Performance Evaluation of AODV, DSR and OLSR Mobile Ad hoc Network Routing Protocols using OPNET Simulator

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Abstract: A mobile ad hoc network (MANET) is a wireless network that uses multi-hop peer-to-peer routing instead of static network infrastructure to provide network connectivity. The network topology in a MANET usually changes with time. Therefore, there are new challenges for routing protocols in MANETs since traditional routing protocols may not be suitable for MANETs. In ad-hoc networks, nodes are not familiar with the topology of their network; instead, they have to discover it. Table-driven (Pro-active) routing protocols like OLSR, maintains fresh lists of destinations and their routes by periodically distributing routing tables throughout the network. On Demand (Reactive) routing protocols like AODV and DSR find a route on demand by flooding the network with route request packets. The metrics like data drop, delay, load and throughput are used for the comparative analysis of the MANET performance using OPNET simulator tool for the AODV, DSR and OLSR protocols operating in different scenarios, with multiple network sizes and multiple average mobility. The results show that OLSR has the best results in terms of delay; load whereas AODV has the best throughput. AODV and OLSR perform well with large network sizes and high mobility, whereas DSR protocol performs at an acceptable level with lower mobility and smaller network sizes.

Keywords: Mobile Ad hoc Network, reactive protocols, pro-active protocol, mobility, throughput.

I. Introduction

MANETs have a dynamic nature, and a large number of applications make them ideal to use. Quick deployment and minimal configuration of MANET in emergencies such as natural disaster makes them more suitable. Extensive research work has been done on the performance evaluation of routing protocols using NS2 network simulator. Different methods and simulation environments give different results for MANET routing protocols performance. The aim of this paper is to evaluate the performance of Proactive MANET protocols (OLSR) and Reactive MANET Protocols (AODV and DSR) using OPNET Modeler. Extensive research work has been done in the field of MANET routing protocols. Different routing protocols have been simulated in different kind of simulators. In this paper three MANET routing protocols in the OPNET modeler such as AODV, DSR and OLSR against four different parameters i.e. data drop, delay, load and throughputs are simulated. Researchers traditionally classify these protocols as proactive protocols, reactive protocols, or hybrid of the two, based on the way they find new routes or update existing ones. Proactive routing protocols keep routes continuously updated, while reactive routing protocols react on demand [1].

The Dynamic Source Routing (DSR) [2] protocol is a distance-vector routing protocol for MANETs. When a node generates a packet to a certain destination and it does not have a known route to that destination, this node starts a route discovery procedure. Therefore, DSR is a reactive protocol. One advantage of DSR is that no periodic routing packets are required. DSR also has the capability to handle unidirectional links. Since DSR discovers routes on-demand, it may have poor performance in terms of control overhead in networks with high mobility and heavy traffic loads. Scalability is said to be another disadvantage of DSR [3], because DSR relies on blind broadcasts to discover routes.

There are two main operations in DSR, namely route discovery and route maintenance. During the route discovery procedure, routers maintain ID lists of the recently seen requests to avoid repeatedly processing the same route request. Requests are discarded if they were processed recently since they are assumed to be duplicates. If a router receives a request and detects that the request contains its own ID in the list of intermediate routers, this router discards the request to avoid loops.

The route maintenance procedure is used when routes become invalid due to the unpredictable movement of routers. Each router monitors the links that it uses to forward packets. Once a link is down, a route error packet is immediately sent to the initiator of the associated route. Therefore, the invalid route is quickly discarded [1].Reactive routing protocols try to use extra acknowledgements or a small number of retransmissions to solve this problem and, thus, introduce more overhead. Proactive routing protocols periodically broadcast control messages and remove local routing entries if they time out. Hence, they do not have this problem. But, of course, the periodically broadcast control messages contribute to overhead.

The Ad hoc On-demand Distance Vector (AODV) routing protocol [4] is a reactive MANET routing protocol. Similar to DSR, AODV broadcasts a route request to discover a route in a reactive mode. The difference is that in AODV, a field of the number of hops is used in the route record, instead of a list of intermediate router addresses. Each intermediate router sets up a temporary reverse link in the process of a route discovery. This link points to the router that forwarded the request. Hence, the reply message can find its way back to the initiator when a route is discovered. When intermediate routers receive the reply, they can also set up corresponding forward routing entries. To prevent old routing information being used as a reply to the latest request, a destination sequence number is used in the route discovery packet and the route reply packet. A higher sequence number implies a more recent route request. Route maintenance in AODV is similar to that in DSR [1]. One advantage of AODV is that AODV is loop-free due to the destination sequence numbers associated with routes. The algorithm avoids the Bellman-Ford "count to infinity" problem [4]. Therefore, it offers quick convergence when the ad hoc net- work topology changes which, typically, occurs when a node moves in the network [4]. Similar to DSR, poor scalability is a disadvantage of AODV [3].

The Optimized Link State Routing (OLSR) protocol [5] is a proactive link state routing protocol for MANETs. One key idea is to reduce control overhead by reducing the number of broadcasts as compared with pure flooding mechanisms. The basic concept to support this idea in OLSR is the use of multipoint relays (MPRs) [5, 6]. MPRs refer to selected routers that can forward broadcast messages during the flooding process. To reduce the size of broadcast messages, every router declares only a small subset of all of its neighbors. "The protocol is particularly suitable for large and dense networks" [5]. MPRs act as intermediate routers in route discovery procedures. Hence, the path discovered by OLSR may not be the shortest path. This is a potential disadvantage of OLSR.

OLSR has three functions: packet forwarding, neighbor sensing, and topology discovery. Packet forwarding and neighbor sensing mechanisms provide routers with in- formation about neighbors and offer an optimized way to flood messages in the OLSR network using MPRs. The neighbor sensing operation allows routers to diffuse local information to the whole network. Topology discovery is used to determine the topology of the entire network and calculate routing tables. OLSR uses four message types: Hello message, Topology Control (TC) message, Multiple Interface Declaration (MID) message, and Host and Network Association (HNA) message. Hello messages are used for neighbour sensing. Topology declarations are based on TC messages. MID messages contain multiple interface addresses and perform the task of multiple interface declarations. Since hosts that have multiple interfaces connected with different subnets, HNA messages are used to declare host and associated network information. Extensions of message types may include power saving mode, multicast mode, etc. [5]

II MANET Simulation using OPNET Modeler

The OPNET modeler software tool can simulate wired or wireless communication network in a short time and the scenario can provide different kinds of services. This modeler includes a collection of routing protocols; each routing protocol depends on a different route discovery mechanism to establish a route from a source to destination. This paper deals with a proactive routing protocol (OLSR) and Reactive protocols (DSR and AODV). For each of these three MANET routing protocols, the same MANET simulation environment was used.

Simulation Parameters

Raw data packets were generated using Poisson's Inter-Arrival time at a data rate of 1 Mbps. The Poisson's regime is a model in which data is communicated by random discrete occurrences in time that obey Poisson's statistics of arbitrarily time-varying mean [7]. In this way, each node in the network generates and sends packets. Determining how many levels of network size (the smallest and the largest network sizes to be considered) will definitely influence the number of simulations such that if the number of network size levels increases, then the number of the network simulations will increase as well. Simulations were performed for evaluation of reactive and proactive routing protocols. The network size varies in each simulation, starting from a network with 4 nodes (assuming that the smallest realistic network could have 4 nodes) and extending to network with 64 nodes (assuming that a reasonably large MANET could have 64 nodes). Consequently, the coverage area was increased; for the first scenario, the coverage area is 500 m × 500 m. The network size was incremented in steps of 500 m to the maximum of 3.5 km × 3.5 km for the last scenario. These simulations were executed to mimic one hour communication time.

Each node in the simulated scenarios considered had its own Random Walk Mobility Model [8], meaning nodes moved for random directions through the whole simulation within the predefined area without any pause time. Determining how many mobility levels and what are the slowest and the fastest network that should be considered in this research will definitely influence the number of simulations; for example, if the number of mobility levels increases, then the number of network simulations also increases. The packets from a source node to a random destination node were sent considering different levels of mobility from stationary network to reasonably fast network. Four levels of user average mobility were considered: (0 m/s), (1 m/s), (10 m/s), and (20 m/s). The latter three levels are defined by varying the speed of the mobile users. As each individual network node moved with its own trajectory and speed, the network nodes' speed were summed and averaged to determine the network mobility. The mobility levels are the average mobility for the whole network.

The infrastructure-less nature of a MANET, allows network nodes the freedom to join or leave the network at any time, will continuously affect the overall network performance. Therefore, this characteristic could be represented by various parameters [9] such as number of traffic sources, node bandwidth, node power and node pause time. In this paper, two important context parameters have been considered to evaluate the network performance: the network size and the nodes' mobility. The number of simulation scenarios needed for modeling the network depends on two important elements:

1. The number of selected network context parameters
2. The number of modeled routing protocols

The simulation scenario increases or decreases depending on the elements, which is expressed by Equation (1). Let P_c represent the selected network context parameter, T_c represent the total network context parameters with $T_c \geq 2$ and $c \geq 1$, and R_T is the total number of MANET routing protocols to be modeled.The total number of the created scenarios S_T is expressed in equation (1) as given below:

$$S_T = \prod_{c=1}^{c=T_c} P_c \times R_T \quad (1)$$

Two context parameters are considered in the simulation environment namely network size level and mobility level. Let P_1 represent the first parameter that is the network size, N_{size} represent the selected network size, T_{size} represent the total number of the network selected cases, and *size* represent the selected case, where $size \geq 1$, P_1 is expressed in the equation (2) as given below:

$$P_1 = \sum_{size=1}^{size=Tsize} N_{size} \quad (2)$$

Let P_2 represent the second parameter, namely mobility levels, M_{level} represent the selected node average mobility level in the network, T_{level} represent the total mobility level cases, and *level* represents the mobility level case, where $level \geq 1$, then P_2 is expressed in equation(3) as given below:

$$P_2 = \sum_{level=1}^{level=T_{level}} M_{level} \quad (3)$$

Let $R_{protocol}$, $T_{protocol}$, and *protocol* represent the MANET routing protocol, the total number of MANET routing protocol cases used and the protocol number respectively, with $protocol \geq 1$ and $T_{protocol} \geq 2$, then R_T is expressed in equation (4) as given below:

$$R_T = \sum_{protocol=1}^{protocol=Tprotocol} R_{protocol} \quad (4)$$

Combining Equations (1), (2), and (3), the equation for the simulations scenario is given in equation (5) as follows:

$$S_T = P_1 \times P_2 \times R_T \quad (5)$$

In Equation (5), the first parameter, P_1 in Equation (2), considers seven cases of network size. Representing various network sizes from small to large, the P_1 cases are 4, 9, 16, 25, 36, 49, and 64 nodes, respectively. The second parameter, P_2 in Equation (3), has four levels of mobility. The P_2 levels are stationary (0 m/s), low (1 m/s), medium (10 m/s), and high (20 m/s). The last parameter, R_T in Equation (4), considers three routing protocols. From the above it can be determined that the total number of simulations needed will be 84 ($S_T = 7 \times 4 \times$

Performance Evaluation Methodology

The performance metrics used for the comparative analysis are as follows:

1. *Data Drop* (bits/s): the total data traffic dropped by the network nodes.
2. *Delay* (s): the end-to-end packets delay experienced by all nodes.
3. *Load* (bits/s): the total data traffic received by all nodes.
4. *Throughput* (bits/s): the total number of bits forwarded in all nodes.

Simulation Study and Results

For each simulation scenario that ran for one hour of simulation time, the results for each respective metrics were recorded and stored. In each scenario, through all the simulation time, the average value for each performance parameter was calculated. For each simulation scenario, four performance values were determined. They demonstrate the efficiency of the network performance during the one hour of simulation. Figures (1) through (4) present the averaged four performance metrics: data drop (bits/s), delay (s), load (bits/s), and throughput (bits/s).

These 2D performance measures are plotted against network size, where subfigure (a) represents station network 0 (m/s), (b) relates to the average network mobility 1 (m/s), (c) relates to the average network mobility 10 (m/s), and (d) relates to the average network mobility 20 (m/s). Each subfigure contains three curves that represent the MANET operated with one of the three routing protocols OLSR, DSR, or AODV. The parameter network size was labelled as “no. of nodes” in these graphs.

Figure 1:

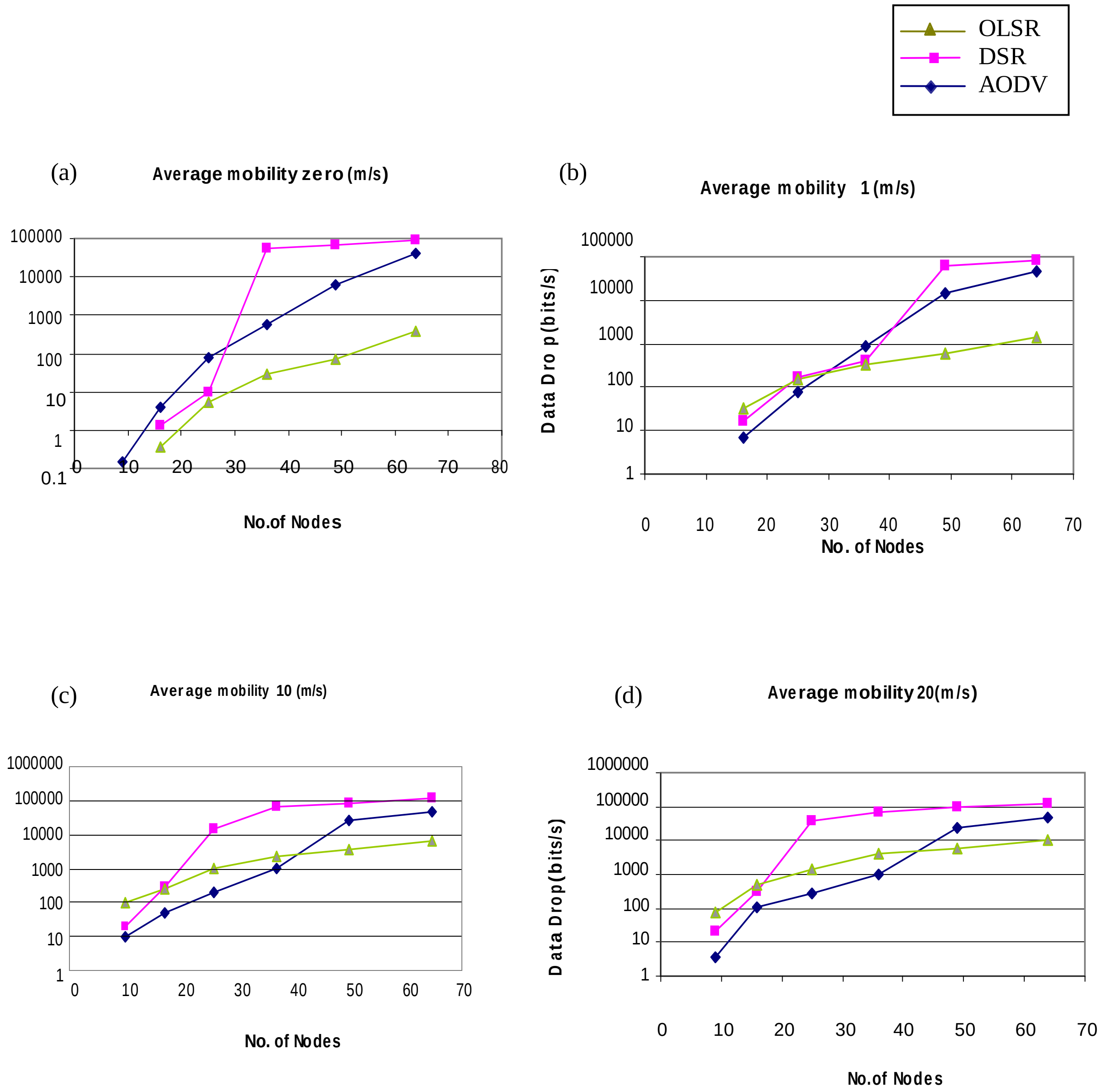

OLSR
DSR
AODV
(a)
Average mobility zero (m/s)
100000
10000
1000
100
10
1
0.1
0 10 20 30 40 50 60 70 80
No.of Nodes
(b)
Average mobility 1 (m/s)
Data Drop(bits/s)
100000
10000
1000
100
10
1
0 10 20 30 40 50 60 70
No. of Nodes
(c)
Average mobility 10 (m/s)
1000000
100000
10000
1000
100
10
1
0 10 20 30 40 50 60 70
No. of Nodes
(d)
Average mobility 20(m/s)
Data Drop(bits/s)
1000000
100000
10000
1000
100
10
1
0 10 20 30 40 50 60 70
No.of Nodes

Figure 2: Delay of Reactive (DSR & AODV) and Proactive (OLSR) Protocols

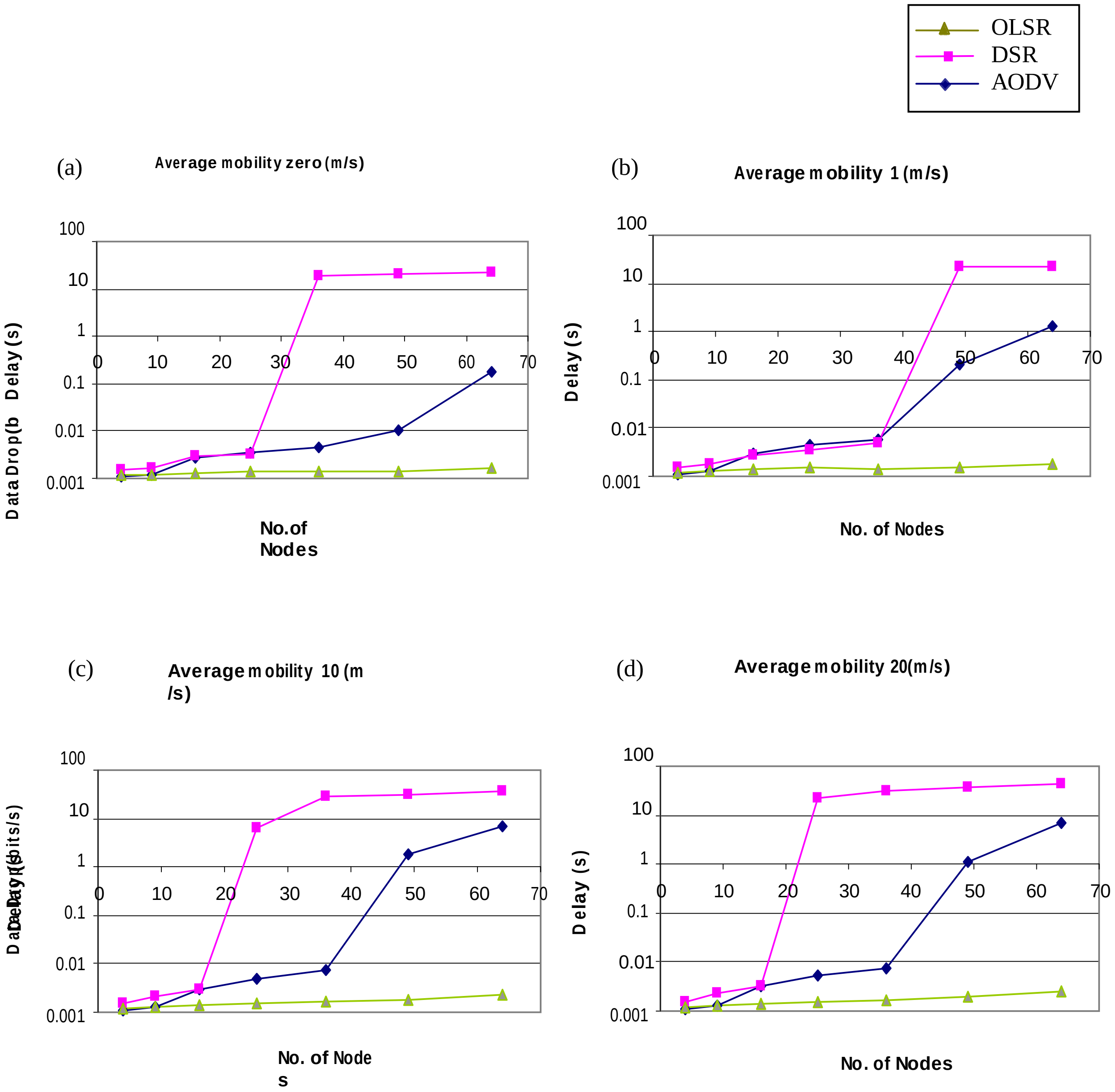


Figure 3: Load of Reactive (DSR & AODV) and Proactive (OLSR) Protocols

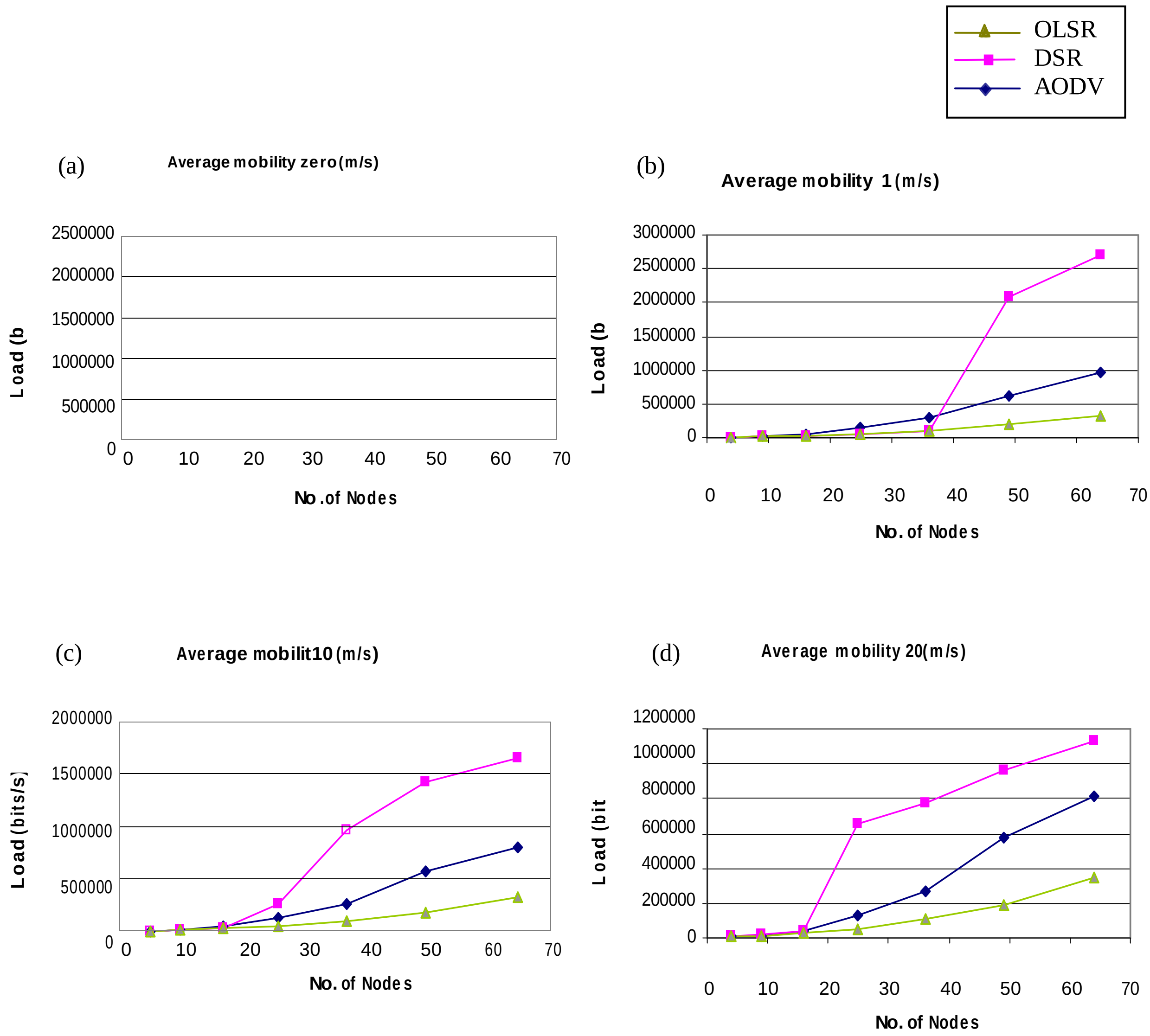
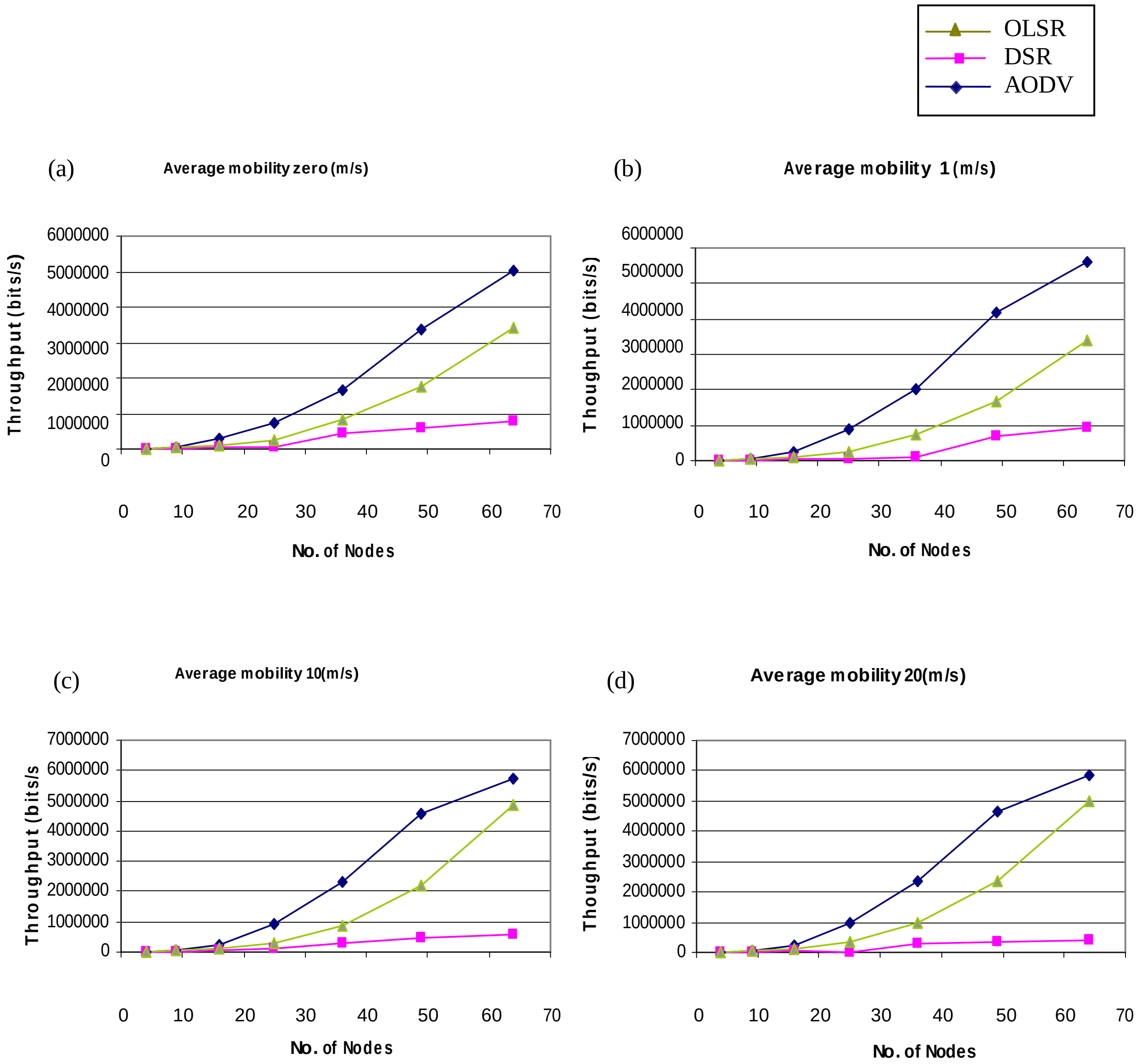


Figure 4: Throughput of Reactive (DSR & AODV) and Proactive (OLSR) Protocols



Data drop

With an increase in the network size, for a network operating with an OLSR routing protocol, the data drop is least. As OLSR is designed to handle scalable networks by implementing the Multipath Routing technique. OLSR proactive mechanism also secures in each MPR node a routing table that contains the routes for all possible destinations. This feature enables OLSR to deliver a good amount of data without dropping as indicated in Fig 1(a).

The DSR routing protocol shows less data drop compared to AODV routing protocols, for a network size of up to 36 nodes. When a network size is increased to more than 36 nodes, the routing protocols (AODV and DSR) switch positions and the network implementing AODV routing protocol achieves less data drop compared to the network that operated with DSR routing protocol. The reason behind this is that the DSR routing protocol is not designed for a scalable network because of its route cache mechanism [12]. The side effect of the incremental increase in network size is that the DSR route cache will also grow. Therefore, the DSR network will suffer from delay increment, as shown in Figure 2 (a), and load increment, Figure 3 (a), which will affect the transmission and cause a significant amount of data drop.

Figure 1 (b) shows the different performances for the networks operating with the three protocols. The network in this figure is dynamic with average mobility (1 m/s). For a network size of up to 36 nodes, the least data drop is shown with AODV, then DSR, followed by the worst network operating on OLSR. With a network size of 36 nodes, the best routing protocol is OLSR, followed by DSR, and then AODV; whereas with a network size of 49 nodes, the best routing protocol is OLSR, followed by AODV, and then DSR. Figures 1 (c) and (d) clearly show that for a network size of less than 25 nodes, the least data drop is for a network which operates on AODV, followed by a network which operates on DSR, and; the worst results are for a network operating OLSR. With a network size ranging from 25 to 49 nodes, the best routing protocol is AODV, followed by OLSR, and then DSR. With a network size ranging from 49 to 64 nodes, the best routing protocol is OLSR, followed by AODV, and DSR. Furthermore, the results in Figure 5.1 (c) and (d) show that the AODV routing protocol is efficient for a dynamic network with high and medium mobility [8].

In Figure 1(a) and (b) when the mobility is low, 0 (m/s) or 1 (m/s), the data started to drop for any network size greater than 16 (except in the AODV graph which started from 9, as shown in Figure 1 (a)); whereas when the mobility is medium, 10 (m/s), or high, 20 (m/s), in Figure 1 (c) and (d), the data started to drop for smaller network sizes, as compared to Figures 5.1 (a) and (b) in which the data started to drop from any network size greater than 9 nodes. Approximately, the AODV routing protocol was the only protocol in which the network data drop increased linearly in the log scale by increasing the average mobility and the network size.

Delay

As indicated in Figure 2 (a), the delay for the networks using AODV and DSR protocols are approximately the same for a network size of up to 36 nodes. Once this size is exceeded, a rapid increment happens to the network delay that operates DSR against an acceptable delay for the network that operates AODV, which will continue through the rest of the simulation. However, the OLSR's delay is significantly small amount and is not affected by the network size increase through the simulation compared with the other two protocols; that is due to OLSR proactive mechanism that stores update table for the whole network and adopts MPR technique that selects the effective neighbour nodes to retransmit the source packets. In Figure 2 (b), the network is operated with average mobility 1 (m/s); the three routing protocols show the same attitude as previously seen in Figure 2 (a) with a rapid shift in the delay of a network operating DSR, for a network size of up to 49 nodes.

Figures 2 (c) and (d) show how medium and high mobility can affect the network delay. The network operating with DSR showed rapid delay increment for a network size greater than 25 nodes, whereas the network operate with AODV showed rapid delay increment for network size greater than 49 nodes.

Load

Figure 3 (a) shows that the stationary networks operating with the three protocols have approximately the same load until the network size is increased to more than 25 nodes, at which point networks operating with DSR have the worst load for the duration of the simulation. In Figure 3 (b), when the network's average mobility is 1 (m/s), the networks operating with OLSR and DSR have less load than the networks operating with AODV.

The load for DSR's network is clearly better than the load for the AODV's network, up to a network size of more than 36 nodes; beyond this point, the load for DSR's network suffers rapid increment. Figures 3 (a), (b), (c), and (d) show that the load for the OLSR's network was significantly less due to the MPR technique, in spite of the increment in network scalability and mobility, especially in subfigures (c) and (d). For networks that operate with On Demand protocols, AODV and DSR have higher load due to the routing establishment mechanism.

Throughput

Figure 4 shows that the best throughput was for a network operating with AODV, followed by a network operating with OLSR, and lastly a network operating with a DSR routing protocol. The AODV routing protocol was able to forward more packets with the mechanism that quickly establishes routes and then forwards more packets.

VI Conclusion

The simulation results for the three MANET protocols Reactive (DSR & AODV) and Proactive (OLSR) protocols operating in different scenarios, with multiple network sizes and multiple average mobility indicate that as the mobility increases; the data drop will increase as well. Also, the figure shows that increasing the mobility affects the data drop for the DSR operated network more than the ones operated with OLSR and AODV routing protocols, as the DSR data drop for a network of 64 nodes reached ten four-figure number (bits/s) with average mobility of 20 (m/s). The best delay is for a network operating on an OLSR routing protocol, which is related to the multipoint routing mechanism (less message) followed by AODV; this may be accounted for by the AODV sequence number mechanism (drop duplicated messages). The network with the DSR routing protocol is last due to the DSR cache route mechanism (carry the full path), as the network scalability and mobility affects DSR routing protocol delay.

The load for the networks operated with On Demand protocols were affected by scalability, especially DSR. The networks' load starts to increase with a stationary network of 25 nodes and higher. The loads of networks with average mobility 1 (m/s), will start to increase with a network size of 36 nodes and higher. When the networks average mobility is increased to 10 (m/s) and 20 (m/s) respectively, the network will suffer from high load that starts to increase past a network size of 16 nodes. The movement of the network nodes breaks the early established route, creating a demand for a *Route discovery* to establish a new route, which in turn causes load over the network. The load for AODV's network was less than the load for DSR's network the majority of the time; this is related to hop by hop and the sequence number mechanisms AODV employs.

These mechanisms will reduce the load by dropping (that is not forwarding) the packets with old sequence numbers, such that only those packets that have the up dated sequence number will be forwarded. Throughout the simulation time, the least load was for the network that operated on the OLSR routing protocol. The results show that OLSR has the best results in terms of delay; load whereas AODV has the best throughput. AODV and OLSR perform well with large network sizes and high mobility, whereas DSR protocol performs at an acceptable level with lower mobility and smaller network sizes. The simulation results proved and confirmed that in certain contexts, one of the routing protocols will give a better performance than the other. However, when the context changes, the first protocol's performance will degrade whereas the second protocol's performance will improve.

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