A Study of MANET Routing Protocols: Joint Node Density, Packet Length and Mobility

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Abstract— **The dynamic topology of a mobile ad hoc network (MANET) poses a real challenge in the design of a MANET routing protocol. Over the last 10 years, a variety of routing protocols have been developed and their performance simulations are made by network researchers. Most of the previous research on MANET routing protocols have focused on simulation study by varying network parameters, such as network size (node density), pause times, or node mobility independently. This paper considers the problem from a different perspective, using a simulation model the combined effect of node density and packet length; node density and mobility on the performance of a typical 802.11 MANET is investigated. This is a common and realistic scenario in MANETs where nodes move around, join and leave the network at any time. Based on the QoS (end-to-end delay, throughput), routing load and packet retransmissions, this paper systematically analyzes the performance of four diverse MANET routing protocols with the different simulation model and configurations, and drew more complete conclusions.**

Keywords: Mobile ad hoc networks, node density, routing protocols

I. INTRODUCTION

A mobile ad hoc network (MANET) is a collection of wireless mobile nodes that are communicating with each other using multi-hop wireless links without a centralized network infrastructure. Such networks are being deployed for many diverse applications, such as military network environments in the battle fields, disaster operations, search and rescue operations, conference rooms [1], and also in commercial applications such as vehicle ad hoc networks used in taxi service operation [2].

Because the nodes in a MANET are mobile, the physical network topology changes frequently and unpredictably. In MANETs, there is no stationary infrastructure such as access points (APs), therefore each node has to act as router for forwarding packets to other nodes.

Over the last 10 years, various MANET routing protocols have been developed by network researchers and designers primarily to improve the MANET performance with respect to establishing correct and efficient routes between a pair of nodes for packet delivery. Examples of popular MANET routing protocols are: Optimized Link State Routing (OLSR) [3, 4]. Ad Hoc On-Demand Distance Vector (AODV) [1, 5], Dynamic Source Routing (DSR) [6, 7], and Temporally Ordered Routing Algorithm (TORA) [8, 9].

OLSR is a proactive (table-driven) routing protocol, finds routing paths in advance for all source and destination pairs and periodically exchange topology information to maintain them. AODV, DSR, and TORA are reactive routing protocols, share the on-demand behaviors and find the route only when packets to be transmitted. However, the routing mechanisms for these reactive protocols are quite different. For example, AODV uses table-driven approach and destination sequence numbers. DSR uses a source initiated routing, whereas TORA uses a link reversal routing mechanism. More details about OLSR can be found in networking literature [7, 10], and AODV, DSR and TORA in [11, 12].

Performance of a MANET routing protocol depends on various factors, including the complex interplay of protocol mechanisms and their specific settings with node density, mobility, packet length (i.e. traffic intensity) and the behavior of wireless nodes used. A good understanding of the joint effect of node density, packet length and mobility on the performance of a typical IEEE 802.11 ("802.11") MANET is required for an efficient design and deployment of such systems. This paper investigates the combined effect of node density and packet length; node density and mobility on the performance of four different MANET routing protocols.

In this paper we address the following research question: *What impact do different routing protocols* (OLSR, AODV, DSR, and TORA) *have on a typical 802.11 MANET* for varying *node density and packet length; node density and mobility concurrently?*

To answer the question posed we carry out a systematic performance analysis (by simulation) for four typical MANET routing protocols, which include one proactive routing protocol OSLR, and three on-demand routing protocols, AODV, DSR, and TORA. These routing protocols were selected based on their popularity, published results, and interesting characteristics and features.

The remainder of this paper is structured as follows. Section II reviews literature, representative of that MANET routing protocols. Section III describes simulation environment and parameters. The simulation results and comparative analysis of four routing protocols are presented in Section IV.

The system implication is discussed in Section V and Section VI concludes the paper.

II. LITERATURE REVIEW

To improve the performance of a typical MANET, various routing protocols have been proposed by many network researchers. For brevity only a selected set of literature that is indicative of the range of approaches used for improving and analyzing MANET routing performance is reported in this section.

Sjaugi et al. [13] proposed a route maintenance mechanism for DSR called DISTANCE. The key idea is to introduce a special node called "bridge node" into the source list for preventing link failures. Each node updates its location by piggybacking into packet header. By preventing link failure, the system improves packet sending ratios and delays.

Taing et al. [6] proposed an improved DSR called Modified DSR (MDSR). MDSR provides better delays and number of hop paths from source to destination than DSR. The idea is to select a shortest path for delay-sensitive traffic using larger power level. For delay insensitive traffic, MDSR uses smaller power level.

Lu et al. [14] developed a MANET routing protocol called Congestion Aware Distance Vector (CADV) to improve network performance in terms of packet delivery and routing load. CADV integrates congestion avoidance strategy into a proactive routing protocol such as Destination Sequence Distance Vector (DSDV).

Wei et al. [15] proposed a routing protocol called Power Control AODV (PC-AODV) to improve network throughput and power consumption. The idea is to establish a route with an appropriate data-rate link within the transmission range and to adjust the transmit power level.

Safa et al. [16] proposed a routing protocol called Heterogeneous AODV (HAODV), optimizes existing AODV to support routing in heterogeneous networks (e.g. Wi-Fi and Bluetooth nodes). HAODV determines an optimum route not only based on path with the lowest hop-count but also with the low traffic and high stability.

Bai et al. [17] developed a routing protocol called DOA (DSR over AODV), focusing on route maintenance. DOA implements two levels of route repair: intra-segment and inter-segment. If a route fails, an intra-segment fixes it by using alternative routes within one segment.

Khamforoosh et al. [18] proposed another class of AODV called Centre base Distance Multi-path AODV (CDM-AODV). The idea is to choose two paths from the centre of the network. The reason being is that there is a reverse relationship between the distances of the node to the centre of network. When request packets are sent, replay packets have the information about the centre of network and distance between nodes.

In addition to the above proposals, earlier works on MANETs focused on routing performance comparison by extensive simulations. For example, Das *et al.* [19, 20] evaluated MANET routing protocols by simulation with varying nodes and pause times. Biao [21] examined the performance of DSDV, AODV, DSR and TORA by extensive simulations with increasing the number of nodes in MANETs.

The MANET routing approaches reviewed in this section are grouped into three main categories shown in Table I.

TABLE I. CATEGORIES OF ROUTING APPROACHES REVIEWED

Approaches	Example of routing protocols
Exchanging location information by piggybacking.	DISTANCE [13].
Selecting shortest path using power level, adjusting transmit power, and route optimization.	MDSR [6], PC-AODV [15], HAODV [16], DOA [22], CDM-AODV [18].
Implementing a congestion avoidance strategy in DSDV.	CADV [14].

III. SIMULATION ENVIRONMENT AND PARAMETERS

A. Modeling the network and simulation parameters

We use OPNET Modeler 15.0 [23] to analyze the performance of OLSR, AODV, DSR and TORA. In the simulations we consider three network scenarios: (1) a small network with $N \leq 10$ nodes; (2) a medium sized network with $10 > N \leq 50$ nodes; and (3) a denser network with $50 > N \leq 100$ nodes. The mobile nodes are placed randomly within a 2000 m × 2000 m area. Radio propagation range for each node is 250 m and channel capacity is 11 Mbps. Each node moves in this area according to the random waypoint mobility model, with a speed of 20 to 30 m/s and no pause time, which means that nodes are always moving in the entire simulation period.

Tables II to VI list the parameter values used in the simulations. Each simulation run lasted for 900 seconds simulated time in which the first 10 seconds was the transient period. The observations collected during the transient period are not included in the final simulation results.

The four performance metrics, such as end-to-end packet delay, throughput, routing load and retransmission were used for performance study of OLSR, AODV, DSR, and TORA. The end-to-end packet delay is defined as the average time (measured in seconds) required in sending a packet from source to a destination. This includes buffering during route discovery, queuing at the interface queue, retransmission at the medium access control (MAC), propagation and packet transmission time. The throughput (measured in bps) is the average rate of successful packet delivery. The routing load is the number of routing control packets transmitted for each data packet delivered at the destination. The retransmission is defined as the resending attempts of packets which have been lost or damaged due to link failure.

TABLE II. GENERAL PARAMETERS USED IN SIMULATION.

Parameter	Value
Simulation area	2000 m × 2000 m
Node density	10, 50, 100 nodes
Packet length	1,000, 5,000 and 50,000 bytes
Node mobility	5, 20, 30 (m/s)
Mobility model	Random waypoint with 0 pause time
Wireless cards	802.11b (11 Mbps)
RTS/CTS	OFF
Propagation range	250 m
Transmitter power	0.005 Watt
Traffic/application	FTP
Transport protocol	TCP
Simulation duration	900 seconds

TABLE III.   OLSR PARAMETERS USED IN SIMULATION.

Parameter	Value
Willingness	default
Hello interval	2 s
TC Interval	5 s
Neighbour hold time	6 s
Topology hold time	15 s

TABLE IV.   AODV PARAMETERS USED IN SIMULATION.

Parameter	Value
Route request retries (route discovery)	5
Route request rate	10 (packets/s)
HELLO interval (uniform)	Between 1 and 1.1 s
Route error rate	10 packets/s
Node traversal time	0.04 sec
Timeout buffer	2
Local repair	enabled

TABLE V.   DSR PARAMETERS USED IN SIMULATION.

Parameter	Value
Request table size (nodes) (route discovery)	64
Max Request retransmission (route discovery)	16
Max request period (sec) route discovery	10
Max buffer size for route maintenance	50 packets
Maintenance hold time	0.25 s
Max maintenance retransmission	2
Maintenance acknowledgement timer	0.5 s
Route replies using cached routes	enabled
Packet salving	enabled

TABLE VI.   TORA PARAMETERS USED IN SIMULATION.

Parameter	Value
Mode of operation	On-demand
OPT transmission interval	300 sec
IP Packet discard timeout	10 sec
Beacon period	20 sec
Max Beacon timer	60 sec
Max tries (number of attempts)	3

B. Model Validation

A credible network simulator may produce invalid results if the simulation parameters are not correctly configured. Therefore, simulation model validation becomes an important part of any simulation study. The OPNET simulation model presented in this paper was verified in several ways. First, the detailed status information including mobility traces was observed throughout the simulation to verify the model. Second, we checked the level of network fragmentation for 10 nodes with 250 m transmission range distributed over a square of 2000 m × 2000 m. In addition, OPNET results were compared with the results obtained from ns-2 [24] and a good match between two sets of results further validated the simulation models.

IV.   RESULTS AND COMPARATIVE ANALYSIS

To investigate the combined effect of node density and packet length, and node density and mobility for OLSR, AODV, DSR, and TORA on an 802.11 MANET (RTS/CTS OFF), we consider three node density scenarios: N = 10, 50,

and 100 nodes; and two node mobility scenarios: 20 and 30 m/s. The data packet length of 1,000, 5,000, and 50,000 bytes were used in the simulations. All simulation results report the network steady state and were obtained with a relative statistical error ≤ 1%, at 99% confidence level.

A. Joint effect of node density and packet length

The combined effect of node density (N = 10, 50, and 100 nodes) and packet length (5,000, 50,000 bytes) on mean packet delay for OLSR, AODV, DSR, and TORA is illustrated in Fig. 1. The mean packet delay is higher for 50,000–byte packets than for 5,000–byte packets for DSR and AODV at both N = 50 and 100 nodes, but not for OLSR and TORA. TORA achieves slightly lower packet delays under high traffic loads (50,000–byte packets) at N = 100 nodes. Overall, OLSR achieved the lowest packet delays than the other three routing protocols examined at N = 100 nodes.
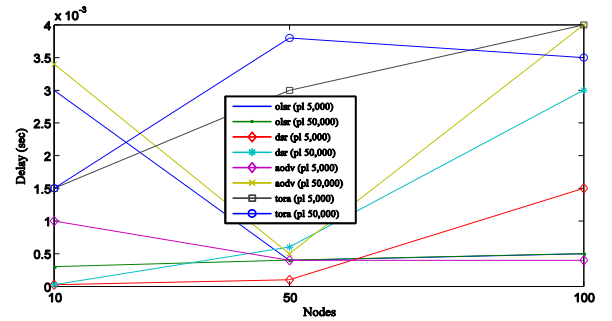

Figure 1.   Packet delay versus node density for packet lengths of 5,000 and 50, 000 bytes (node mobility: 5 m/s).

The combined effect of node density and packet length on network throughput for OLSR, AODV, DSR, and TORA is demonstrated in Fig. 2. The network throughput is higher for 50,000–byte packets than for 5,000–byte packets for DSR and TORA at N = 100 nodes, but not for OLSR and AODV. TORA achieved the highest throughput than the other three routing protocols at N = 100 nodes. Overall, the network throughput increases with the number of active nodes for all four routing protocols studied.
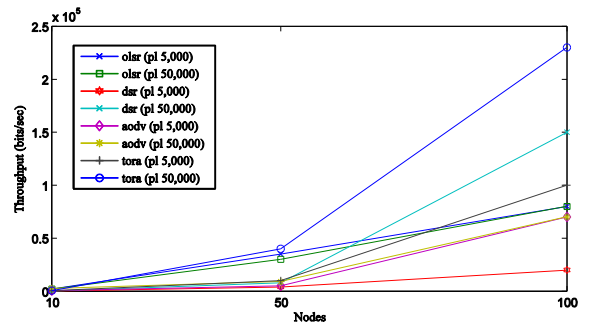

Figure 2.   Throughput versus node density for packet lengths of 5,000 and 50, 000 bytes (node mobility: 5 m/s).

The combined effect of node density and packet length on routing load for OLSR, AODV, DSR, and TORA is illustrated in Fig. 3. The routing load characteristics for all four routing protocols are similar to the network throughput performance discussed earlier (Fig. 2). OLSR maintains a low and consistent routing load at N = 100 nodes.
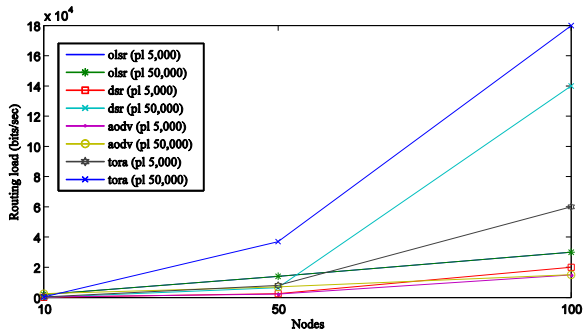

Figure 3. Routing load versus node density for packet lengths of 5,000 and 50, 000 bytes (node mobility: 5 m/s).

The combined effect of node density and packet length on packet retransmission attempts for OLSR, AODV, DSR, and TORA is illustrated in Fig. 4. The packet retransmission is higher for 50,000–byte packets than for 5,000–byte packets for DSR and TORA at N = 100 nodes, but not for OLSR and AODV. TORA has higher retransmission attempts than DSR for 50,000–byte packets at N = 100 nodes. Another observation is that TORA has slightly lower packet retransmissions under high traffic loads at N = 50 nodes.
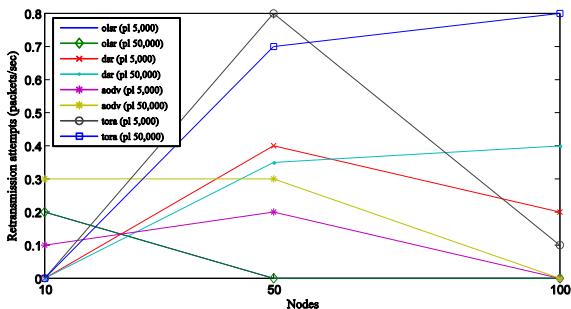

Figure 4. Retransmission versus node density for packet lengths of 5,000 and 50, 000 bytes (node mobility: 5 m/s).

B. Joint effect of node density and mobility

The combined effect of node density (N = 10, 50, and 100 nodes) and node mobility (20 and 30 m/s) on mean packet delay for OLSR, AODV, DSR, and TORA is illustrated in Fig. 5. The packet delay increases when the number of nodes increases from 50 to 100 for all routing protocols examined.

Of the four routing protocols, TORA has high packet delays especially for a large network with high mobility. OLSR achieves shorter delays because it is a kind of proactive routing protocol where each node maintains a routing table with possible destinations and the number of hops to each

destination. When a packet arrives at a node; it is either forwarded immediately or dropped off.

AODV uses the source-initiated approach in the route discovery process, but for route maintenance it uses table-driven mechanism. AODV performs better (in terms of packet delays) than DSR when node mobility is high. Our findings are in close agreement with the work of other researchers [20].
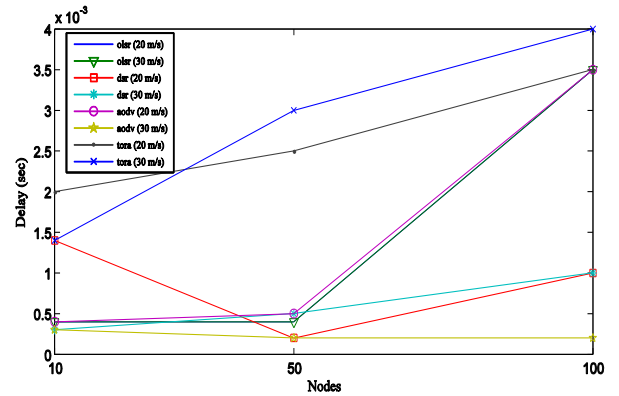

Figure 5. Packet delay versus node density for mobility 20 and 30 m/s.

The combined effect of node density and node mobility on network throughput for OLSR, AODV, DSR, and TORA is illustrated in Fig. 6. The network throughput increases quickly for TORA, OLSR, and AODV with increased node density and mobility.

DSR on the other hand has difficulties in finding routes when both node density and mobility increase, throughput drops slightly for the node density fewer than 50 nodes. However, OLSR achieves slightly better throughput than the other reactive protocols (TORA, AODV, and DSR) for a small to medium sized network. This is because OLSR senses neighboring nodes to establish a connection and finds a valid route. AODV reacted in the same way as TORA; however the high node mobility reduces network throughputs. TORA offers better throughput for a large network with high mobility than AODV and DSR.
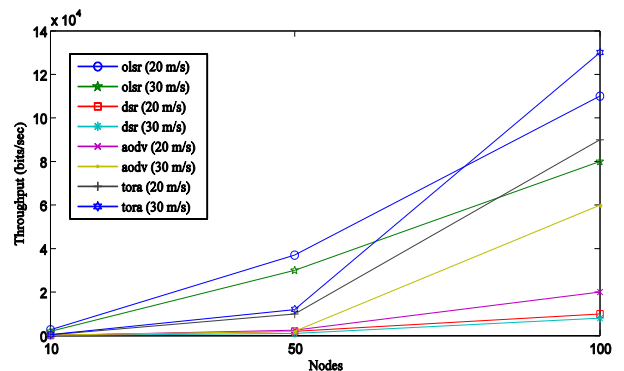

Figure 6. Throughput versus node density for mobility 20 and 30 m/s.

The combined effect of node density and node mobility on routing load for OLSR, AODV, DSR, and TORA is illustrated in Fig. 7. The routing load of a protocol can influence node's

efficiency of battery energy and scalability. The four routing protocols have different routing overhead. For example, OLSR has higher routing load than AODV, DSR, and TORA for node density fewer than 50 nodes. However, in the case of a large network (around 100 nodes), OLSR has slightly smaller routing load than TORA. DSR achieved the lightest routing load than other three routing protocols.
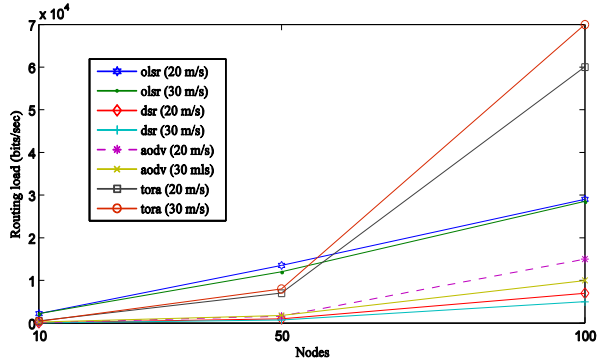

Figure 7.   Routing load versus node density for mobility 20 and 30 m/s.

The combined effect of node density and mobility on packet retransmission attempts for OLSR, AODV, DSR, and TORA is demonstrated in Fig. 8. Of the four routing protocols, OLSR has the least packet retransmission attempts, whereas TORA has the highest retransmission rate for all network scenarios. However, AODV's packet retransmission rate is slightly lower than DSR especially for a large network with more than 50 nodes and high mobility.
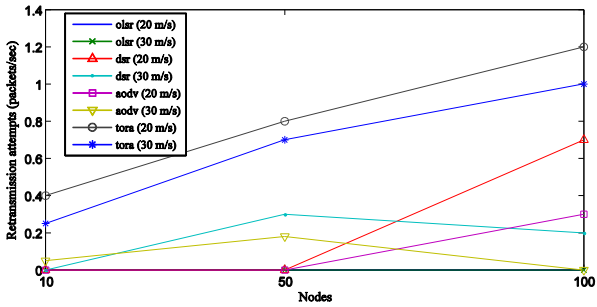

Figure 8.   Retransmission versus node density for mobility 20 and 30 m/s.

V.   DISCUSSION AND PRACTICAL IMPLICATIONS

The results presented in Section IV provide some insight into the combined effect of node density, packet length and mobility for OSLR, AODV, DSR, and TORA on the performance of a typical 802.11 MANET. Empirical results show that the combined node density and mobility has a significant effect on network throughput and packet delays for all four routing protocols studied. However, the effect of packet length has minor effects on network throughput and packet delays specifically for selected routing protocols (Figs. 1 and 2).

For a network of up to 10 active nodes with low mobility, all four routing protocols performed well to a certain degree.

However, as the number of nodes increases to 100, there is a significant variation in throughputs obtained by each of the four routing protocols. For example, both OLSR and TORA performed well (in terms of throughput) especially for a network with 50 to 100 nodes. TORA reacted favorably to node mobility; achieves better throughput with high mobility. AODV reacted in the same way as TORA; however, the high node mobility reduces its throughput. TORA's packet delay deteriorates with high node mobility.

From a practical networking point of view, a question may arise about the right routing protocol to use for a particular network scenario.

Table VII lists the six network scenarios and the corresponding MANET routing protocol to use for best system performance. For instance, for a denser network with N = 100 nodes moving at high speed (30 m/s) under high traffic loads, TORA is the best routing protocol to use. For another scenario where a small network with fewer than 10 nodes moving at medium speed (20 m/s) under low loads, OLSR is the best routing protocol to use.

TABLE VII.   NETWORK SCENARIOS AND THE BEST PROTOCOL TO USE.

Scenario	Best protocol to use
1. Small network with low traffic and medium mobility	OSLR, TORA
2. Small network with high traffic and high mobility	AODV, OLSR
3. Medium network with low traffic and medium mobility	TORA, OLSR
4. Medium network with high traffic and high mobility	
5. Large network with low traffic and medium mobility	
6. Large network with high traffic and high mobility	TORA, DSR
Network -> Small: 10 nodes; medium: 50 nodes; large: 100 nodes. Mobility -> medium: 20 m/s; high: 30 m/s Low traffic -> Packet length: 1000 bytes; High traffic-> Packet length: 50,0000 bytes.	

VI.   CONCLUSIONS

The combined effect of node density, packet length and mobility for four routing protocols (OLSR, AODV, DSR, and TORA) on an 802.11 MANET is investigated in this paper. We developed OPNET-based simulation models to study the performance of OLSR, AODV, DSR, and TORA for small, medium and large (dense) network scenarios with varying packet length and node mobility.

Simulation results obtained show that node density and mobility has a significant impact on underlying routing protocols. None of the protocols investigated can offer an optimum routing solution under various network scenarios. For example, OLSR and DSR work well in a small network (fewer than 10 nodes) with low mobility. For a medium-sized network (around 50 nodes) with node mobility, OLSR and AODV offer better performance. In a large network with 100 nodes, TORA and OLSR can offer better performance.

To provide an optimum MANET routing solution, we are currently implementing an efficient MANET routing protocol in OPNET Modeler 15.0 and a future paper will report the projected performance.

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