

A Performance Comparison of Routing Protocols for Ad Hoc Networks

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ABSTRACT

Mobile Ad hoc Network (MANET) is a collection of mobile nodes in which the wireless links are frequently broken down due to mobility and dynamic infrastructure. Routing is a significant issue and challenge in ad hoc networks. Many routing protocols have been proposed like OLSR, AODV so far to improve the routing performance and reliability. In this paper, we describe the Optimized Link State Routing Protocol (OLSR) and the Ad hoc On-Demand Distance Vector (AODV). We evaluate their performance through exhaustive simulations using the Network Simulator 2 (ns2) by varying conditions (node mobility, network density).

Keywords - MANET; OLSR; AODV; ns2.

I. INTRODUCTION

A mobile ad hoc network (MANET) is a collection of nodes, which are able to connect on a wireless medium forming an arbitrary and dynamic network. Implicit in this definition of a network is the fact that links, due to node mobility and other factors, may appear and disappear at any time. This in a MANET implies that the topology may be dynamic and that routing of traffic through a multi-hop path is necessary if all nodes are to be able to communicate.

A key issue in MANETs is the necessity that the routing protocols must be able to respond rapidly to topological changes in the network. At the same time, due the limited bandwidth available through mobile radio interfaces, it is imperative that the amount of control traffic, generated by the routing protocols is kept at a minimum.

Over recent years many routing protocols for MANETs have been proposed and enhanced to efficiently route data packets between the nodes in a network. However, the performance of a routing protocol depends on many factors. A protocol may be the best for one network topology and mobility pattern, but the worst for another topology.

Classification of routing protocols in MANETs can be done on routing strategy wise or network structure wise. According to routing strategy the routing protocols can be categorized as proactive routing (AODV)[1] or reactive routing (OLSR) [2]. Each of these types of protocols behaves differently on different wireless conditions. Hence the performance analysis of these protocols is a must task to know its behavior and work in that environment. Several factors will affect the overall performance of any protocol operating in an ad hoc network. For example, node mobility may cause link failures,

which negatively impact on routing and quality of service (QoS) support. Network size, control overhead, and traffic intensity will have a considerable impact on network scalability along with inherent characteristics of ad hoc networks may result in unpredictable variations in the overall network performance.

The rest of this paper is organized as follows. The next section provides an overview of the related work in the area of evaluation of routing protocols for wireless ad hoc networks. We discuss routing protocols in Section 3. In Section 4, we introduce the metrics under which we perform our evaluation. In Section 5, we evaluate AODV and OLSR routing protocols based on quantitative metrics, and Results from extensive ns-2 simulations are presented Finally Sec. 6 will conclude this paper.

II. Related Work

Over recent years, significant work has been conducted to evaluate the performance of routing protocols in ad hoc wireless networks. Josh Broch et al. [3] presented one of the first and popular performance evaluation studies of multiple routing protocols (DSDV, TORA, DSR, and AODV) through simulations conducted with the network simulation software ns-2 [4]. They used a simple mobility scenario (random waypoint model) and a small number of network-centric metrics, such as the packet delivery ratio and the routing overhead in order to evaluate the performance of the tested protocols. In Boukerche [5] the performance evaluation of three routing protocols (AODV, CBRP, and DSR) is presented. The throughput and the average end-to-end delay are used as the evaluation metrics in simulations with a maximum number of 40

nodes. Their main finding is that source routing is much more efficient than the distance-vector-based protocols, like AODV. Boukerche [6] suggests that position aware routing protocols, in which nodes are equipped with a GPS device, present better performance and minimize routing overhead. Another performance evaluation study for military communications is presented in Choi and Ko [7]. The authors evaluate a number of routing protocols (i.e. AODV, DSR, LAR, and OLSR) under scenarios that reflect the transmission patterns of military radios and conclude that DSR and LAR achieve better performance than the other tested protocols. In Plesse et al. [8] the OLSR performance is studied in military mobile ad hoc networks. Simulation results show that the OLSR presents good performance, although some internal parameters of the protocol should be tuned for optimal performance. Ahmed and Alam [9] compare three routing protocols (DSR, AODV, and TORA) through simulations conducted with a discrete-event simulator (OPNET Modeler 10.5 version). Simulation results indicate that under specific simulation parameters TORA presents a higher performance than AODV and DSR. In Divecha et al. [10] the effects of various mobility models on the performance of DSR and AODV are studied. For experimental purposes, four mobility scenarios are presented: Random Waypoint, Group Mobility, Freeway and Manhattan models. Performance comparison has also been conducted across varying node densities and number of hops. The experimental results illustrate that the performance of routing protocols varies across different mobility models, node densities and length of data paths. In Kumar et al. [11], a comparison of the performance of two prominent on-demand reactive routing protocols for MANET (DSR and AODV) is presented, along with the traditional proactive DSDV protocol. In Rahman and Zukarnain [12] the performance comparison between three routing protocols, namely AODV, DSDV and an improvement of DSDV, is presented. The authors use three network metrics, namely packet delivery ration, end-to-end delay, and routing overhead. Another performance evaluation study is presented in Qasim et al. [13]. The evaluation process is based on multiple network metrics in an effort to better assess the performance of the tested routing protocols. This work does not present any new optimization of the tested protocols; however, it stands as a good example in terms of the used metrics.

III. Routing Protocol in MANETs

Proactive routing is also known as table driven routing. This class of routing protocol keeps track of routes from a source to all the destinations whether or not the routes are required. To maintain the routes, periodic routing updates are exchanged between the

nodes in the network. The main advantage of such an algorithm is that there is no delay in establishing a communication session and routing table is updated as soon as there is a change in topology. Disadvantages are additional control traffic to keep the routing table up to date irrespective of whether all the routes are used in a session or not. Example of proactive algorithm is Optimized Link State Routing (OLSR).

Reactive routing is also called on-demand routing as the routes are established only when needed to forward the data packets. This algorithm has significantly low routing overhead when the traffic is light and network is less dynamic, since there is no need maintain the routes when there is no data traffic. The major disadvantages are longer delay in establishing the routes for forwarding the data and excessive flooding of the control messages that may lead to network clogging. Example of reactive routing are Ad hoc On-demand Distance Vector (AODV) and DSR (Distance Source Routing).

Since AODV and OLSR are the most researched protocol in research community, this paper will concentrate on these two protocols only. In order to better understand the mechanism and implementation of these protocols, below is the detailed description of each.

1. Ad hoc On-demand Distance Vector

The message types defined by AODV are Route Request (RREQ), Route Reply (RREP) and Route Error (RRER). AODV does not play any role as long as the endpoints in the communication link have valid routes to each other. When a route to a new destination is required, a node broadcasts the RREQ message to find a route. A route is found when the RREQ reaches the destination itself, or an intermediate node that has a 'fresh enough' route to the destination. The route is made available by unicasting the RREP message back to the source of the destination. Since, each node that receives the RREQ caches the route back to the source, the RREP can be unicasted to the origination of the RREQ. The link status of active routes is continuously monitored for any link breakage. When a link breaks, RRER message is propagated down the route to notify the affected nodes about the loss of link. The purpose of RRER message is to indicate which destinations are now unreachable because of the link breakage. Each node keeps a 'precursor list' that contains the IP address for each of its neighbors that are likely to use it as a next hop towards each destination.

The basic operation of AODV can be divided into two phases:

1.1. Route Discovery

When a node wants to communicate with another node it first checks its own routing table if an

entry for this destination node exists. If this is not the case, the source node has to initialize a route discovery. This is done by creating a RREQ message, including the hop count to destination, the IP address of the source and the destination, the sequence numbers of both of them, as well as the broadcast ID of the RREQ. This ID and the IP address of the source node together form a unique identifier of the RREQ. When the RREQ is created the source node broadcasts it and sets a timer to wait for reply.

All nodes which receive the RREQ first check by comparing the identifier of the message with identifiers of messages already received. If it is not the first time the node sees the message, it discards silently the message. If this is not the case the node processes the RREQ by updating its routing table with the reverse route. If a node is the destination node or has already an active route to the destination in its routing table with sequence number of the destination host which is higher than the one in the RREQ, it creates a RREP message and unicasts it to the source node. This can be done by analyzing the reverse route for the next hop. Otherwise it increments the RREQ's hop count and then broadcasts the message to its neighbors.

When the source node receives no RREP as a response on its RREQ a new request is initialized with a higher TTL and wait value and a new ID. It retries to send a RREQ for a fixed number of times after which, when not receiving a response, it declares that the destination host is unreachable.

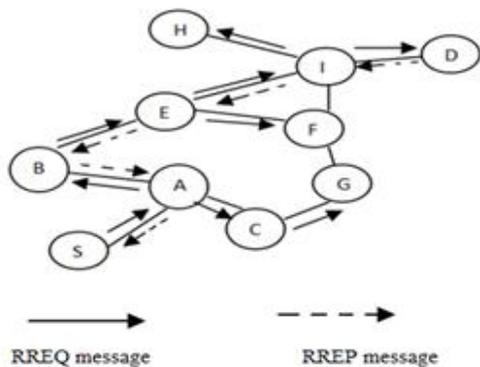


Fig 1. AODV Route Discovery Process

Figure 1 shows the route discovery process from source node S to destination node D. At that time, a reply packet is produced and transmitted tracing back the route traversed by the query packet as shown in Fig 1.

1.2. Route Maintenance

When a route has been established, it is being maintained by the source node as long as the route is needed. Movements of nodes effect only the routes passing through this specific node and thus do not

have global effects. If the source node moves while having an active session, and loses connectivity with the next hop of the route, it can rebroadcast an RREQ. If though an intermediate station loses connectivity with its next hop it initiates an Route Error (RERR) message and broadcasts it to its precursor nodes and marks the entry of the destination in the route table as invalid, by setting the distance to infinity. The entry will only be discarded after a certain amount of time, since routing information may still be used when the RERR message is received by a neighbor it also marks its route table entry for the destination as invalid and sends again RERR messages to its precursors.

When the link in the communication path between node 1 and node D breaks the upstream node that is affected by the break, in this case node 4 generates and broadcasts a RERR message. The RERR message eventually ends up in source node S. After receiving the RERR message, node E will generate a new RREQ message (Fig 2).

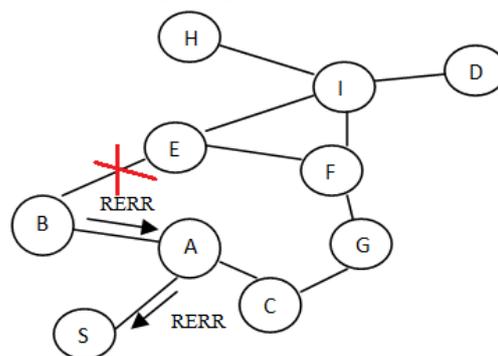


Fig.2. AODV Route Error message generation

2. Optimized Link State Routing Protocol

The Optimized Link State Routing Protocol (OLSR)[1], is a proactive link routing protocol, designed specifically for mobile ad hoc networks. OLSR employs an optimized flooding mechanism to diffuse link state information to all nodes in the network. In this section, we will describe the element of OLSR, required for the purpose of investigation security issues.

2.1. OLSR Control Traffic.

Control traffic in OLSR is exchanged through two different types of messages.

2.1.1 HELLO messages

To detect its neighbors with which it has a direct link, each node, periodically and at regular intervals (HELLO Interval seconds) broadcasts hello messages, containing the list of neighbors known to the node and their link status (symmetric, asymmetric, Multi-Point Relay or Lost). These messages are broadcast by all nodes and heard only by immediate neighbors; they are never relayed any

further, i.e. these packets have a Time-To-Live (TTL) value of 1.

In addition to information about neighbor nodes, the periodic exchange of HELLO messages allows each node to maintain information describing the link between neighbor nodes and nodes which are two hops away. Based on this information, each node independently selects its own set of Multi-Point Relay (MPR) among its one-hop neighbors so that the MPR covers all two-hop neighbors.

2.1.2. Topology Control (TC) messages

TC (Topology Control) messages are also broadcast by MPR-nodes in the network at regular intervals (TC_Interval second). Thus, a TC message contains the list of neighbors that have selected the sender node as a MPR (MPR Selector Set), and an Advertized Neighbor Sequence Number (ANSN) is used by a receiving node to verify if the information advertized in the TC messages is more recent. The TC messages are flooded to all nodes in the network and take advantage of Multi-Point Relay to reduce the number of retransmissions.

Using information of a TC message, a node generates topology tuples (T_des_adr, T_last_adr, T_seq, T_time), the set of these tuples is denoted the "Topology Set". Here T_des_adr is the destination address, T_last_adr is the address of the node that generated the TC message, T_seq is a sequence number of the TC message and the T_time is the time duration after which the topology tuple expires [2].

Based on the information in the topology set, the node calculates its routing table; each entry in the table consists of R_des_adr, R_next_adr, R_dist, and R_iface_adr. Such entry specifies that the node identified by R_dest_adr is estimated to be R_dist hops away from the local node, that the symmetric neighbor node with interface address R_next_adr is the next hop node in the route to R_des_adr, and that this symmetric neighbor node is reached through the local interface with the address R_iface_adr. All entries are recorded in the routing table for each destination in the network for which a route is known [14].

2.2 Multi-Point Relays Selection.

Multi-Point Relays Selection is done in such a way that all the two-hop neighbors are reachable from the MPR in terms of radio range. The two-hop neighbor set found by the exchange of HELLO messages is used to calculate the MPR set and the nodes signal their MPRs selections through the same mechanism.

The aim of Multi-Point Relays is to minimize the flooding of the network with broadcast packets by reducing duplicate retransmission in the same region Fig 3. Each node of the network selects the smallest set (MPRs) of neighbor nodes that can reach all of its

symmetric two hop neighbors which may forward its messages. Each node in the network maintains an MPR selector set, which has selected this node as an MPR.

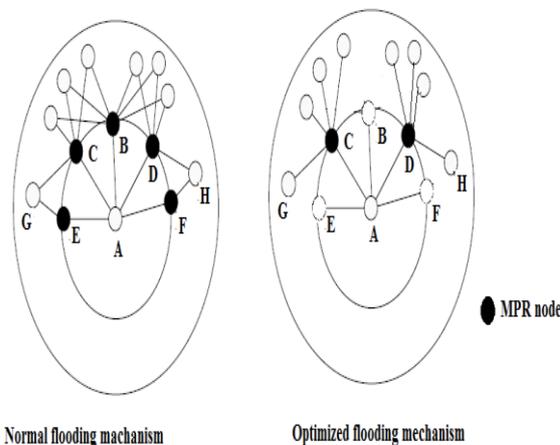


Fig. 3. Reduction of duplicate retransmission by MPR selection

IV. EVALUATION METRIC

In our performance evaluation, we use four quantitative metrics similar to those in Das et al. [15]. The packet delivery ratio and average end-to-end delay are more important for best-effort traffic. The normalized routing load will be used to evaluate the efficiency of the routing protocol. The normalized MAC load is a measure of the effective utilization of the wireless medium for data traffic. All these metrics are defined in the following paragraphs.

1. Packet delivery ratio (PDR)

The packet delivery ratio is defined as the fraction of all the received data packets at the destinations over the number of --data packets sent by the sources. This is an important metric in networks. If the application uses TCP as the layer 4 protocol, high packet loss at the intermediate nodes will result in retransmissions by the sources, which may result in network congestion.

2. Average end-to-end delay

End-to-end delay includes all possible delays in the network caused by route discovery latency, retransmission by the intermediate nodes, processing delay, queuing delay, and propagation delay. To average the end-to-end delay we add every delay for each successful data packet delivery and divide that sum by the number of successfully received data packets. This metric is important in delay sensitive applications such as video and voice transmission.

3. Normalized routing load

The normalized routing load is defined as the fraction of all routing control packets sent by all nodes over the number of received data packets at the

destination nodes. This metric discloses. How efficient the routing protocol is. Proactive protocols are expected to have a higher normalized routing load than reactive ones. The larger this fraction is, the less efficient the protocol is.

4. Normalized MAC load

The normalized MAC load is defined as the fraction of all control packets (routing control packets, Clear-to-Send (CTS), Request-to-Send (RTS), Address Resolution Protocol (ARP) requests and replies, and MAC ACKs) over the total number of successfully received data packets. This is the metric for evaluating the effective utilization of the wireless medium for data traffic.

**V. PERFORMANCE EVALUATION
 BASED ON QUANTITATIVE
 METRICS.**

TABLE 1: SIMULATION PARAMETER

Parameter	Values
Connection type	CBR/UDP
Simulation area	1000*1000
Transmission Range	250 m
Packet size	512 bytes
Number of Nodes	30-50-70-90
Duration	150 s
Pause time	0 s
CBR_Start	30s
Number of connexions	10

In this section we evaluate two routing protocols that were chosen based on quatitative metrics. Simulations were implemented using network simulator NS-2.35. All the default values for the OLSR and AODV protocols were used. The simulations were performed for 30 to 90 nodes with a transmission range of 250 meters, in an area of size 1000*1000 meters during 150 seconds. Random waypoint model is used as the mobility model of each node. Nodes speed is varied from 0m/s to 20 m/s. (Table 1).

1. Varying network mobility

We start with a mobility scenario in which the nodes have a low velocity of 5 m/s (18 km/h). We then increase the node velocity up to 20 m/s (72 km/h). Our intention is to investigate the behavior of the two protocols in networks with varied mobility.

Figure 4 shows the packet delivery ratio of the protocols. All protocols present a similar performance, having the best performance at all mobility rates. We observe again that AODV have a better performance when the speed of the nodes increases, because the network load is more evenly distributed among the nodes at higher mobility rates.

In the case of static nodes, OLSR has a better performance than AODV.

Figure 5 shows the end-to-end delay of the protocols. OLSR has the lowest end-to-end delay at low and high mobility, Because of proactive routing approach of OLSR protocol; every node in the network has route to any possible destination in its routing table at any given time. Data received from the upper transport layer are immediately transmitted, as a route to the destination is already in the node's routing table

Figure 6 shows the normalized routing load. AODV has the best performance, with a decrease of the routing load at a higher mobility. That stable behavior of AODV is a desirable property of a protocol as it indicates that it can scale well in networks in which the mobility changes over time. While the OLSR performance increases when nodes move at lower speeds.

Figure 7 shows the normalized routing load. OLSR has lower normalized MAC load than AODV, despite having a higher normalized routing load. The explanation is that under this simulation scenario the route discovery in OLSR is more accurate than in AODV. OLSR is the most stable protocol in terms of the normalized MAC load in networks with varying mobility.

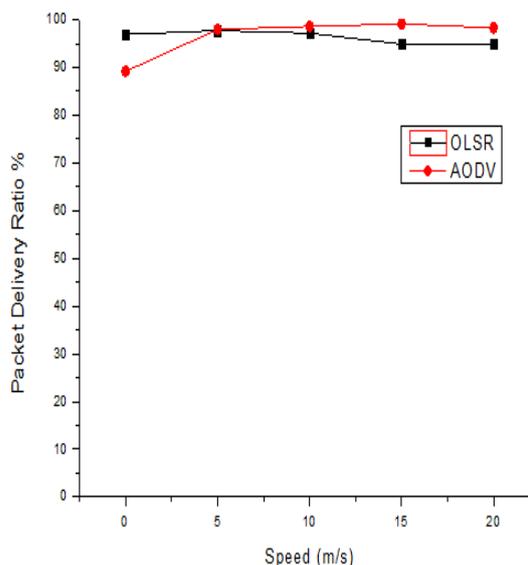


Fig.4. Packet Delivery Ratio VS mobility

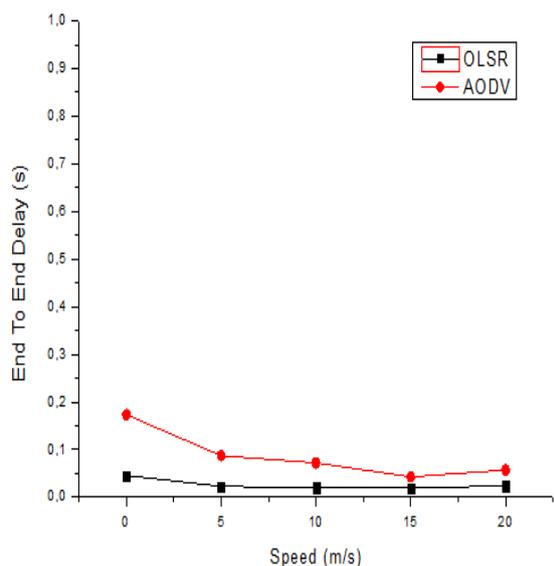


Fig.5. End To End Delay VS mobility

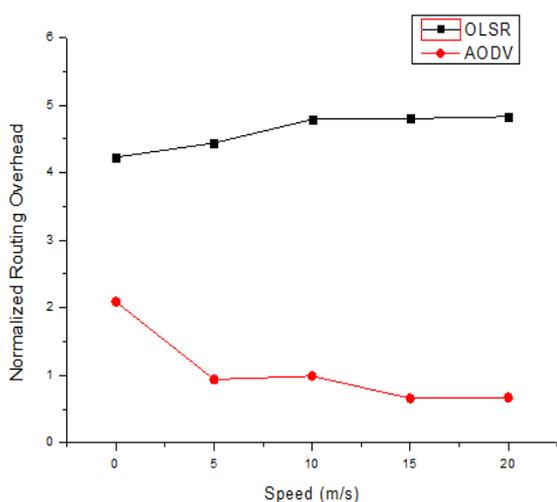


Fig.6. Normalized Routing Overhead Vs mobility

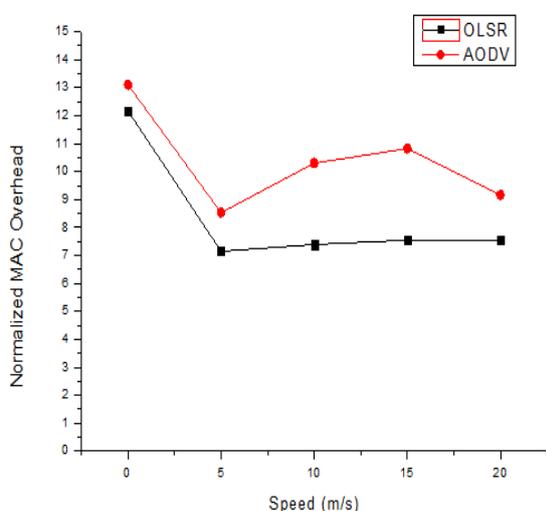


Fig.7. Normalized MAC Overhead Vs mobility

2. Varying network density

In the final set of the simulation, we vary the number of nodes in the network. Our objective is to investigate the impact of node density on the protocol's performance. We use the same simulation area as in our previous simulations and gradually increase the number of nodes in the network. A desirable property of a protocol is to have stable behavior regardless of the number of nodes in the network.

All protocols have a similar packet delivery ratio in high density, but in the case of low density OLSR performance drops significantly compared to that of AODV (Fig.8).

Fig.9 shows the end-to-end delay of the protocols. OLSR has the lowest end-to-end delay at low and high density, except in the case of 50 nodes, in which AODV performance is better than OLSR.

Fig.10 shows the normalized routing load. AODV has the lowest normalized routing load, which is almost independent of the number of nodes in the network. AODV scales well when the number of nodes in the network increases, this is a desirable property of a protocol. The OLSR is inefficient to operate properly in a network with an increasing number of nodes. This is a direct result of the OLSR proactive behavior, but we expected that the proposed optimization of the Link State algorithm with the implementation of the MPRs would result in a much lower normalized routing load, thereby increasing OLSR performance.

Fig.11 shows the normalized MAC load. OLSR has the high normalized MAC load except in the case of 30 nodes, in which OLSR generates a lower number of control packets MAC. That high number of normalized MAC load reveals that the network is congested, not by data packets, but from the routing packets generated by OLSR.

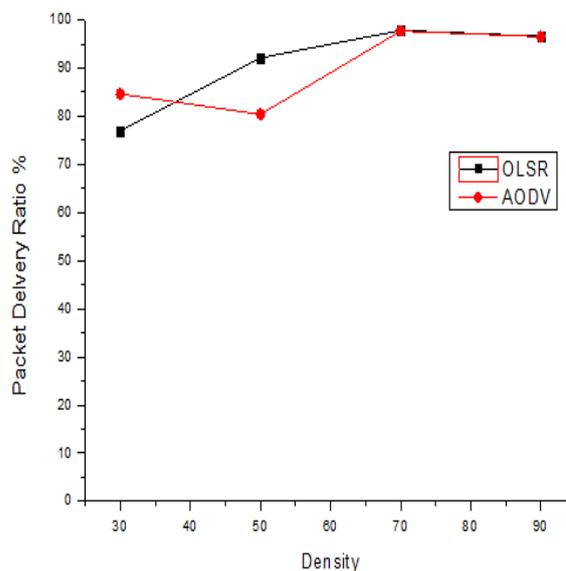


Fig.8. Packet Delivery Ratio VS density

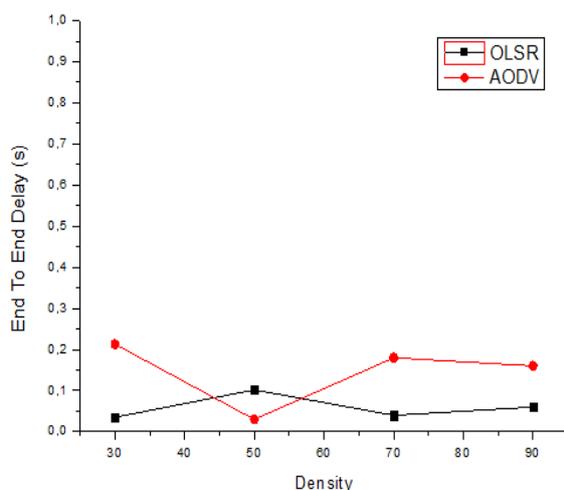


Fig.9. End To End Delay VS density

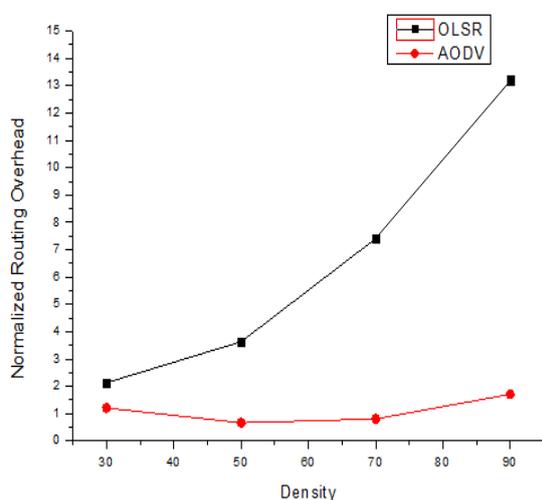


Fig.10. Normalized Routing Overhead Vs density

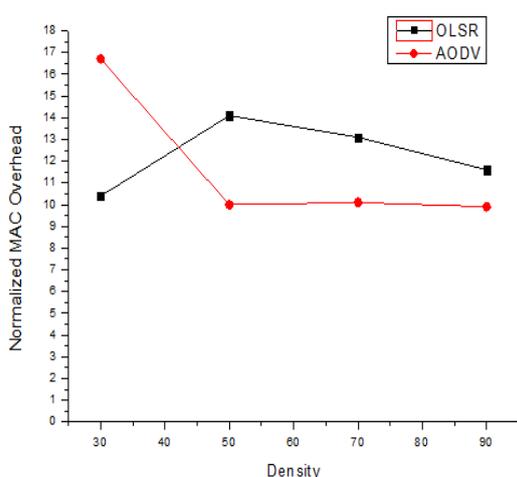


Fig.11. Normalized MAC Overhead Vs density

VI. CONCLUSION

In this paper we evaluated the four performance measures i.e. PDR, control overhead, end-to-end

delay, control overhead MAC with different number of nodes and different speed of nodes.

OLSR had the lowest performance in terms of the packet delivery ratio than AODV in all of the simulations. The reason lies in the proactive behavior of OLSR, because the Multipoint Relay (MPR) nodes flood the network with Topology Control (TC) packets every 5 s (default value). Therefore, when the network load increases, data packets are dropped by the mobile nodes due to network congestion caused by the periodic transmission of TC packets.

OLSR presented the lowest end-to-end delay in almost all of the simulations, and in most cases the end-to-end delay was independent of the varying simulation parameters. OLSR is a good compromise when combining the protocol performance, in terms of the packet delivery ratio and the end-to-end delay. It is concluded that OLSR is the most efficient protocol for time-sensitive applications such as voice and video transmission.

AODV had a best packet delivery ratio, lower normalized routing and MAC loads, and a higher end-to-end delay than OLSR. In networks with a small number of nodes and low mobility, AODV did not suggest a good solution as a routing protocol. However, AODV had better performance in networks with higher mobility and a greater number of nodes.

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