Hoc Networks, Flying Ad-Hoc Networks, Unmanned Aerial Vehicles, Routing Protocols, Topology**

I. Introduction

The impact of wireless communication has been and will continue to be profound. The fifth generation and beyond (5G+) is apparent in the growth. New research area of ad-hoc networks are unmanned aerial vehicles (UAVs) and the advancement to overcome the short comes is called Flying Ad-Hoc Networks (FANETs). With this modification, its network architecture has changed.

An ad-hoc network is a peer-to-peer network, which allow communication between devices without the need for any central infrastructure. In the 5th Generation, drones are considered as a mobile platform and they set up temporally an ad-hoc network. Owing to the huge number of participants, the cell size has shrunk, while there are 10 to 100 times greater number of connected devices.The recent technological advances in shrinking and more efficient of electronics and communication systems, make the production of small UAVs (Unmanned Air Vehicles) possible. It was the precursor for the conception of low-cost Flying Ad-Hoc Network. The usage of FANETs has attracted more attention in military, commercial and civilian applications.The characteristics of FANETs differ from Mobile Ad-Hoc Network and Vehicular Ad-Hoc Network. The main difference is the fact that UAVs in general, but particularly when organized are FANETs, are mission-based.

The network flying platforms are high mobility, which means that they are operating with the speed of 30-460 km per hour. This is the reason why there cannot be used the conventional Internet protocol (IP) and there is a need for some new methods. The mobility is causing rapid topology change. Routing is one of the Major challenges in FANET. The Experimental Analysis on Routing Protocols in Flying Ad Hoc Networks (FANET) will show what is the better choice in choosing a routing protocol.

The rest of this paper is organized as follows. Section II discusses our research on different journal papers in the area of Flying Ad-Hoc Networks, the social impacts which come along technical application, communication architectures and routing protocols. Section III presents our implementation of proactive and reactive protocols in ns-3. Section IV show the results in comparison between OLSR and DSDV, AODV and DSR, followed by conclusions in Section VII.

II. Related Work

A. Networking Models in Flying Ad-Hoc Networks (FANETs): Concepts and Challenges

This paper [1] sheds lights on the capabilities and roles of Unmanned Aerial Vehicles (UAVs), their rapid evolution, and their usage in military and civilian areas as the result of the advances in technology of robotic systems. In this paper, the author identifies the challenges with using UAV's as relay nodes in an Ad-Hoc manner, introduces network models of UAV's, and depicts open research issues with analyzing opportunities.

B. Technological and Social Implications - Flying Ad-Hoc Networks

The paper [2] covers the important positive and negative social impacts for our community and the technical aspects such as quality of life and surrounding environment. The areas where FANETs will can be used are emergency situation in places which are unmanageable for people, for surveillance and monitoring applications (Border Surveillance) or Managing Wildfire. The use of Surveillance tasks require a high act of accuracy with sensitivity of the data. The technical aspects include besides the choice of one of the FANET Communication Types (UAV-to-UAV and UAV-to-infrastructure) as well Security Concerns and owned to the high mobility the Communication Challenges.

C. Topology Construction for Flying Ad-Hoc Networks (FANETs)

The main taking points in this paper [3] is the future prospect of the application of Flying Ad-Hoc Network (FANET) that consists of multiple UAV's. A way to construct a topology for FANET guarantees end to end communication between the ground station and each mission UAV that performs it's given task via optimizing the locations of the relay UAV's. The author proposes a topology construction algorithm based on a Particle Swarm Optimization (PSO) algorithm. Numerical results show that the proposed algorithm achieves a significantly higher performance gain over existing topology construction schemes.

D. Near-Optimal Resource Allocation Algorithms for 5G+ Cellular Networks

The paper [4] is about one optimization problem with Near-Optimal Resource Allocation Algorithms for 5G+ Cellular Networks. The authors concluded that using centralized (HBCA) and a distributed (SMBDA) algorithm the optimal association between the NFPs and small cells (SCs). They consider the NFP bandwidth, the number of supported links and the minimum required Signal-to-interference-plus-noise ratio SINR.

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

In this paper [5], the writers emphasize the limitations in the productions of UAV's and the need of an advanced network system that can integrate the UAV's to the network on a large scale. 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. This kind of network can provide the UAV's with mobility, lack of central control, self - organizing and ad-hoc nature between the UAV's which could expand the connectivity and extend the communication range at infrastructure-less area. 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. The main contribution of this paper includes the introduction of suitable communication architecture, and an overview of different routing protocols for FANETs.

F. Social and Technical Implications

The technical advance in FANET should considers the social impacts that come along with the 5th Generation and other applications in the wireless communication. Especially in areas without built out infrastructure or exceptional situations like earth creak, the mobility of the network flying platform is an advance. For example, such ad-hoc networks allowed communication between devices in April 2015 after the Nepal earthquake [2]. The areas where FANETs will can be used are emergency situation in places which are unmanageable for people, for surveillance and monitoring applications (Border Surveillance) or Managing Wildfire (refer figure 1). The immediate processing and transmitting of data can bring some negative social impacts along. The possibility to use FANETs as a monitoring applications, for example watching the border crossings, is powerful tool. Based on the sensitive information handling, FANETs are a probable victim of attacks. The use of Surveillance tasks require a high act of accuracy with sensitivity of the data. The Security Concerns must be covered.

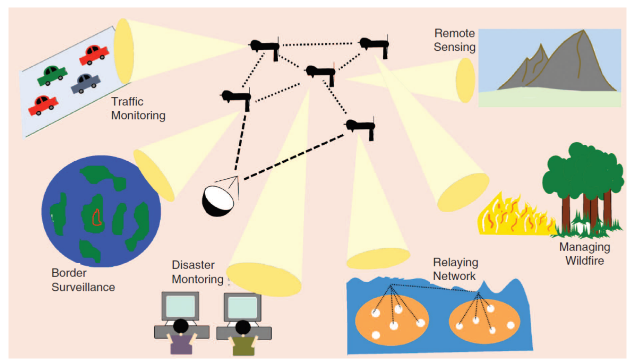

Fig. 1. Areas of FANET [2]

However, the Quality of Service (QoS) is a very important value to obtain the Low Latency Requirement. This can be done by decreasing the hop counts with long transmission ranges. Furthermore, by using drones in sensitive applications like military or surveillance the communication must be highly reliable. The reliability is given by the infrastructure of the swarm formed flying ad-hoc network and the use of routing protocols. Therefore is Routing one Challenge of FANETs (II-H).

G. Communication Architectures

UAVs and base station must exchange information through a predefined infrastructure called communication architecture. It holds an important role for real time communication between multiple components for a robust and reliable connection. Some of the crucial communication architectures have been discussed below.

1) UAV Ad-Hoc Network: In this type of network, there is no pre-established communication between UAV's and base station. A backbone UAV acts as a gateway for communication. The distance between the UAV's is relatively small. The speed and directions among the UAV's should be similar for a persistent connection. Therefore, it is suitable for smaller wireless networks.

2) Multigroup UAV Ad-Hoc Network: Multiple UAV's are connected in an Ad-Hoc manner within a group, and the groups are further connected via the backbone UAV's to the ground station in a centralized manner. This type of network is suitable for large networks with multiple communication characteristics. Intragroup communication is done without involving the ground station, but inter-group communication is performed with the help of the ground station.

3) Multi-Layer UAV Ad-Hoc Network: This communication architecture consists of heterogeneous UAVs forming a network. 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. Only one backbone UAV is connected to the ground station. It is best suited for one to many interactions. Multi-layer ad-hoc network is highly robust as there is no single point of error.

H. Routing Protocols

1) Static Routing Protocols: Static routing protocol is used in cases where the topology does not change frequently. Due to this the routing tables are not updated while ongoing mission. Ground station is responsible for storing entire mission's information. Updating of routing table is a limitation in this protocol and hence if any failure occurs, it must wait for the completion of mission. Following are types of Static Routing Protocol:

1) Load Carry and Deliver Routing (LCAD)
2) Multilevel Hierarchical Routing (MLH)
3) Data Centric Routing (DCR)

2) Proactive Routing Protocols: Proactive Routing Protocol is opposite to Static Routing Protocol. It updates the topology of the entire network periodically. This type of nature also has a disadvantage as it stores overhead of information and might decrease overall throughput. It is not suitable for dynamic and large networks. It has a very slow reaction to connection or information failure. Following are types of Proactive Routing Protocol:

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

3) Reactive Routing Protocols: RRP is widely known as on-demand routing protocol. Unlike in other protocols, the routes are not calculated if there is no information to be sent. Two types of messages are generated while calculating routes: (i) RouteRequest and (ii) RouteReply message. RouteRequest message using flooding mechanism to establish a path between source and destination. RouteReply message is sent by destinating using unicast communication mode. They are known for being bandwidth efficient. One of the limitations of using Reactive Routing Protocol is high latency due to finding optimal route. Following are types of Reactive Routing Protocol:

1) Dynamic Source Routing (DSR)
2) Ad Hoc On-Demand Distance Vector (AODV)
3) Time-Slotted On-Demand Routing

4) Hybrid Routing Protocols: Combination of Proactive Routing Protocol and Reactive Routing Protocol is called Hybrid Routing Protocol. The shortcomings and advantages of both are being used in this protocol. It is suitable for wide area networks. Proactive Routing executes intra-zone routing whereas Reactive Routing introduces inter-zone routing. Following are types of Hybrid Routing Protocol:

1) Zone Routing Protocol (ZRP)
2) Temporarily Ordered Routing Algorithm (TORA)

5) Geographic/Position Based Routing Protocols: Geographical information of the network is used in this network for increasing mobility efficiency. UAVs are aware about their geographical location without performing route discovery. They calculate their location using the application of GPS. A forwarding approach is used to push data packets between source and destination. Following are types of Geographic/Position Routing Protocol:

1) Greedy Perimeter Stateless Routing (GPSR)
2) Geographic Position Mobility Oriented Routing

6) Hierarchical Routing Protocols: In this type of routing protocol, proactive routing and reactive routing are performed in hierarchical or architecture level. Using the proactive nature, routing tables and routes are pre-planned and information is sent to the nodes using reactive routing. As there exists a tier level system, the complexity of the network while data traffic increase with time. Following are types of Hierarchical Routing Protocol:

1) Mobility Prediction Clustering Algorithm (MPCA)
2) Clustering Algorithm of UAV Networking

hyperref

I. Topology Construction

Communication between ground station and relay UAVs should be reliable and robust. Multiple algorithms have been performed to achieve best results without lag in efficiency. A paper was proposed where author built a topology algorithm using Particle Swarm Optimization (PSO) algorithm. In this proposed system, the location of ground system and missions are stated but no pre-configured topologies are given. Usually the topology has a direct relationship with routing protocols, but Do-Yup Kim's proposed system does not depend on any routing protocols. This is considered as a NP Hard problem and to solve this, they used Particle Swarm Optimization. Two types of algorithms were discussed including Optimization and Construction scheme of PSO algorithm. This topology algorithm was compared with multiple random based topology construction schemes. It proves to be a better algorithm in end to end communication quality and safety threats. The fitness function (F) of proposed system is stated as follows where

X_{vr} consists of all UAV locations and P_v is the routing path from mUAV to GCS. The other parameters are, number of UAVs (V_m) and (λ , μ) are penalty coefficients with d_0 as their communication rang and d_{safe} is safety distance.

$$F(\boldsymbol{X}_{V_R}, \Re) = \sum_{v \in V_M} \sum_{k=1}^{|\boldsymbol{p}_v|-1} d\big(\boldsymbol{p}_v(k), \boldsymbol{p}_v(k+1)\big)^{\alpha}$$
$$+ \sum_{v \in V_M} \lambda_v \left(\left[\max_{k} \; d\big(\boldsymbol{p}_v(k), \boldsymbol{p}_v(k+1)\big) - d_0 \right]^+ \right)^2$$
$$+ \mu \left(\left[d_{safe} - \min_{u,v \in V} d(u,v) \right]^+ \right)^2.$$

III. Implementation

The Experimental Analysis on Routing Protocols in Flying Ad Hoc Networks is done by using the a discrete-event network simulator called ns-3. Ns-3 provides models of how packet data networks work and perform and provides a simulation engine for users to conduct simulation experiments. Ns-3 use C++ libraries as back-end and an OTcl interpreter as front-end.

We implemented a centralised communication architecture in ns-3.30 to get an idea what routing protocols are working better with FANET. An overview of the used parameters are listed in the table I. Through simulation we were able to compare the among themselves to find the best proactive and best reactive protocol for FANET. The decision of the better protocol is based on 3 measurements. The Packet Delivery Ratio (PDR) is defined as the percentage of packets delivered successfully to the destination node by source node (see equation 1). Higher the PDR, the better the protocol performs.

$$PDR = \frac{|ReceivedPackets|}{|SentPackets|} \tag{1}$$

The second measurement is the End-to-End (E2E) Delay. It is regarded as the time taken by the packets to reach from source to destination (see equation 2). It includes the time taken by protocols for node discovery and delivery the complete data packets.

$$E2EDelay = \frac{PacketArrivaltime - PacketSentTime}{Connections} \tag{2}$$

The third factor is the Throughput. It is defined as the successful packets delivered at the destination node at particular period of time (see equation 3). The better the Throughput, the better is the routing protocol's performance.

$$Throughput = \frac{DeliveredPackets}{|Time|} \tag{3}$$

In the implementation of the Optimized Link State Routing Protocol (OLSR) all nodes have a routing table containing routing information which is used by the entire node to choose a route from source to destination. This protocol has low overhead in the network because of the use of multiple relays (MPR). Also the usage of bandwidth gets increased.

Parameters	**Values**
Simulator	ns- 3.30
Channel Type	Wireless
Protocols	OLSR, DSDV, AODV, DSR
Duration	1200s
Nodes	20
MAC Layer Protocol	802.11
Data Size	512 bytes/packet
Node Speed	10, 20, 30, 40, 50

TABLE I
SIMULATION PARAMETERS

The implementation of Destination-Sequenced Distance Vector Routing (DSDV) gives the loop free paths. A table driven routing scheme for MANET which is based on the Bellman-Ford algorithm to calculate shortest-path developed by C. The difficulty is to maintain the route table for the large network because every entry is updated in the route table.

The implementation of Ad hoc On Demand Distance Vector (AODV) is one of the most widely used routing protocol in MANET. It is an on demand algorithm which is capable of both unicast and multicast routing. An Advantage is the less overhead in the network. To detect the next hop node, it require on broadcast medium so that each node can detect each other's broadcasts.

The implementation of Dynamic Source Routing (DSR) is an efficient routing protocol, witch is used for the wireless networks where multiple hops can takes place. A single route discovery may yield many routes to the destination, due to intermediate nodes replying from local caches. The Packet header size grows with route length due to source routing.

IV. Results

Experimental analysis was performed on proactive and reactive protocols using the above performance metrics i.e. Packet Delivery Ratio, End - End Delay and Average Throughput. Initially, we will compare OLSR and DSDV protocols and later AODV and DSR. Following are the analysis results in form of graphs and tables.

A. Comparison between OLSR and DSDV

Packet delivery of OLSR seems to be consistent and is almost 100% with increase in speed (see table II). OLSR seems to be stable even with increase in speed.

Routing Protocol	**Speed (m/s)**				
	10	**20**	**30**	**40**	**50**
OLSR	1	0.996	1	0.997	1
DSDV	0.994	0.986	0.949	0.931	0.916

TABLE II
PACKET DELIVERY RATIO VS SPEED

DSDV does not perform well with high speed nodes.Initially. OLSR had high delay but with increase in speed, it is relatively less than DSDV. DSDV seems to have high end-end delay. (see figure 3).

Routing Protocol	Speed (m/s)				
	10	20	30	40	50
OLSR	6.233	6.234	6.233	6.333	6.533
DSDV	5.931	6.493	6.972	6.993	7.293

TABLE III
END - END DELAY VS SPEED

Figure 4 depicts that throughput is consistent for OLSR whereas for DSDV it fluctuates with high speed nodes. Evaluating all the results for these two protocols, OLSR is outperforming DSDV.

Routing Protocol	Speed (m/s)				
	10	20	30	40	50
OLSR	64.61	64.61	64.61	64.61	64.61
DSDV	60.93	62.11	62.27	61.93	62.77

TABLE IV
THROUGHPUT VS SPEED

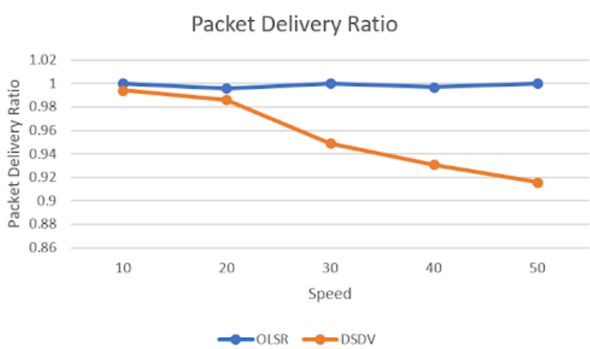

Fig. 2. OLSR vs DSDV

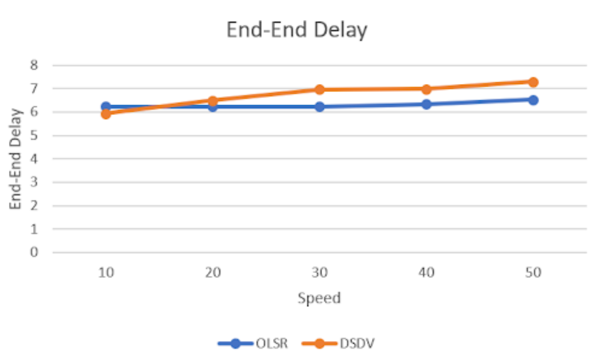

Fig. 3. OLSR vs DSDV

B. Comparison between AODV and DSR

Both protocols start with high packet delivery ratio close to 100% but with increase in speed they reduce . DSR still seems to perform better than AODV (see table V).

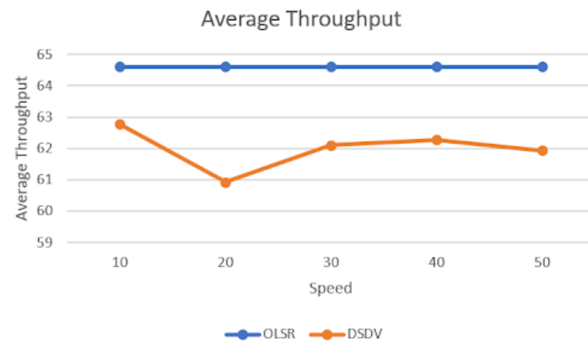

Fig. 4. OLSR vs DSDV

Routing Protocol	Speed (m/s)				
	10	20	30	40	50
AODV	0.996	0.989	0.981	0.951	0.923
DSR	0.997	0.991	0.990	0.960	0.933

TABLE V
PACKET DELIVERY RATIO VS SPEED

End-end delay for these two protocols does not give much insights as they are neck to neck and don't show much variation.

Routing Protocol	Speed (m/s)				
	10	20	30	40	50
AODV	6.230	6.850	7.150	7.689	8.234
DSR	6.540	7.210	7.504	8.124	8.099

TABLE VI
END - END DELAY VS SPEED

AODV seems to be having high throughput for low speed nodes but depletes quickly after 30m/sec. Whereas DSR seems to be more consistent throughout. (see figure 7) Evaluating all the results for these two protocols, DSR is outperforming AODV.

Routing Protocol	Speed (m/s)				
	10	20	30	40	50
AODV	64.56	66.98	59.98	58.78	57.87
DSR	62.68	62.79	61.47	61.45	58.14

TABLE VII
THROUGHPUT VS SPEED

V. CONCLUSION

UAVs are playing an important role in conducting wide area missions. In this paper, we have discussed multiple communication architectures and their routing protocols. As this type of network violates some privacy restrictions, some of the social and technological implication have also been discussed. UAVs suffer with topology and communication problems. To tackle this issue, Particle Swarm Optimization construction algorithm is being used. After simulating the protocols on NS3 and analysing the results, we have deduced that Optimized Link State Routing (OLSR) outperforms Destination-Sequenced Distance Vector (DSDV) in all metrics whereas

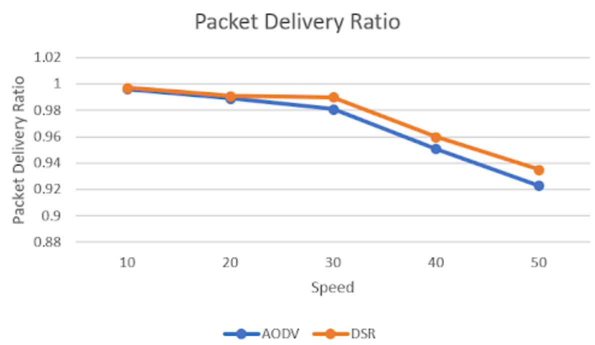

Fig. 5. AODV vs DSR

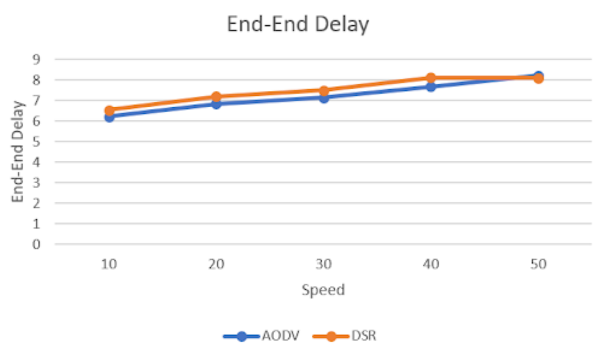

Fig. 6. AODV vs DSR

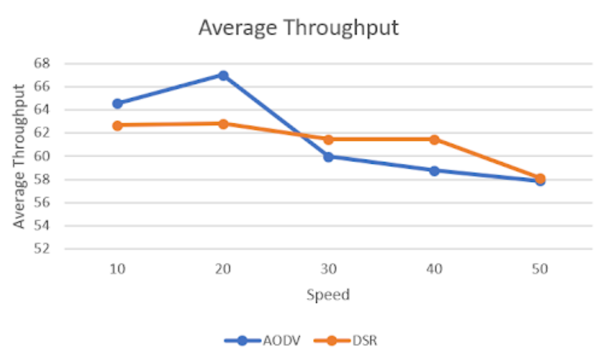

Fig. 7. AODV vs DSR

Dynamic Source Routing (DSR) achieves better performance than Ad hoc On Demand Distance Vector (AODV). Due to their high mobility nature, UAVs have a complex communication network. It is difficult to design routing protocols to meet the need. Optimal routing states are still being developed.

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