Low Latency Routing Algorithm for Unmanned Aerial Vehicles Ad-Hoc Networks

Abdel Ilah Alshabtat, Liang Dong

***Abstract*—**In this paper, we proposed a new routing protocol for Unmanned Aerial Vehicles (UAVs) that equipped with directional antenna. We named this protocol Directional Optimized Link State Routing Protocol (DOLSR). This protocol is based on the well known protocol that is called Optimized Link State Routing Protocol (OLSR). We focused in our protocol on the multipoint relay (MPR) concept which is the most important feature of this protocol. We developed a heuristic that allows DOLSR protocol to minimize the number of the multipoint relays. With this new protocol the number of overhead packets will be reduced and the End-to-End delay of the network will also be minimized. We showed through simulation that our protocol outperformed Optimized Link State Routing Protocol, Dynamic Source Routing (DSR) protocol and Ad-Hoc On demand Distance Vector (AODV) routing protocol in reducing the End-to-End delay and enhancing the overall throughput. Our evaluation of the previous protocols was based on the OPNET network simulation tool.

***Keywords*—**Mobile Ad-Hoc Networks, Ad-Hoc Routing Protocols, Optimized link State Routing Protocol, Unmanned Aerial Vehicles, Directional Antenna.

I. INTRODUCTION

ONE of the major problems in Ad-Hoc networks is the routing protocols. Since nodes in Mobile Ad-Hoc Networks (MANET) are all mobile, a routing protocol should be able to find an alternate route quickly and efficiently. Many routing protocols have been developed in this area to solve different issues that affect the performance of the network. Routing protocols in Ad-Hoc networks are classified into two classes: proactive protocols and reactive protocols.

Proactive routing protocols follow the conventional method of finding and maintaining the route between the source and the destination; they maintain up to date routing information for all nodes in the network even before it is needed [1]. This information is exchanged periodically between nodes and updated as the network topology changes. Because of this situation, proactive protocols may benefit those applications that require low latency. Examples of this type include Optimized Link State Routing protocol (OLSR) [2] and Destination Sequenced Distance Vector (DSDV) routing protocol [3].

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Reactive Routing Protocols do not maintain routing information at the nodes if there is no activity between them. When a node wants to send a packet to some destination, it first checks its routing table to find if it has a route to the destination or not. If no route exists, the node will perform route discovery procedure to find a path to the destination. Nodes in reactive protocols are trying to minimize the overhead by only sending routing information as soon as the communication is initiated between them [4]. Examples of this type include Ad- Hoc on Demand Distance Vector (AODV) Routing protocol [5] and Dynamic Source Routing (DSR) protocol [6].UAV Ad-Hoc Communication Network is a new type of wireless network in which a collection of autonomous UAVs dynamically form a temporary multihop radio network with- out the aid of any centralized station. This new concept of networking enables UAVs to be equipped with a wireless transmitter and receiver for the purpose of data transmission [7].Nowadays, there has been an interest in employing UAV in wireless communication networks, mainly in MANET. UAVs were first used by the military in different applications [8]. They have been used mainly in surveillance and reconnaissance missions. With the advent of commercial off the shelf (COTS) technologies, a network of a swarm UAV can form a cost-effective multi-hop wireless communication network in the air [9]. A wireless link created by this network may vary over time due to a number of factors. In particular; blocking of line-of-sight by the aircraft body, as a result, the End- to-End delay will increase. In order to reduce End-to-End delay, there is a need to design a routing protocol for such network that implement directional antenna. Current MAC protocol that implements the Omni-directional antenna may not be suitable while using directional antenna. Thus we assume that such a network implements a directional medium access control protocol [10], [11], [12], [13], [14] that is capable of adapting any constraints imposed by the UAV.

The remainder of this paper is organized as follows. In the next section we start with a survey of current research regarding the Ad-Hoc routing protocols, mainly Optimized Link State Routing Protocol. In section III, we describe the Optimized Link State Routing Protocol. In Section IV, we present our Directional Optimized Link State Routing (DOLSR) protocol and in Section V, we present our OPNET simulation results and we provide a comparison between the OLSR, DOLSR, AODV and DSR. Finally, we summarize the main results in section VI.

II. RELATED WORK

Due to the limited transmission range of the Ad-Hoc members, other nodes may be needed to exchange data with others across the network. Recently, a lot of protocols targeting specifically the issue of how to route the data across the network have been developed. In [15], [16], [17], the authors presented a survey and comparison of current routing protocols for mobile Ad-Hoc networks. All classified the protocols into three types: flat routing, hierarchical routing, and geographic position assisted routing. Flat routing protocols uses a flat addressing scheme, hierarchical routing protocols require a scalable addressing system and geographic position assisted routing assumes that each node is equipped with the global positioning system. They conclude that the flat routing protocols, mainly the OLSR, are producing less control overhead than the others and they are more efficient than classical algorithms when networks are dense.

Other researchers classified the routing protocol according to the routing strategy. In [18], [19], [20], the authors classified the routing protocols into proactive (table-driven) and reactive (on demand) protocols. Proactive routing protocols update the route periodically while reactive routing protocols maintain the routes that are currently in use. In terms of high mobility, they claimed that proactive protocols have the capability of producing higher routing efficiency than reactive protocols. As an example, OLSR, which forces the updates of the link state only at MPR nodes, reduces both the size of the routing packets and the number of nodes that is needed for forwarding such packets.The majority of the research is focusing on building routing protocol using Omni-directional antenna. A limited number of routing protocols have been proposed to take the advantage of directional antennas [21], [22], [23], [24]. In [21], directional antenna is used to improve the efficiency of the on-demand routing protocols. The main idea is to utilize the directional antenna in order to reduce the routing overhead by reducing the number of routing packets transmitted during route discovery. In contrast, the author in [22] focused on reducing the overhead of route maintenance by modifying the dynamic source routing protocol and on-demand routing protocol. In [23], the author addressed the issue of routing in mobile Ad-Hoc networks using directional antenna. He used the directional antenna to improve the performance of the network in two situations. The first one is the use of directional antenna during the process of route repair as a result of node movement. The second issue is the use of directional antenna in the case of dynamic network partitioning as a result of node mobility. The same issue was addressed in [24]; they optimized the reactive protocol, DSR, to be used in Ad-Hoc using directional antenna. If the source does not receive a reply from the destination, the source will send hello message in order to update the location information of the destination node. By this process, the directional antenna has been shown to find the route with fewer hops.

The authors in [25] evaluated the impact of directional antennas on the performance of routing protocols. They proposed a routing strategy that adapts the routing protocol to the use of directional antenna. Simply, they presented a sweeping mechanism that avoids forwarding request in the direction where the channel is busy. As a result of the deafness problem that is created while using directional antenna, the authors concluded that the advantage of using directional antennas will not be satisfactory, thus in some scenarios it would be better to use Omni-directional antennas rather than the directional antenna.

Due to mobility of nodes in MANET, network topology may change rapidly and unpredictably, thus it is difficult to provide quality-of-service (QoS) routing in an Ad-Hoc network. A number of studies have been proposed to provide quality- of-service in MANETs. The author in [26] discussed how to support QoS routing in OLSR by developing heuristics that allow this protocol to find the maximum bandwidth path. He proposed three algorithms for MPR selection: In the first algorithm, the node will select the one-hop neighbor that reaches the maximum number of uncovered two-hop neighbors as MPR. In the second algorithm, the node will select the best bandwidth neighbors as MPRs until all the two-hop neighbors are covered. Finally, in the third algorithm, the node will select the MPRs in such a way that all the two-hop neighbors have the optimal bandwidth path through the MPRs to the current node. He showed that the above three heuristic algorithms are increasing the opportunity to find a path that is optimal under a bandwidth constraint. Moreover, he proved that algorithms two and three are indeed optimal for the Ad-Hoc network.

In [27], the author analyzed the performance of the OLSR routing protocols. In particular, they focused on the size of the MPRs in the network. They showed that the size of the MPR set has a significant effect on the diffusion of the information over the network. The authors in [28] were also interested in the performances of the Multipoint Relay selection. They analyzed the mean number of the selected MPR per node and their spatial distribution by providing two bounds (lower and upper) as a function of the network density. They also gave analytical results on the performance of MPRs and their implications on the efficiency of broadcasting and on the reliability of OLSR.

In [29], the authors compared two Ad-Hoc routing protocols: Ad-Hoc On Demand Distance Vector (AODV) and Optimized Link State Routing (OLSR) protocols. They have shown that AODV and OLSR are the most attractive protocols for multimedia transmission. Based on this paper, AODV performs well in the networks with static traffic and thus it can be used in environments with critical resources. On the other hand, OLSR is more efficient in high density networks and it can be used to reduce the overhead load.

III. OPTIMIZED LINK STATE ROUTING PROTOCOL (OLSR)

Optimized link state routing protocol is a popular type of proactive routing protocols (Table-driven) that is designed for

MANET. It is considered as an enhancement of the pure link state protocols in that it reduces the size and the number of the control packets. In contrast to other protocols, OLSR protocol reduces the message overhead when it is compared with the classical flooding mechanism in which every node retransmits each message as soon as it receives the first copy of the message. The key point in OLSR is the use of the multipoint relay (MPR). MPR is a node chosen by another node that is willing to transmit its data, this node is used to forward packets and flood the control message and thus reduce the number of the retransmission in the network. In addition, this node is a one hop node and it is chosen so that it covers other two hop nodes, Fig. 1 shows the MPR selected by the source node.

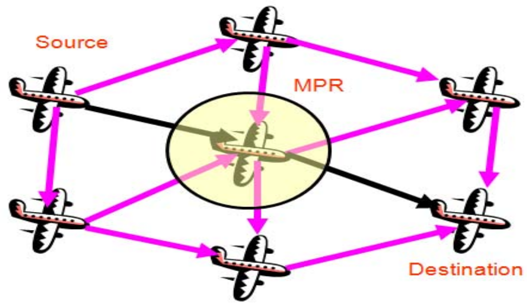

Fig. 1 Multipoint Relay (MPR)

IV. Directional Optimized Link State Routing Protocol (DOLSR)

The most important step in OLSR protocol is the selection of the MPR. In this paper we place an emphasis on how to reduce the overhead in the UAV Ad-Hoc network. Generally speaking, as the number of MPRs shrinks, the number of the overhead packets is reduced. To this respect, we proposed a new mechanism that leads to the reduction in MPR numbers. Fig. 2 shows our block diagram for the proposed DOLSR. For each packet, the UAV tests the distance to the destination; if the distance is larger than the Dmax/2 (the maximum distance that can be achieved through the use of the directional antenna), the node will apply the DOLSR mechanism. On the other hand, if the distance is smaller than the Dmax/2, the UAV will apply the OLSR in cases that the omni-directional antenna is used, otherwise, the UAV will go back to the DOLSR.

A. *Neighbor Discovery*

To discover the neighbors in the UAV Ad-Hoc network using DOLSR, Hello messages will be broadcasted

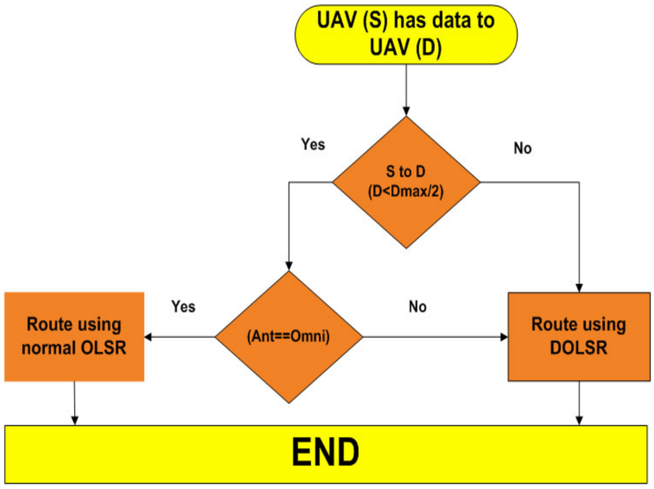

Fig. 2 DOLSR routing protocol block diagram

periodically to all nodes as in OLSR. These messages are only broadcasted one hop away and are not relayed to any further nodes. Through this procedure, each node is capable of recognizing all its neighbor nodes including those one-hop and two-hops away. We assumed that the two-hop nodes are located within the range of the directional antenna. Any node located far away will not be counted as a two-hop node. Fig. 3 shows our procedure for exchanging hello messages between the UAVs.

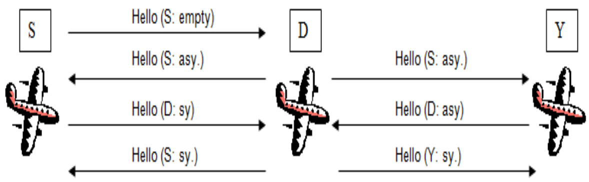

Fig. 3 Selection of Multipoint Relays (MPR)

B. *Selection of Multipoint Relays in DOLSR*

As an example, we will consider the UAV Ad-Hoc topology that is shown in Fig. 4. We present a simple seven node scenario to illustrate our mechanism. In OLSR MPR selection mechanism, a UAV marked as A will select C and D as its MPRs. These UAVs cover all the unreachable two-hop neighbors. Node F knows that it can reach A via C and node G also knows that it can reach A via D. On the other side, node E can reach A either through node C or node D. In DOLSR MPR selection mechanism, the idea is to benefit from the use of directional antenna. Node A will build its routing table based on the OLSR selection as follows: A-C-F, A-C- E, A-C-B, A-D-G, A-D-E, A-D-B. Based on these results, node A has two routes to nodes E and B. Our scheme will calculate the distance between node A and nodes E and B; the longest distance will be considered as MPR. Table I shows the selection of MPRs for both mechanisms, where node E is selected as A's MPR in DOLSR mechanism while nodes C and D are selected in OLSR.

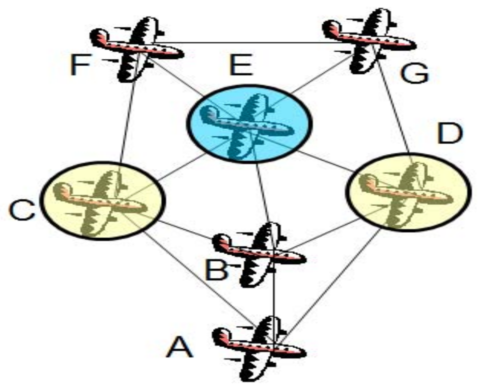

Fig. 4 Ad-Hoc topology, illustration of multipoint relays in DOLSR and OLSR

TABLE I
MPR SELECTION IN DOLSR AND OLSR MECHANISMS

Node	Two Hop Neighbors	OLSR MPR(s)	DOLSR MPR(s)
A	E , F , G	C, D	E
F	A , B , D	C, G	B

C. Route Maintenance

Due to the mobility of the UAVs, route links in Ad-Hoc networks will be broken frequently. Each UAV implements a DOLSR is sending out Hello message to maintain local connectivity with other UAVs. Failure to receive Hello message from other UAVs is considered as an indication that the link to the UAV is broken. A link failure notification message is then forwarded back until it reaches the source node. Once the error message reaches the source node, the source should respond by switching back to the normal OLSR selection technique.

V. OPNET Simulation Results and Discussions

A. Simulation Environment

To demonstrate the performance of the DOLSR protocol presented above, we compared our scheme to the original OLSR protocol, AODV and DSR protocols. For our simulation, which is different from others [30], we have used an OPNET 14.5, a discrete event network simulator that includes a rich set of detailed models for Ad-Hoc network. 25 UAVs are placed in a 2000 X 2000 m area and form a mobile Ad- Hoc network, data rate is 11Mbps. The power transmit level of 1mw was used for all scenarios. The simulation period is 10 minutes and the UAVs are moving in the simulation area according to a random waypoint model [31] with a zero pause time and a constant speed of 40 m/sec. The packet size is set to 1024 bits and the distribution is exponential. All UAVs in the network are configured to run OLSR protocol during the first scenario and DOLSR protocol during the second one. Fig. 5 shows the OLSR process model in OPNET. The same model was modified and used for the DOLSR protocol. Other scenarios were conducted to evaluate the performance of our scheme and compare it with various mobile Ad-Hoc network routing protocols. We compared our scheme to the AODV and DSR protocols.

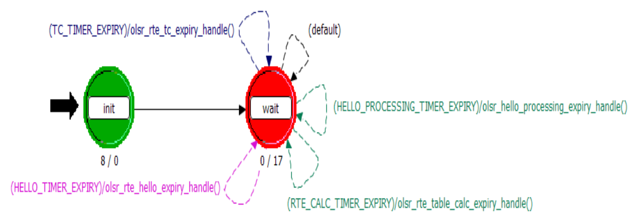

Fig. 5 Process Model for OLSR Protocol

B. Performance Comparison between OLSR and DOLSR

We have conducted several scenarios and analyzed the results of simulation obtained by the use of OLSR and DOLSR routing protocols for the average number of MPRs selected by the network, total number of TC messages forwarded by the MPRs, and finally we make a comparison between the two protocols in terms of End-to-End delay.

Fig. 6 compares the two protocols in terms of the number of MPRs selected by the network. As shown in the figure, our scheme gave better results than the original OLSR. 14 MPRs are selected during the use of the OLSR while 10 MPRs are selected during the use of DOLSR. After 200 seconds, when the nodes have selected their MPR set, the number of MPRs becomes stable and converges to 14 and 10 nodes.

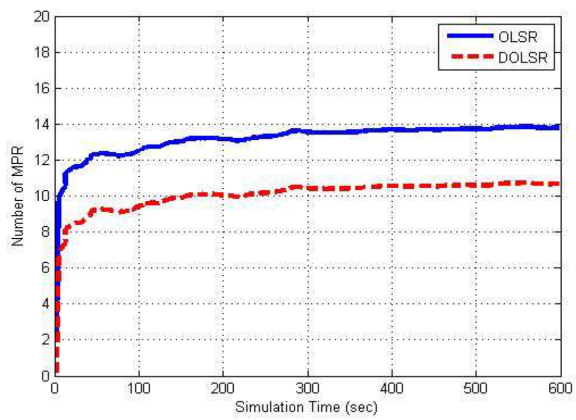

Fig. 6 Comparison between OLSR and DOLSR Protocols for the Average Number of MPRs Selected by the Network

Fig. 7 shows the number of TC messages forwarded during the simulation time. Since all nodes are mobile, TC messages are used to propagate the changes in the network topology. The number of the TC messages in the original OLSR is higher than 200 during the first 100 seconds, while in DOLSR the number is less than 160. This is due to the reduction of the MPR set.

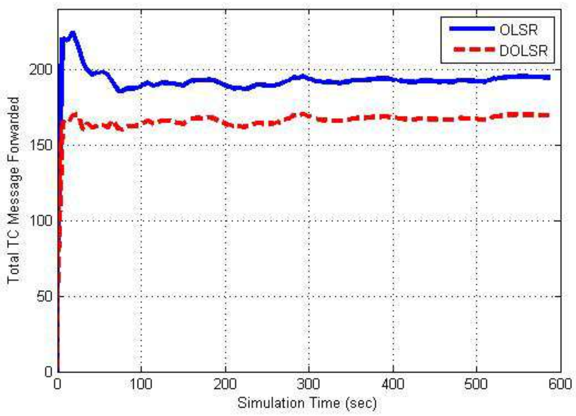

Fig.7.Comparison between OLSR and DOLSR Protocols for the Total Number of TC Messages Forwarded by the MPRs

Fig. 8 shows the performance comparison results for End-to- End delay between the DOLSR protocol using directional antenna and the OLSR protocol using omni-directional antenna. Generally speaking, there are three factors affecting the End- to-End delay of a packet: time to discover the route, buffering waiting time and the number of hops for each path. Since the number of the MPR set is reduced while using DOLSR, clearly the time should also decrease.

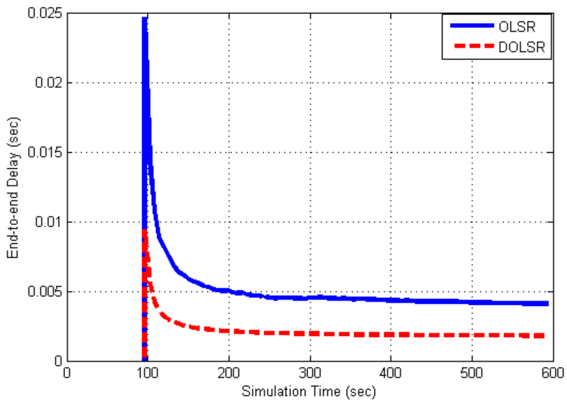

Fig. 8 Comparison between OLSR and DOLSR Protocols for the End-To- End Delay

The figure shows that DOLSR has less End-to-End delay than OLSR. The End-to-End delay for both protocols is high at the beginning of the simulation time. This reflects the fact that the size of the control traffic is high before the selection of the MPR set. After each node selected its MPR set, the number of nodes used for flooding the control messages will be decreased and restricted only for the MPR set and thus the time will also be reduced.

C. Performance Comparison between OLSR, DOLSR, AODV and DSR

The implementation of OLSR, DOLSR, AODV and DSR in this simulation is mainly to evaluate End-to-End delay and traffic received (packets/ sec). We chose these two parameters for our simulation in order to study the efficiency of our scheme in reducing the time taken to send the packets from source to destination.

In general, UAV Ad-Hoc networks have characteristics in which the network topology changes very rapidly and unpredictably. If nodes are within the communication range of each other, messages will be exchanged between the senders and the receivers, otherwise messages should be sent through intermediate node. The major challenge in mobile Ad-Hoc networks is how to route the packets with frequent node movement. To see the effects of the routing protocols on the performance of the UAV Ad-hoc networks, we selected two reactive protocols, AODV and DSR, and one proactive protocol OLSR.

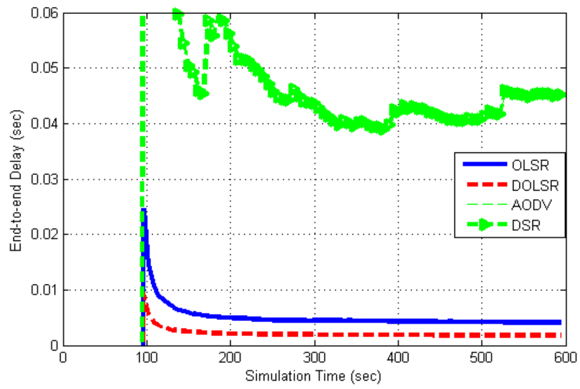

Fig. 9 Comparison between OLSR, DOLSR, AODV and DSR protocols for End-To-End Delay.

Fig. 9 shows the total delay in the network. The total delay is represented by the End-to-End delay. The End-to- End delay represents the time interval that is calculated from the instant a packet is generated by the source node, to the instant that the packet is received by the destination node. This figure compares the End-to-End delay between the DOLSR protocol using directional antenna and the OLSR, AODV, and DSR protocols using Omni-directional antenna. The total delay using Omni-directional antenna is higher than that of using directional antenna. This behavior may be explained as follows: The range of the UAVs is extended as a result of using directional antenna, and thus the number of MPRs is reduced due to the use of the DOLSR. The figure also shows that DOLSR and OLSR provide smaller End-to-End delay than AODV and DSR which is less than 0.005 seconds. Moreover, the End-to-End delay for the AODV and DSR start at an average of 0.25 second and then fall to 0.05 seconds. The difference in time can be related to the fact that AODV and DSR are reactive protocols and construct their route on demand while the OLSR and DOLSR are proactive protocols in which the table is available and has the destination addresses. For all protocols, the graph starts after one hundred seconds because we programmed the OPNET to deliver a packet after other modules register themselves. Fig. 10 compares the traffic received using the OLSR, DOLSR, AODV and DSR protocols. It can be seen that DOLSR received more than 20 pkt /s over 10 minutes simulation time, while AODV and DSR received less than 17 packets /s over the same time. The reason is that AODV and DSR protocols tend to flood the network with heavy control traffic which increases the End-to-End delay, while DOLSR minimizes the control messages by multipoint relays which reduces the End-to-End delay.

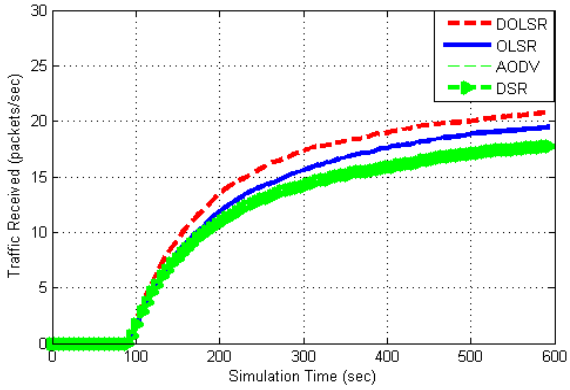

Fig. 10 Comparison between OLSR, DOLSR, AODV and DSR Protocols for Traffic Received (packets/ sec)

VI. CONCLUSION

In this paper, a novel Directional Optimized Link State Routing (DOLSR) protocol is proposed for UAV mobile Ad-Hoc networks. Our protocol is capable of reducing the number of the multipoint relays in the network. As a result, the End-to- End delay is reduced and the overall throughput is increased. Performance evaluation and comparison between OLSR and AODV are studied using OPNET Modeler 14.5. The simulation results show that OLSR achieves better performance than AODV in terms of End-to-End delay. Another comparison was conducted between OLSR and DOLSR using the same simulator. The simulation results show that DOLSR achieves better performance than OLSR and AODV in terms of End-to- End delay. It can be concluded that as the number of MPRs shrinks, the number of the overhead packets is reduced and thus the overall performance is enhanced.

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