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Comprehensive OPNET based Scalability Analysis and Performance Evaluation of MANET Routing Protocols

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Abstract
A Mobile Ad-hoc Network (MANET) is a collection of communication and computing devices equipped with communication capabilities in which the nodes communicate with each other without any pre-existing infrastructure. Unlike the infrastructure based networks, there are no BTSs and BSCs in MANETs. The nodes involved in the MANETs, therefore, act as both routers and hosts. The nodes involved in the MANETs, therefore, act as both routers and hosts. The network topology varies dynamically and unpredictably due to mobility of the nodes. The conventional IP based routing protocols are not able to handle the unique characteristics of MANETs. Different protocols that can handle the unique characteristics such as dynamic and unpredictably varying topology have therefore been developed. These protocols have different performance and scalability behaviors in different network operation conditions. It is therefore imperative to analyze their scalability and evaluate their performances with respect to the control variables on which MANET networks are mainly optimized and characterized such as the network size, mobility and traffic type and load. In this paper, the scalability and performance behaviors of AODV, DSR and OLSR are analyzed under scalable network size, mobility speed and FTP traffic loads with respect to average end-to-end delay and throughput. OPNET Modeler 14.5 was used as a simulation tool. The results indicated that there is an overall throughput performance increment with increasing network size and FTP traffic load while the delay performance was decreasing. It was also observed that the mobility scaling has not a significant effect on the performance behavior of the protocols. OLSR performs better than the AODV and DSR in terms of delay while AODV performs better than the other two in terms of throughput in all the scenarios considered.
Keywords: AODV, Delay, DSR, Throughput, FTP, MANET, OLSR

1. Introduction

A Mobile Ad-hoc Network (MANET) is a collection of communication and computing devices equipped with communication capabilities in which the nodes communicate with each other without any pre-existing infrastructure. MANETs have unique characteristics in addition to the characteristics inherited from the conventional infrastructure based networks. They are characterized by highly dynamic topology due to mobility of the nodes involved in the networks, self-organizing and self-configuring ability as there is no centralized controlling unit, and easily deployable nature as there is no need for pre-existing infrastructure [1-3]. Unlike the infrastructure based networks, there are no BTSs and BSCs in MANETs. The nodes involved in the MANETs, therefore, act as both routers and hosts. The network is decentralized where all network activity, including delivering messages and discovering the topology must be executed by the nodes themselves. The issue of routing is, therefore, the most challenging and main issue of concern in mobile ad hoc networks. Classical IP based routing protocols are not appropriate for MANETS because of the mobile and dynamic nature of the network links. Routing protocols for such environments must, therefore, be able to keep up with the high degree of node mobility that often changes the network topology dynamically and unpredictably. Therefore, different types of mobile ad hoc network routing protocols such as Ad hoc On-demand Distance Vector (AODV), Dynamic Source Routing (DSR), Optimized Link State Routing (OLSR) and others have been developed through prominent researches. These protocols have different scalability, performance characteristics and efficiencies in different network operation conditions. It is therefore imperative to analyze their scalability and evaluate their performances with respect to a broad range of control variables on which MANET routing protocols are mainly optimized and characterized such as the network size, mobility and traffic type and load in order to deploy the most suitable protocol and do further optimizations. MANETs hold the promise of the future, with the ability to establish networks at anytime, anywhere [4]. The absence of inessential hardware makes them an ideal candidate for critical application domains such as rescue operations in high risk disasters and mission critical military operation [5]. Efficiency and reliability of the routing protocols are therefore of utmost important.

2. MANET Routing Protocols

Based on their routing approaches, MANET routing protocols are broadly classified in to three as proactive, reactive and hybrid routing protocols [9, 10].

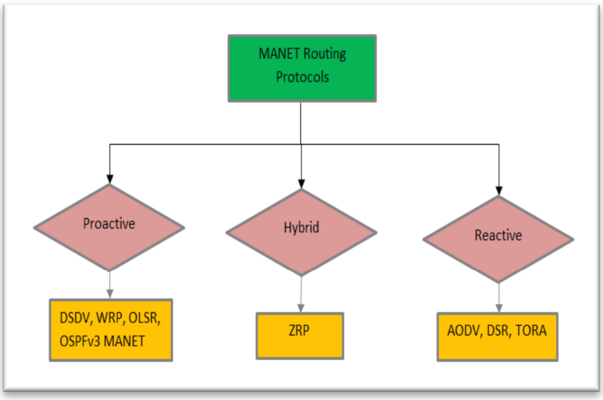


Figure 1: Classification of MANET Routing protocols

Proactive routing protocols are protocols that require nodes in mobile ad hoc networks to maintain up-to-date route information in a route table and update topology changes periodically to all nodes and possible destinations so that when a packet needs to be forwarded, the route is already known and can be used immediately [11]. As the packets can be immediately forwarded through an already identified route in the routing table, these protocols have low latency but high routing overhead because of the periodic transmission of route table update packets regardless of the network traffic [12, 13]. Example of proactive routing protocols is Optimized Link State Routing (OLSR). Reactive routing protocols, on the other hand, are protocols which find path by exchanging the routing information (by flooding the network with Route Request packets) only when a node requires a path to communicate with the destination. Unlike proactive protocols, there is no periodic dissemination of routing table update messages. This prevents the nodes from updating every possible route in the network, and instead allows them to focus either on routes that are in the process of being set up or that are being used at that time [14, 15]. Examples of reactive routing protocols are Ad hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR) protocols. The third group of MANET routing protocols are the hybrid routing protocols. They have combined characteristics of proactive and reactive protocols. Zone Routing Protocol (ZRP) is an example of hybrid routing protocol. A brief description of DSR, AODV and OLSR, which are targeted in this paper, is presented below.

2.1 DYNAMIC Source Routing (DSR) Protocol

Dynamic Source Routing Protocol (DSR) [13] is a link state source routed reactive protocol in which a node in the network maintains route caches containing the source routes that it has learnt. That is, the entire path from the source to the destination is provided by the source in a packet header. The routing metric method is the shortest path or next path available. In DSR, when a node needs to send its packets to a destination a route has to be discovered before the actual data packet is transmitted. This initial search latency may degrade the performance of real-time and interactive applications. Moreover, the quality of path is not known prior to call setup [13]. The routing philosophy of DSR has three phases known as Route discovery, Route maintenance and Route reply. It uses a route cache network information maintenance technique. DSR has no beacon of hello messages. DSR has larger end to end delay and scalability problems due to flooding and source routing mechanisms.

2.2 Ad hoc On-demand Distance Vector (AODV) Protocol

Ad-hoc On-demand Distance vector (AODV) [14] protocol is a reactive routing protocol that builds routes using a route request (RREQ) and route reply (RREP) query cycle [15]. It is developed based on the DSDV and DSR routing algorithms. It uses periodic beaconing of “Hello Messages” and sequence numbering procedure like that of DSDV and a routing discovery procedure similar to that of DSR [14]. The major differences between AODV and DSR are that in DSR the full routing information is carried by each packet, where as in AODV packets carry the destination address [14]. This implies that AODV has a relatively less routing overhead than DSR. Another difference is that route replies in AODV carry only the destination IP address and sequence numbers while route replies in DSR carry the addresses of all nodes along the path. AODV is adaptable in very dynamic networks but there may be larger delays during route construction and while initiating another route discovery during link failures.

2.3 Optimized Link State Routing (OLSR) Protocol

Optimized Link State Routing Protocol (OLSR) [11] is a modular link state proactive IP routing protocol optimized to work for MANETs. The routes to all possible destinations are immediately available in a route table. It uses Hello messages, Topology control (TC) and Multiple Interference Declaration control messages to discover and distribute link state information of the entire topology to the other nodes in the network. OLSR provides a mechanism to optimize link-state messaging contrasting classical link-state routing schemes in which all nodes need to flood network with link-state information. The key feature of the protocol is that it uses the concept of a Multi-Point Relaying (MPR) to optimize flooding. OLSR configured at each participating node performs election of a set of MPRs from the neighbor nodes in a distributed manner by discovering 2-hop neighbor information using hello messages. Each Node selects MPRs independently such that there is a path to each of its 2-hop neighbors via a node selected as an MPR. The MPR nodes selection starts in the neighbor of the source node. Topology control messages with in which the MPR selectors are contained is periodically declared and broadcasted throughout the network by each node. OLSR uses the 'Hello Messages' to detect links to neighbors and identity of neighbor nodes and to signal MPR selection. 'TC Messages' are used to signal link-state information to the entire nodes in the network. Only MPR nodes selected generate and forward link-state messages and thereby limit the nodes that generate link-state messages.

3. Related Works

Several researches have been done on the scalability analysis and performance evaluation of MANET routing protocols under different network scenarios. A group of researchers (Asha. A. et al, 2010) studied and compared the performance of AODV and DSR using NS-2 2.33 with respect to varying pause time (5, 10, 15, 20, 25, 30, 35 and 40 seconds) using random waypoint mobility model and constant bit rate (CBR) traffic type under a fixed network size of 100 nodes [5]. They used packet delivery ratio, packet loss ratio and routing overhead parameters to illustrate the performances of the protocols. It was found out that both AODV and DSR perform equally well until a certain limit of pause time (10 to 20 seconds). But AODV performs better for larger pause time (20 to 35) and DSR performs better for pause time ranges of 5 to 10 seconds and 35 to 40 seconds under a given scenario. The packet loss ratio and routing overhead are generally higher in AODV than in DSR. AODV performs better only for the pause times of less than 5 to 7.5 and 35 to 40 whereas DSR has a better performance in the remaining pause times in terms of both performance metrics. The authors finally concluded that AODV performs well compared to DSR for larger pause times whereas DSR performs better in a relatively lesser pause times.

Gowrishankar.S et al, (2007) studied the performances of AODV and OLSR in different scenarios using NS-2 simulator in terms of end-to-end delay, packet delivery ratio and routing overhead with respect to network size and pause time variations [6]. According to this study, AODV performs better in terms of packet delivery ratio and average end to end delay when the mobility of nodes is high and this is because since OLSR is a table driven protocol, it is not as adaptive as AODV. The authors also assert that AODV performs better in networks where the traffic is static and the number of source and destination pairs for each host is relatively small [6]. Therefore, AODV can be used in resource critical situations [6]. On the other hand, OLSR performs better in situations where the networks have dense and highly irregular traffic and particularly when the number of hosts is large [6].

Vadhwani et al, (2013) analyzed the scalability and performance behavior of DSR with a fixed load of HTTP traffic using OPNET 14.5 modeler in 50, 70 and 100 mobile nodes [7]. Delay, throughput, routing traffic sent and received and HTTP traffic sent and received were used as performance metrics. The authors asserted that DSR has higher throughput in the 100 nodes network than in the 50 and 70 nodes networks and the delay was found to be higher in 50 nodes than in the 70 nodes. Simulation results indicated that the routing packets sent and received and HTTP packets sent and received increase with increasing the number of nodes. Manoj. K et al, (2012) made effective analysis of data traffic received, control traffic received and sent, retransmission attempts, throughput, and traffic received parameters in ad hoc networks for AODV, DSR and TORA using OPNET simulator with 30 fixed number of nodes and three different mobility speeds [8]. According to this study, TORA was found to perform better in terms of control traffic sent, control traffic received, and data traffic sent [8]. However, AODV was found to perform better in terms of throughput and data traffic received.

Most of the researches conducted on the scalability analysis and performance evaluation of MANET routing protocols have not been done on a broad range of control variables by which the MANET routing protocols' performances can be greatly affected and on which the routing protocols are mainly optimized. In this paper, the scalability analysis and performance evaluation of AODV, DSR and OLSR have been carried out through extensive simulations with respect to scalable FTP traffic loads, network sizes and mobility speeds. Three FTP traffic levels, three network sizes and two mobility speeds are considered.

4. Simulation Environment, Scalability Analysis and Performance Evaluation

4.1 Simulation Setup

There are different tools to model, simulate and analyze MANETs such as GloMoSim, NS-2, NS-3, QualNet and OPNET. In this research an Optimized Network Engineering Tool version 14.5 (OPNET 14.5) modeler was used to model, simulate and perform the scalability analysis and performance evaluation of MANETs and MANET routing protocols. OPNET Modeler is high level event based network simulation and development tool. It is industry's leading tool suitable in evaluation and design of MANET routing protocols. It is more reliable, robust and efficient compared to other simulators [17]. WLANs (MANETs) of different network sizes were modeled and deployed in an area of 1500mX1500m. Application configuration, Profile configuration and Mobility configurations were deployed. Three different MANET Models with network sizes of 5, 20 and 30 nodes, two mobility speeds of nodes with speeds of 10m/s and 20m/s each and three FTP traffic loads with 1,000 bytes, 5,000 bytes and 50,000 bytes were considered to analyze the scalability of the routing protocols. The summary of the MANET Model design and simulation parameters used are given in the following table.

Table 1. Summary of the main MANET model design and simulation parameters

Environment Area (mXm)	1500x1500
Mobility Model	Random waypoint
Routing Protocol	AODV, DSR, OLSR
Data rate	11 Mbps
Traffic source (Bytes)	FTP [Low Load: 1000, Medium Load: 5000, High Load: 50000]
Network Size (No. of nodes)	5, 20, 30
Mobility speed (m/s)	10, 20
Simulation time (seconds)	1800
MAC protocol/Physical	802.11/802.11b
Transmission power (W)	0.005
Node placement	Random
Pause time	150
Antenna of nodes	Omnidirectional

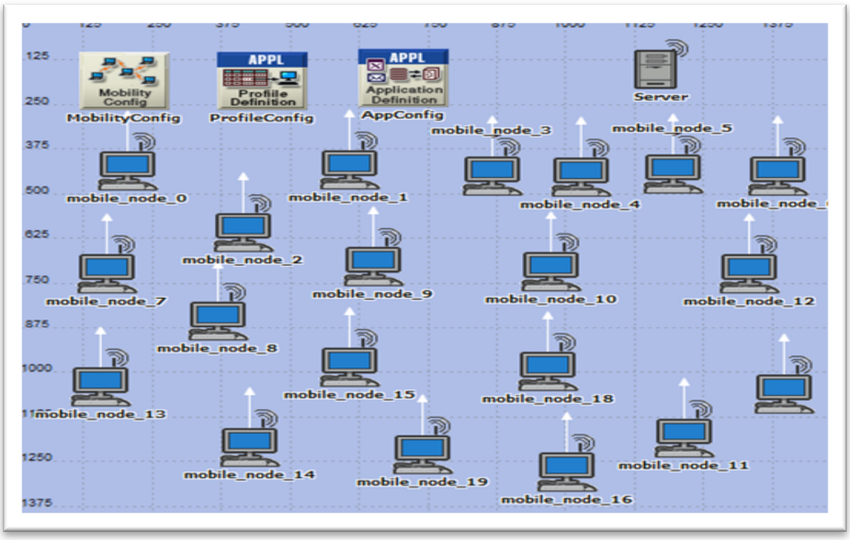


Figure 2. Sample Mobile Ad hoc Network Model with 30 mobile nodes

4.2 Performance Metrics

The scalability analysis and performance evaluation of the MANET routing protocols were done with respect to performance metrics of average end-to-end delay and throughput.

Throughput: Throughput is defined as the ratio of the amount of data that arrives at a receiver from a sender to the time it takes for the receiver to get the last packet [4]. It is expressed in terms of bits or bytes per second (bits/second or Bytes/second) or packets per second (Packets/second). Mathematically it is expressed as,

$$\text{Throughput} = \frac{Number\ of\ delivered\ Packets * Packet\ size * 8}{Total\ duration\ of\ simulatio} \qquad (1)$$

Packet End-to-End delay: The packet end-to-end delay refers to the average time taken for the packet to traverse the network from the sender to the receiver [16]. This accounts all the delays from the generation of the packet in the source, the propagation, processing and buffer queuing delays in the intermediate nodes and up until it is delivered to the destination node. Mathematically, the end-to-end delay is expressed as [17]:

$$d_{End-End} = [d_{trans} + d_{prop} + d_{proc} + d_{queue} + d_{RDD} + d_{rt}] = [T_{receive} - T_{sent}] \qquad (2)$$

Where

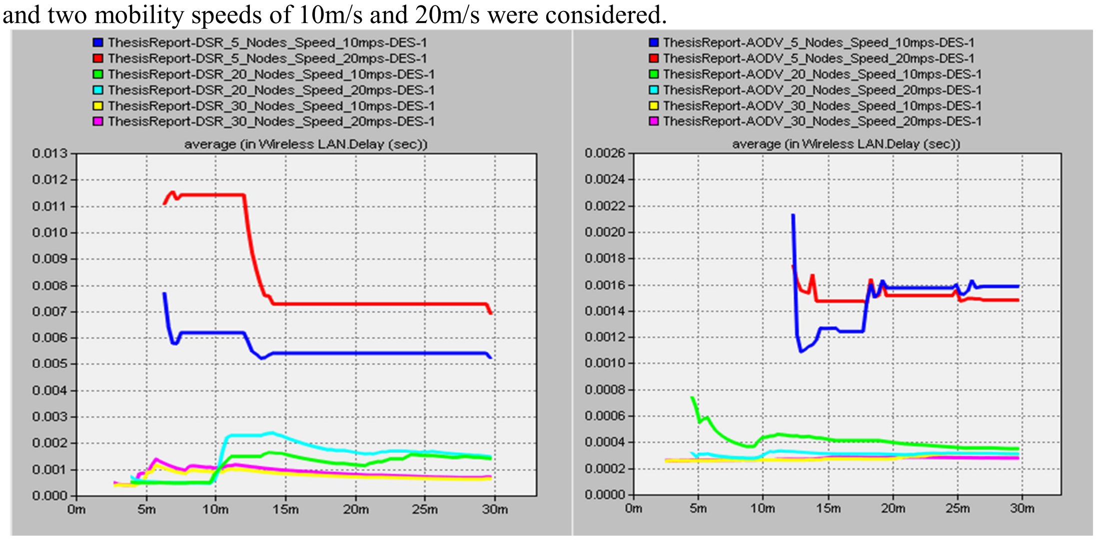
$d_{End-End}$= End-to- end delay
$T_{receive}$ = Receive time
T_{sent} = sent time
d_{trans} = Transmission delay
d_{prop} = Propagation delay
d_{proc} = Processing delay
d_{queue} = Queuing delay
d_{RDD} = Route Discovery Delay
d_{rt} = Retransmission delay

5. Results and Discussions

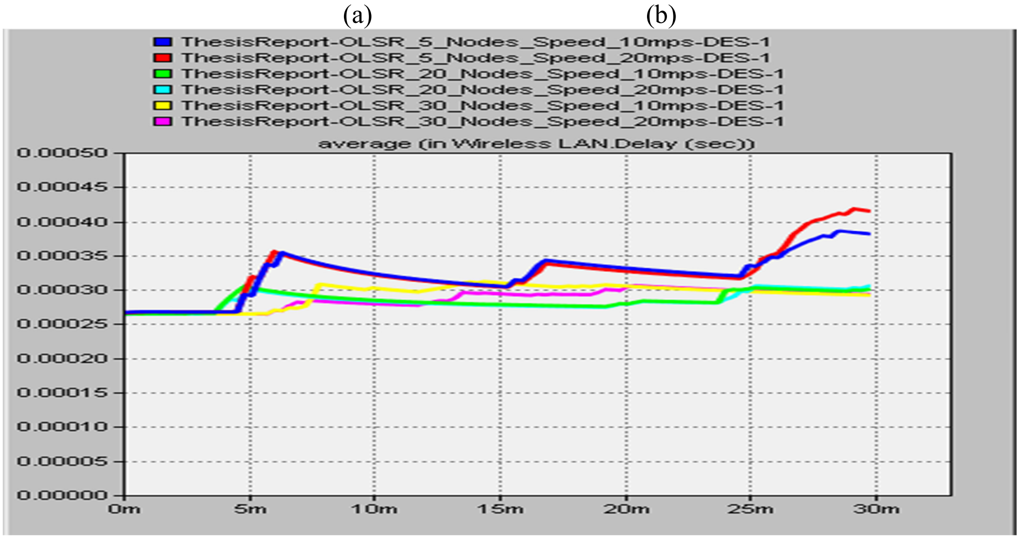
5.1 Analysis of the effect of Network size and Mobility scalability on the performance behaviors of the protocols

Case1: Delay

The graphs in Figure 3 (a), (b), and (c) depict the effect of network scalability and mobility on the delay performance behaviors of DSR, AODV and OLSR respectively. Three network size with 5, 20, and 30 nodes each and two mobility speeds of 10m/s and 20m/s were considered.



(a) (b)



(c)

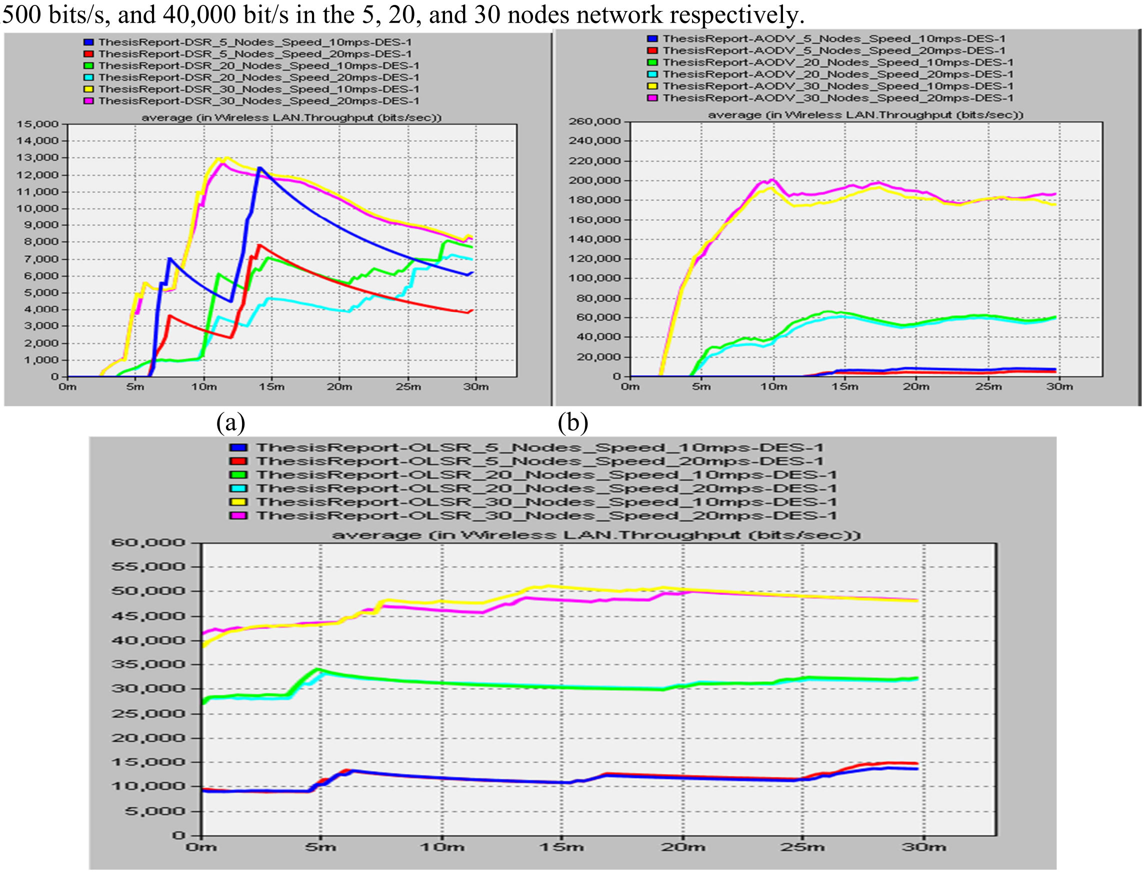
Figure 3. Effect of Network size and mobility scalability on the delay of (a) DSR, (b) AODV, and (c) OLSR

As it is evident from the graphs, the delay was observed to be higher in the 5 nodes network in all the three protocols regardless of the mobility speeds. When the network size is increased to 20 and then to 30, the delay decreases. This indicates that when the network size increases, there will be more neighboring nodes and possible redundant links that reduce frequent link breaks and hence more stable links. When there are more stable links or routes, the delay becomes less and more consistent. The effect of the network size variation is higher in DSR and AODV than in OLSR. There are also a lot of inconsistencies in DSR and AODV and higher delay compared to OLSR. As DSR and AODV are reactive routing protocols, there will be inconsistencies due to link breaks and route discovery processes whereas in OLSR, a proactive routing protocol, the routes are already available in the routing table which help it to have relatively less inconsistencies and delays. In OLSR, at the beginning of the simulation, there are no variations and inconsistencies on the delay. This is because that since OLSR is a proactive routing protocol where routes are always ready through the periodic transmission of route update tables, there will not be a delay associated with a route discovery process.

The effect of mobility speed is also observed to be higher in the reactive protocols (DSR and AODV) and when the network size is small (5 nodes). As the mobility speed increases, the delay increases. But when the network size is increased to 20 and 30 nodes, the delay becomes smaller. In general, according to the mobility speeds considered, the mobility speed scaling has not significant effect on delay performance when the network size gets larger. Both in the network size and mobility scaling, OLSR outperforms DSR and AODV in terms of delay followed by AODV while DSR performs the least.

Case 2: Throughput

The graphs in figure 4 (a), (b), and (c) indicate the impacts of network size and mobility scaling on the throughput performance characteristics of AODV, DSR, and OLSR respectively. As it is seen in the graphs, there is a general increment on the throughput performance of the three protocols with increasing network size regardless of the mobility speed variations. Relatively more inconsistencies are observed in the throughput performances of DSR when the network sizes are 5 and 20 nodes. This indicates that the impact of mobility scalability is higher when the network size is relatively small. The throughput of DSR and AODV remains zero for some time in the beginning of the simulation time. This is due to the time delay associated with the route discovery process from the source to the destination. Since OLSR is a proactive protocol, routes are already available prior to the actual packet transmission and there is an immediate packet transmission. As it is shown in graphs in figure 4 (c), the throughputs of OLSR in the beginning of the simulation are approximately 10,000 bit/s, 27,500 bits/s, and 40,000 bit/s in the 5, 20, and 30 nodes network respectively.



(a) (b)

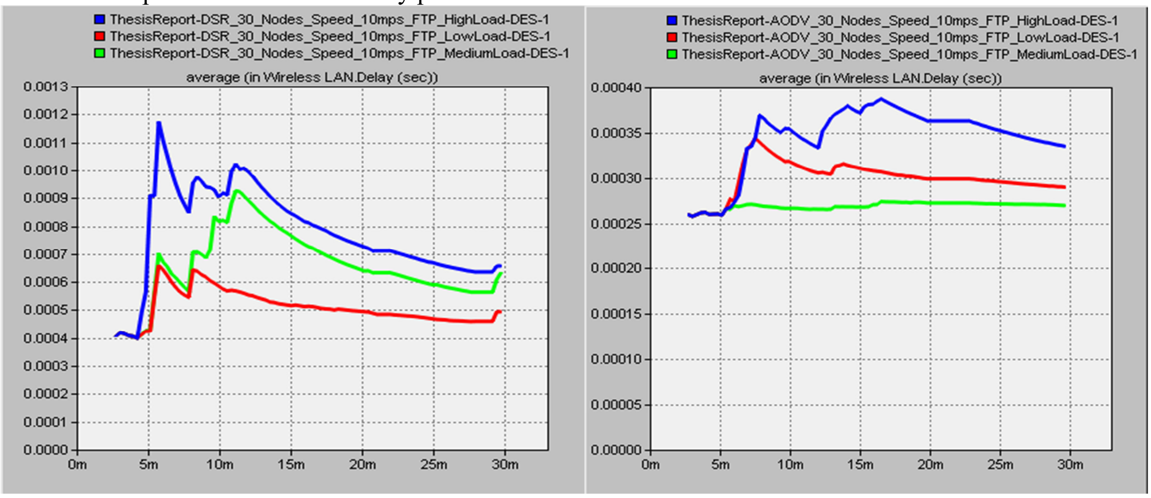
(c)

Figure 4. Effect of Network size and mobility scalability on the throughput of (a) DSR, (b) AODV, and (c) OLSR

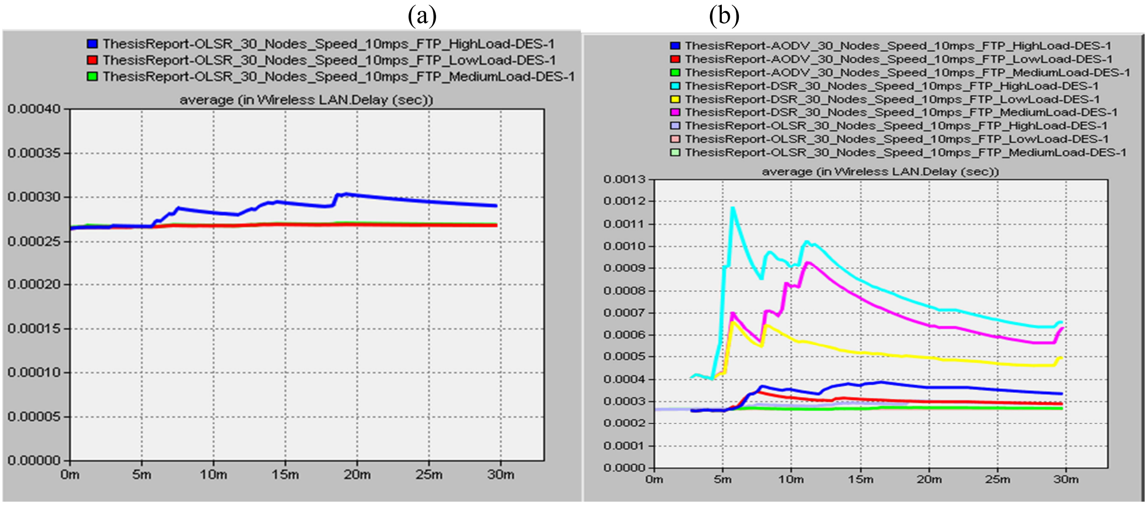
5.2 Analysis of the effect of FTP traffic load scaling on the performance behaviors of the protocols

Case 1: Delay

The graphs in figure 5 (a) to (d) depict the effect of FTP traffic scalability on the delay performance characteristics of DSR, AODV and OLSR. As it is indicated in the graphs, the delay in all the protocols was observed to be highest in the high traffic load. There is a general increment in delay with increasing in FTP traffic load except in AODV where delay performance was observed to be best in the medium FTP traffic load.



(a) (b)



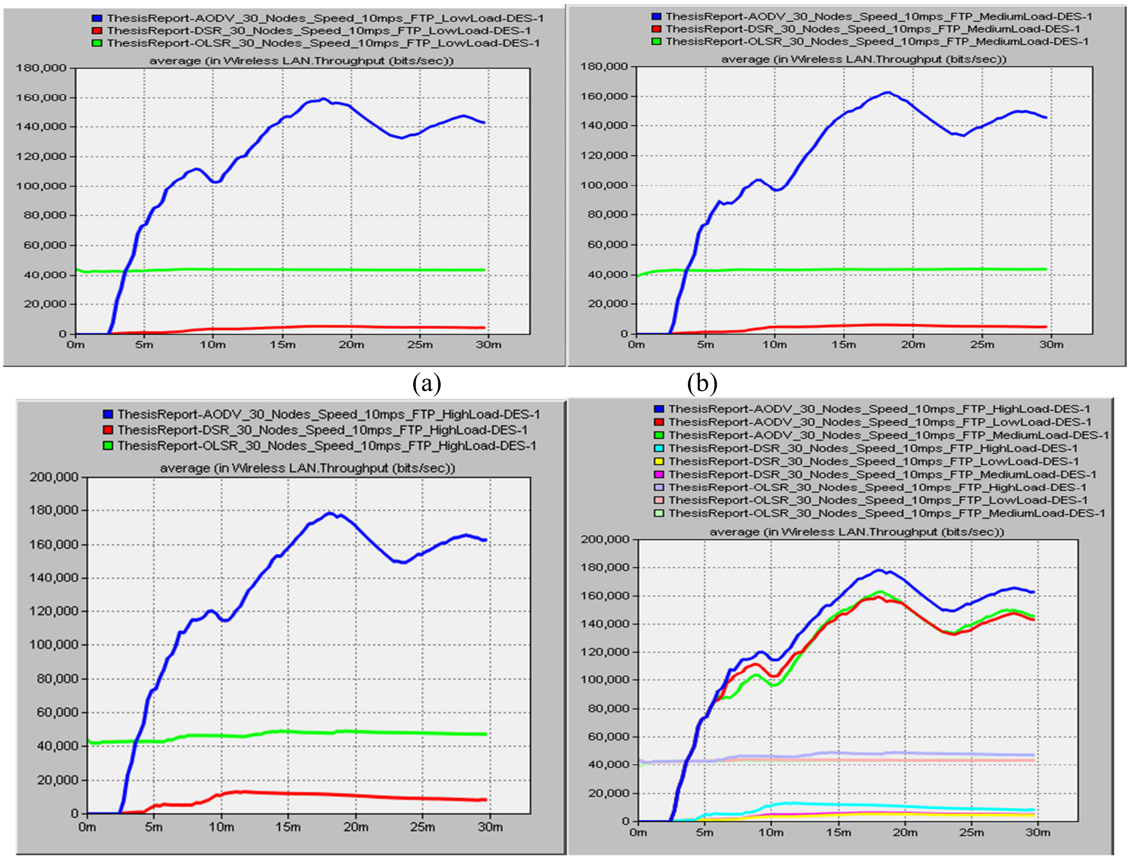
(c) (d)

Figure 5. Effect of FTP traffic scalability on the delay performance of (a) DSR, (b) AODV, (c) OLSR (d) DSR, AODV and OLSR

OLSR performs equally well in the low and medium FTP traffic loads. Unlike AODV and DSR which have higher and inconsistent delay at the beginning of the simulation time (up to 5 minutes of the simulation), the delay in OLSR remains low and consistent up to 5 minutes of the simulation. This is due to the proactive nature of OLSR where routes are already available prior to the actual data transmission. Figure 5 (d) indicates the delay performance comparison of the three protocols with scalable FTP traffic load. DSR has the highest delay in all the traffic load levels and hence poor performance. AODV has the second highest delay while OLSR has the least delay and hence the best performance.

Case 2: Throughput

The graphs in Figure 6 (a) to (d) depict the effect of FTP traffic scaling on the throughput performance characteristic of DSR, AODV, and OLSR protocols.



(c) (d)

Figure 6. Effect of FTP traffic scalability on the delay performance of DSR, AODV, OLSR and DSR (a) low FTP load, (b) medium FTP load, (c) high FTP load, (d) low, medium and high FTP traffic loads.

In all the protocols there is an overall increment in throughput when the FTP traffic load is increased from low load to high load. The throughput of the reactive protocols (AODV and DSR) remains zero up to 3 minutes of the simulation time while that of OLSR is around 40,000 bits/s. The zero throughputs at the beginning of the reactive protocols are because there is no actual data transmission before a route is discovered. In the case of OLSR, a proactive protocol, there is a pre-established route and data packets can be immediately sent.

6. Conclusions and recommendations

In this paper, the scalability analysis and performance evaluations of MANET routing protocols was carried out under scalable network size, mobility and FTP traffic loads which are the main control variables on which the routing protocols are optimized and performance of MANET protocols are highly affected. OPNET Modeler 14.5 software was used as a modeling and simulation tool. Scalability analysis was performed on DSR, AODV, and OLSR protocols based on three network sizes with 5, 20, and 30 nodes each, two mobility speeds of 10m/s and 20m/s each and three FTP traffic loads of 1,000 bytes, 5,000 bytes, and 50,000 bytes each. Average end-to-end delay and throughput were used as performance metrics. It was observed, from the simulation results, that the delay decreases as the network size increases in all the protocols considered and hence a better performance. The delay was also observed to be higher in the reactive protocols (DSR and AODV) than the proactive protocol (OLSR). The throughput also increases as the network size increases. According to the mobility speeds considered, there is also a slight increment in delay as the mobility speed increases in the small size networks. But when the network size increases, mobility has not any profound effect on both the delay and throughput performances of the protocols

With respect to the FTP traffic load variation, OLSR outperforms DSR and AODV in terms of delay whereas AODV outperforms OLSR and DSR in terms of throughput. DSR has the least performance in terms of both delay and throughput in all the traffic load levels. But there is a general throughput performance increment while delay performance reduces with traffic load increment in all the protocols. The sensitivity response to the traffic load variation of DSR was observed to be higher than the other two protocols in terms of both the performance metrics considered. In summary, it can be concluded from this research that in all the scenarios considered the proactive protocols particularly OLSR has the best performance in terms of delay and therefore it is the best choice in applications where delay is the main issue of concern, for example, in real-time applications. AODV which is reactive protocol on the other hand has the best overall throughput performance in almost all the situations considered in this research. It is therefore desirable in situations where throughput is the main issue of concern.

The scenarios considered in this research are not exhaustive. Therefore, other researchers can do further researches by taking other variables such as different traffic types and load levels and expanding scenarios considered in this research. Optimizations and performance enhancements of the protocols using intelligent optimization techniques such as neural networks and genetic algorithms can also be done in future works.

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