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Performance Evaluation of Important Ad Hoc Network Protocols

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A wireless ad hoc network is a collection of specific infrastructureless mobile nodes forming a temporary network without any centralized administration. A user can move anytime in an ad hoc scenario and, as a result, such a network needs to have routing protocols which can adopt dynamically changing topology. To accomplish this, a number of ad hoc routing protocols have been proposed and implemented, which include dynamic source routing (DSR), ad hoc on-demand distance vector (AODV) routing, and temporally ordered routing algorithm (TORA). Although considerable amount of simulation work has been done to measure the performance of these routing protocols, due to the constant changing nature of these protocols, a new performance evaluation is essential. Accordingly, in this paper, we analyze the performance differentials to compare the above-mentioned commonly used ad hoc network routing protocols. We also analyzed the performance over varying loads for each of these protocols using OPNET Modeler 10.5. Our findings show that for specific differentials, TORA shows better performance over the two on-demand protocols, that is, DSR and AODV. Our findings are expected to lead to further performance improvements of various ad hoc networks in the future.

1. INTRODUCTION

A collection of autonomous nodes or terminals that communicate with each other by forming a multihop radio network and maintaining connectivity in a decentralized manner is called an ad hoc network. There is no static infrastructure for the network, such as a server or a base station. The idea of such networking is to support robust and efficient operation in mobile wireless networks by incorporating routing functionality into mobile nodes.

Figure 1 shows an example of an ad hoc network, where there are numerous combinations of transmission areas for different nodes. From the source node to the destination node, there can be different paths of connection at a given point of time. But each node usually has a limited area of transmission as shown in Figure 1 by the oval circle around each node. A source can only transmit data to node B, but B can transmit data either to C or D. It is a challenging task to choose a really good route to establish the connection between a source and a destination so that they can roam around and transmit robust communication.

There are four major ad hoc routing protocols. At this time, OPNET has three built-in models for DSR, AODV, and TORA ad hoc routing protocols. The other major protocol is destination sequence distance vector (DSDV). All these protocols are constantly being improved by IETF [1]. As a result, a comprehensive performance evaluation is of ad hoc routing protocols essential. In this work, OPNET Modeler 10.5 version is used to simulate three ad hoc routing protocols, that is, DSR, AODV, and TORA. We evaluated all available metrics supported by OPNET for these protocols and then performed a comparative performance evaluation. Since these protocols have different characteristics, the comparison of all performance differentials is not always possible. However, the following system parameters are utilized for comparative study on the protocols:

(i) number of hops per route,
(ii) traffic received and sent,
(iii) route discovery time,
(iv) total route requests sent,
(v) total route replies sent,
(vi) control traffic received and sent,
(vii) data traffic received and sent,
(viii) retransmission attempts,
(ix) average power,
(x) throughput,
(xi) utilization.

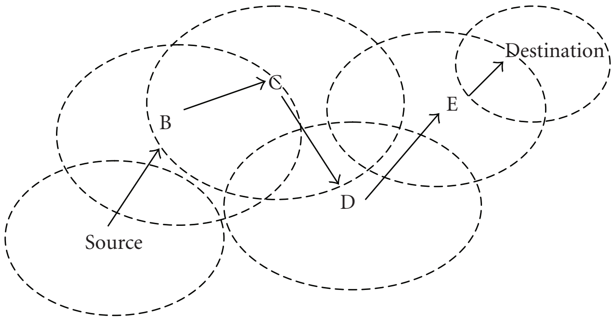

Figure 1: Ad hoc networking example.

To the best of our knowledge, no published work is available in the literature, which compares as many criteria as we have done in this research. Moreover, this work is the first major comprehensive performance evaluation of ad hoc routing protocols using OPNET Modeler 10.5. We also simulated these protocols under different loads (number of nodes in a network) and showed their corresponding performance differences.

The rest of the paper is organized as follows. In the following section, we briefly review the TORA, DSR, and AODV protocols. In Section 3, we present the performance metrics of our simulation. Section 4 discusses performance comparison of the protocols. Section 5 presents the result of simulation under various loads. We draw our conclusions in Section 6 followed by recommendations for future work in this regard.

2. AD HOC ROUTING PROTOCOLS

Among the various ad hoc routing protocols proposed in the literature [1, 2], TORA, DSR, and AODV appear to be the most promising. TORA [3, 4] is a distributed routing protocol for ad hoc networks, which uses a link reversal algorithm. TORA performs the routing portion of the protocol but depends for other functions on the internet MANET encapsulation protocol (IMEP) [5, 6]. A few important characteristics of TORA are listed below:

(i) it is an adaptive protocol, that is, it finds out routes when required,
(ii) it reacts minimally to topological changes and thus minimizes the communication overhead,
(iii) for any message, TORA ensures to provide more than one route to destination,
(iv) routes are not necessarily optimal,
(v) it uses a loop-free algorithm for routing,
(vi) it is a fast route finder algorithm,
(vii) it is more scalable.

TORA involves four major functions: creating, maintaining, erasing, and optimizing routes [7–9]. To create a route, it selects the height of each node in a way that leads to the creation of a directed sequence of links up to the destination. Since it is an ad hoc network, there will be considerable topological changes. Maintaining routes in reaction to such a change is a major task. Since every node must have a height, any node which does not have a height is considered as an erased node. By making the height as null, the routing protocol performs that job. Sometimes the routers are given new heights to improve the linking structure. This function is called the optimization of routes.

The foremost feature of the DSR protocol [1, 10, 11] is that it uses source routing. It is also an on-demand protocol that allows nodes to find out a route over a network dynamically. The interesting idea behind source routing is that all the packet headers of DSR contain a complete list of nodes through which they will pass to reach their destination. As a result, there is no route discovery mechanism of broadcasting packets in DSR. This reduces network bandwidth overhead. However, if there is a better route, the nodes update their route cache. DSR has two modes of operations: route discovery and route maintenance [9].

The AODV algorithm [12] is a confluence of both DSR and destination sequenced distance vector (DSDV) [13] protocols. It shares on-demand characteristics of DSR, and adds the hop-by-hop routing, sequence numbers, and periodic beacons from DSDV. It has the ability to quickly adapt to dynamic link conditions with low processing and memory overhead. AODV offers low network utilization and uses destination sequence number to ensure loop freedom. It is a reactive protocol implying that it requests a route when needed and it does not maintain routes for those nodes that do not actively participate in a communication. An important feature of AODV is that it uses a destination sequence number, which corresponds to a destination node that was requested by a routing sender node. The destination itself provides the number along with the route it has to take to reach from the request sender node up to the destination. If there are multiple routes from a request sender to a destination, the sender takes the route with a higher sequence number. This ensures that the ad hoc network protocol remains loop-free. AODV keeps the following information with each route table entry [12]:

(i) destination IP address (IP address for the destination node),
(ii) destination sequence number,
(iii) valid destination sequence number flag,
(iv) network interface,
(v) hop count, that is, number of hops required to reach the destination,
(vi) next hop (the next valid node that did not rebroadcast the RREQ message),
(vii) list of precursor,
(viii) lifetime, that is, expiration or deletion time of a route.

3. PERFORMANCE METRICS

We evaluated key performance metrics for three different applications using DSR, TORA, and AODV protocols, which includes wireless LAN, radio receiver, and radio transmitter. The effects of load variation on different protocols were also investigated. The parameters used for wireless LAN

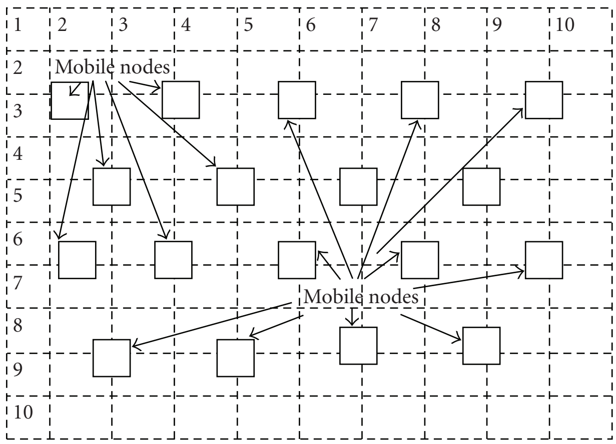

FIGURE 2: A setup model of the ad hoc network protocol simulation.

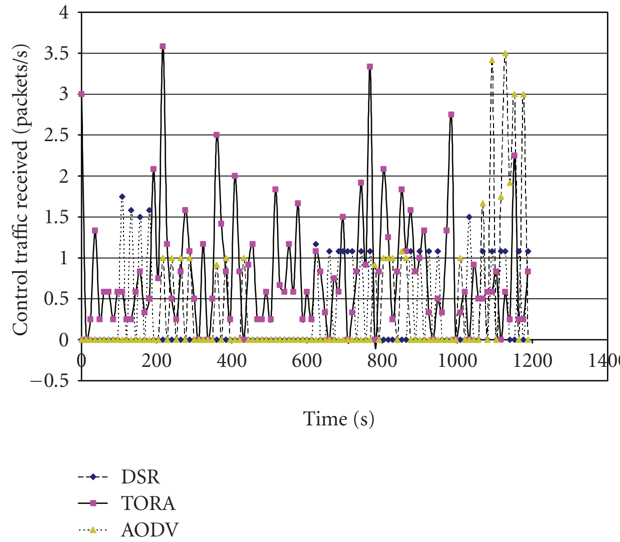

FIGURE 3: Control traffic received for different protocols in wireless LAN.

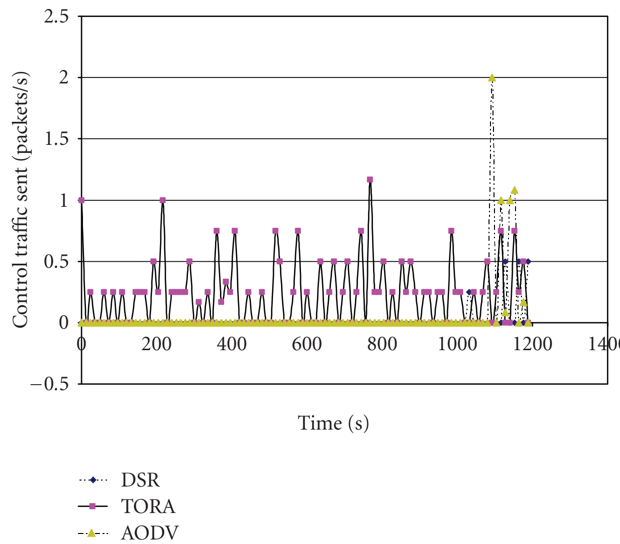

FIGURE 4: Control traffic sent for different protocols in wireless LAN.

application performance evaluation include: control traffic received and sent, data traffic received and sent, throughput, and retransmission attempts. We evaluated radio receiver and radio transmitter applications using the following parameters: utilization, throughput, and average power. We used the following parameters for evaluating the effect of load variation on different protocols: routing traffic received and sent, total traffic received and sent, number of hops, route discovery time, and ULP traffic received and sent.

4. PERFORMANCE COMPARISON OF THE PROTOCOLS

For performance evaluation of different protocols, the latest version of OPNET was used, which supports DSR, TORA, and AODV protocols. For all simulations, the same movement models were used, and the number of traffic sources was fixed at 40. Figure 2 shows a model of nodes used to simulate different ad hoc network protocols. A square of 10 meters is used to define the area of node's mobility. We used a mobility model of variable trajectory.

In the simulation, the following parameters are used:

(i) duration: 20 minutes,
(ii) speed: 128, 256, 512,
(iii) values per statistics: 100,
(iv) update interval: 100000,
(v) nodes: 40,
(vi) simulation kernel: based on "kernel-type" preference (development).

4.1. *Wireless LAN*

Figure 3 shows the control traffic received in packets/s for DSR, TORA, and AODV protocols for a wireless LAN application. Figure 2 shows that the TORA protocol performs better than the other two. Although AODV does not perform well at the beginning, later it does well. DSR's performance remains average during the entire evaluation time. Figure 4 shows the control traffic sent in packets/sec. It is obvious that TORA performs better than AODV and DSR. Although DSR and AODV have shown an average performance throughout the entire simulation, they show better performance compared to TORA at the end. TORA uses a fast router-finder algorithm, which is critical for TORA's better performance. Both DSR and AODV have to go through route creation using RREQ and RREP messages. Once the routes are created, DSR and AODV tend to do better than TORA. As a result, we observe from Figures 3 and 4 that, near the end of simulation time, both AODV and DSR show better performance than TORA.

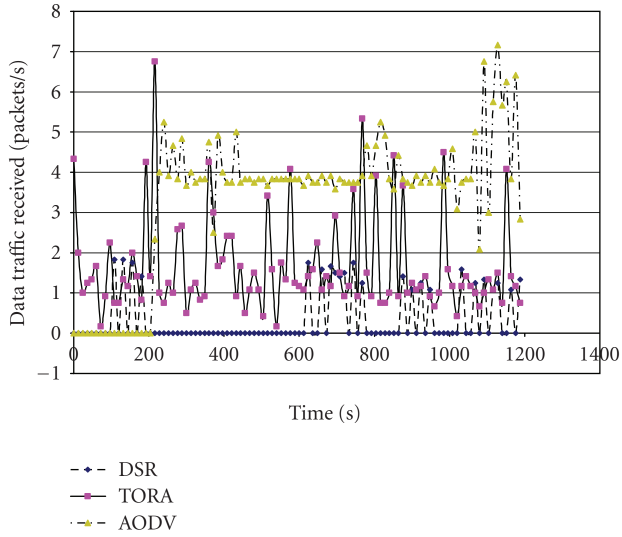

Figure 5: Data traffic received for different protocols in wireless LAN.

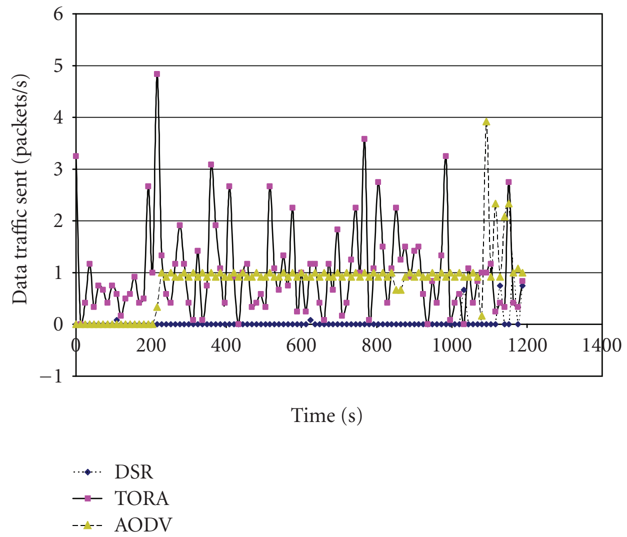

Figure 6: Data traffic sent for different protocols in wireless LAN.

Figures 5 and 6 show the data traffic received and data traffic sent in packets/sec, respectively, for DSR, AODV, and TORA protocols. From Figure 5, it is evident that, at the beginning of the simulation TORA appears to dominate over AODV and DSR, but at the end, AODV yields the best result. DSR shows poor performance and the traffic remains always at the lower level, whereas AODV performs well most of the time. In Figure 6, we observe that TORA performs well during most of the simulation time. AODV shows consistent performance and peaks at the end of the simulation. DSR does not show any positive traffic except for the last few seconds of the simulation.

Figure 7 shows the throughput in bits/sec for DSR, TORA, and AODV protocols, where AODV shows significantly better performance than the other two, and TORA performs slightly better than DSR. Figure 8 shows the retransmission attempts in packets/sec as a function of time for wireless LAN involving different protocols. It is evident from Figure 8 that TORA requires a lot of retransmission attempts before it can successfully transmit data due to the fact that only TORA uses UPD packet. When a node first gets a QRY message for a destination, if it does not have a route for the requested destination, it broadcasts a UPD message and increases the height of the node. In this way, it tries to transmit the UPD message until it gets the destination node. DSR and AODV have almost the same logic to find a route and show almost similar performance near the end of the simulation time.

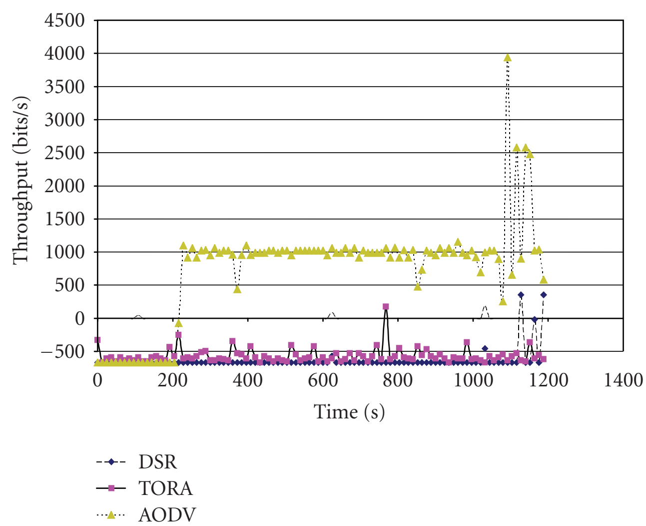

Figure 7: Throughput of different protocols in wireless LAN.

4.2. Radio receiver

Figure 9 shows the radio receiver utilization of DSR, TORA, and AODV protocols for channel bandwidth. From Figure 9, we observe a high network utilization (full usage of channel bandwidth) for AODV. This may be due to the storage of a large amount of information with each table entry. TORA shows consistent performance in the range of 0.25 (1/4th usage of channel bandwidth) due to the reason of route discovery algorithm. Since there is no mechanism of route discovery broadcasting packets in DSR, the network bandwidth utilization is reduced. At the beginning, DSR reaches 1 (full usage of channel bandwidth), then it remains at 0 (no usage) for a considerable amount of time. For the last half of simulation time, it shows a performance of about 0.75 (3/4th usage of channel bandwidth).

Figure 10 shows the throughput in packets/sec for different MANET protocols, which shows that for average number of packets received by the receiver, the TORA protocol shows good performance followed by AODV and DSR. Although AODV shows consistent performance, DSR shows inconsistency. Figure 11 shows the average power for radio receivers

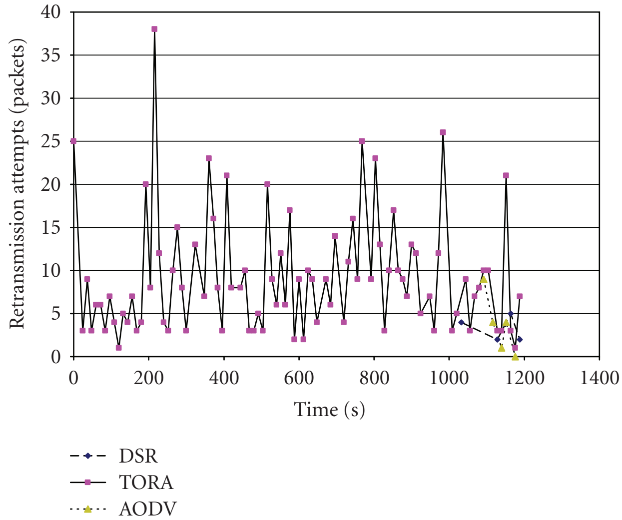

Figure 8: Retransmission attempts for different protocols in wireless LAN.

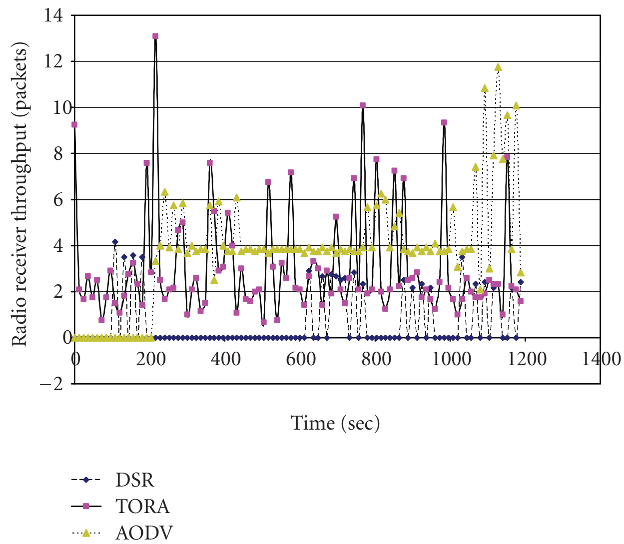

Figure 10: Radio receiver throughput for different protocols in wireless LAN.

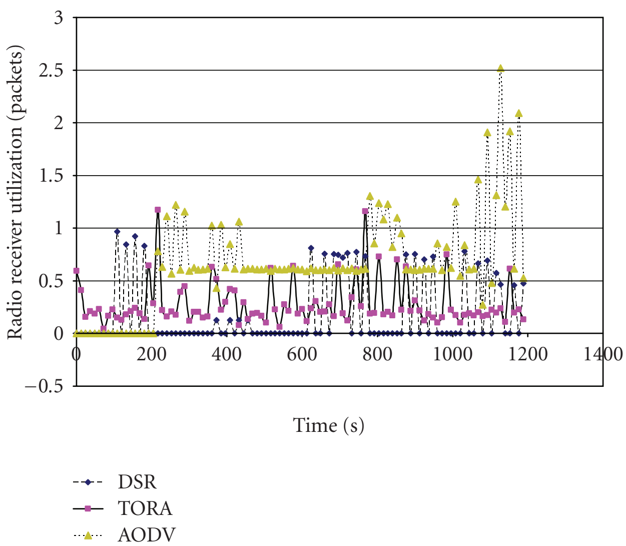

Figure 9: Radio receiver utilization for different protocols in wireless LAN.

using DSR, TORA, and AODV protocols. The average power of a packet arriving at a receiver channel is so low that it could not be shown in the graph. However, a snapshot of the OPNET screen is shown in Figure 11, where the y-axis represents the power (in joules) and the x-axis represents the simulation time (in minutes). It is evident that DSR shows better performance compared to TORA and AODV. DSR shows almost similar average power over the entire simulation time. However, for TORA and AODV, the average power increases after a considerable amount of time and then it remains almost constant.

4.3. Radio transmitter

Figure 12 shows the radio transmitter utilization for DSR, AODV, and TORA protocols. TORA uses a lot of packets to create, maintain, erase, and optimize routes for the radio transmitter link. As a result, TORA performs better than AODV and DSR for most of the simulation time except at the end when AODV outperforms TORA. AODV shows consistent performance after 200 simulated seconds. However, DSR shows a spike at the end of the simulation and remains at the zero level for most of the earlier portion of simulation time. The behavior of AODV and DSR are consistent with the fact that once routes are created, the utilization of radio channel remains high for node communication. For transmitter utilization, radio transmitter throughput also shows the same type of performance. Figure 13 displays the throughput for different protocols, where TORA shows a lot of spikes throughout the entire simulation time. However, TORA shows better throughput over DSR and AODV except at the end when AODV exceeds TORA. AODV shows consistent performance for most of the time and DSR remains at zero until the end of simulation time.

5. EFFECT OF LOAD VARIATION

To study the effect of load (number of nodes in a network) variation, the following number of nodes were used to evaluate the performance of the different protocols: 20, 40, and 80. For some cases, we used 40, 80, and 100 nodes to achieve better statistical results for a few characteristics. Figures 14 and 15 show the routing traffic received and routing traffic sent in packets/sec, respectively, for different loads using the DSR algorithm. Figures 14 and 15 show that the whole network is very sensitive towards load variation. However, in case of 20 and 40 nodes, the difference is minor. Figures 16 and 17 show

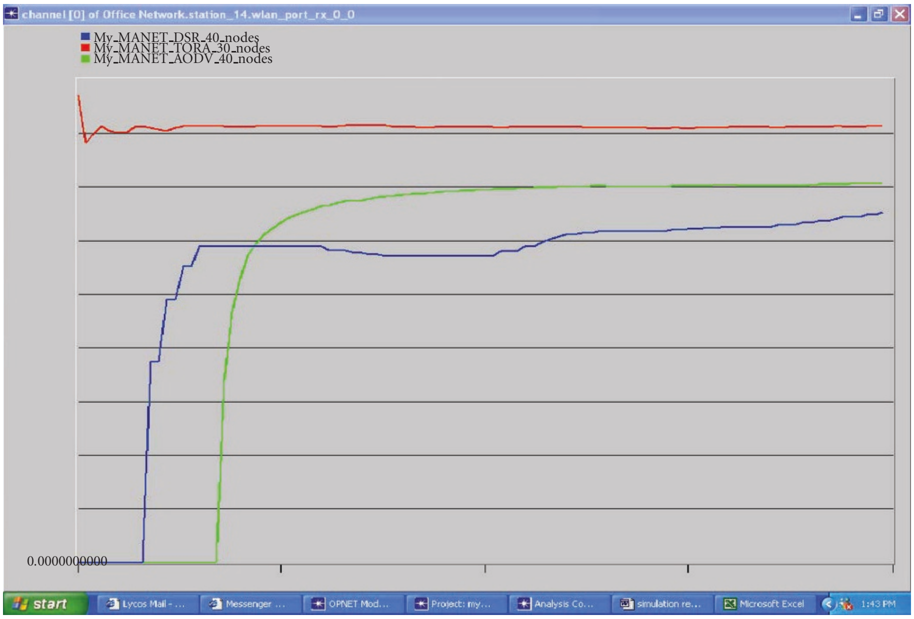

FIGURE 11: Average power for different protocols in wireless LAN.

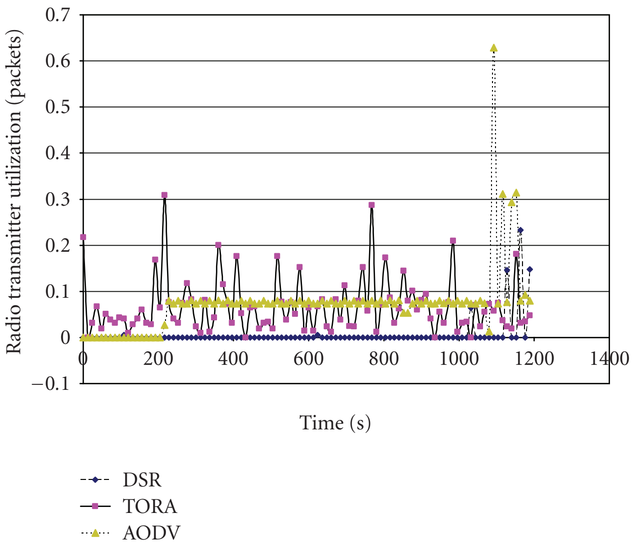

FIGURE 12: Radio transmitter utilization for different protocols in wireless LAN.

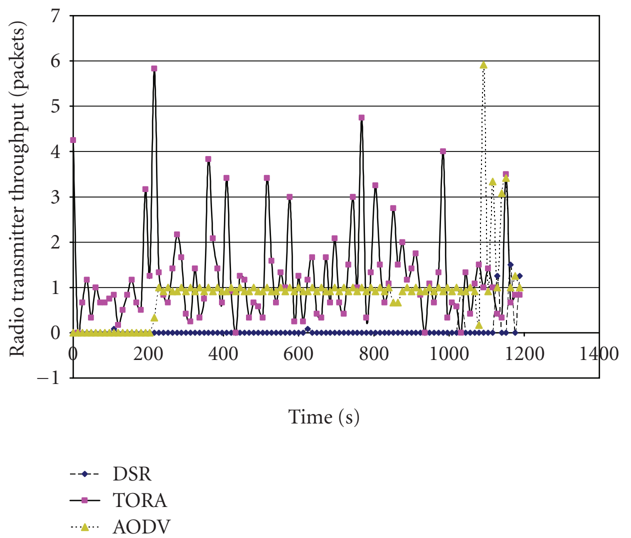

FIGURE 13: Radio transmitter throughput for different protocols in wireless LAN.

the total traffic received and total traffic sent in packets/sec, respectively, for different loads in DSR protocol. In Figures 16 and 17, we observe the same phenomenon, that is, the whole network increases its usage of traffic received and traffic sent as the load increases. As the number of nodes increases, the performance of the protocols is highly affected. One possible reason may be due to the broadcasting of RREQ message during route discovery. DSR creates RREQ packets and broadcasts the RREQ to all the neighbors. In a network of 80 nodes, the number of total neighbors of a particular node is always higher than that of a network involving 20 or 40 nodes. As a result, the routing traffic received and routing traffic sent is higher in a network of 80 nodes compared to 40 or 20 nodes.

Figure 18 shows the performance characteristics of the DSR algorithm in terms of the number of hops per route as a function of time involving 40, 80, and 100 nodes. Figure 19 shows route discovery time for all destinations as a function of time (in seconds) for DSR protocols under various loads. From Figures 18 and 19, we observe that each network

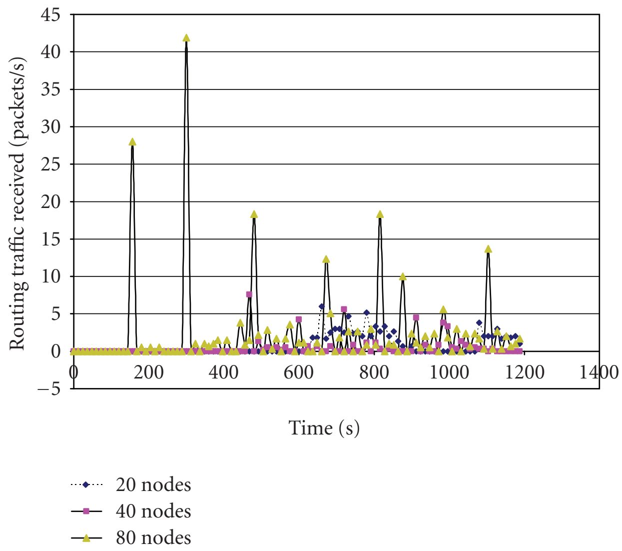

FIGURE 14: Routing traffic received for DSR protocols under various loads.

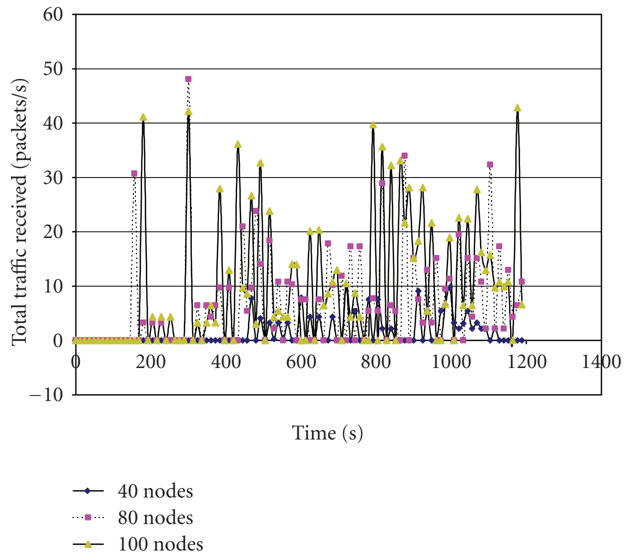

FIGURE 16: Total traffic received for DSR protocols under various loads.

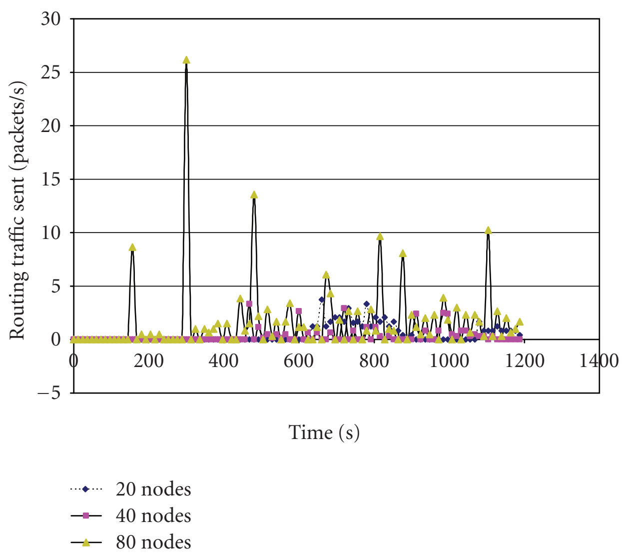

FIGURE 15: Routing traffic sent for DSR protocols under various loads.

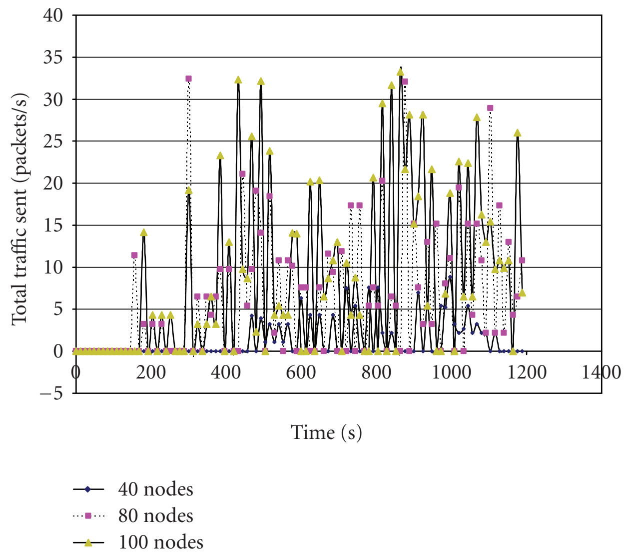

FIGURE 17: Total traffic sent for DSR protocols under various loads.

behaves in a similar manner regardless of the number of nodes. DSR keeps a cache of the entire destination in a packet header. As a result, even if the number of nodes changes, the characteristics of keeping a large cache of destination nodes do not change. Hence, we get similar performance for different loads.

We also investigated the effect of different loads on TORA protocol performance by changing the number of nodes to 40, 80, and 100, respectively. Figures 20, 21, 22, and 23 show the performance characteristics of IMEP control traffic received, IMEP control traffic sent, IMEP ULP traffic received, and IMEP ULP traffic sent, respectively, for the TORA protocol for different loads. It is obvious that the characteristics vary a lot due to the difference in loads. The differences are mainly due to the number of packets TORA uses to create and maintain routes. TORA uses query and update packets to create routes. Moreover, for any message, TORA provides more than one route to a destination, which requires a lot of control overhead. For large number of nodes, these control messages are higher than those of lower numbers of nodes, thus exhibiting a difference between their respective characteristics.

Next, we investigated the effect of different loads (40, 60, and 80 nodes) on AODV protocol performance. Figures 24

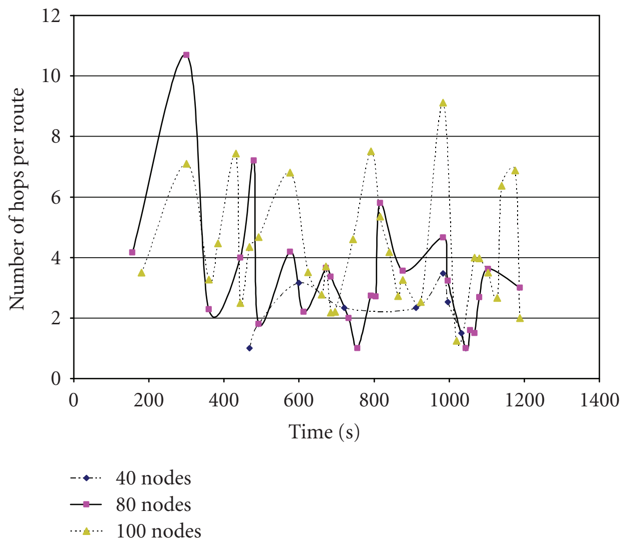

Figure 18: Number of hops for DSR protocols under various loads.

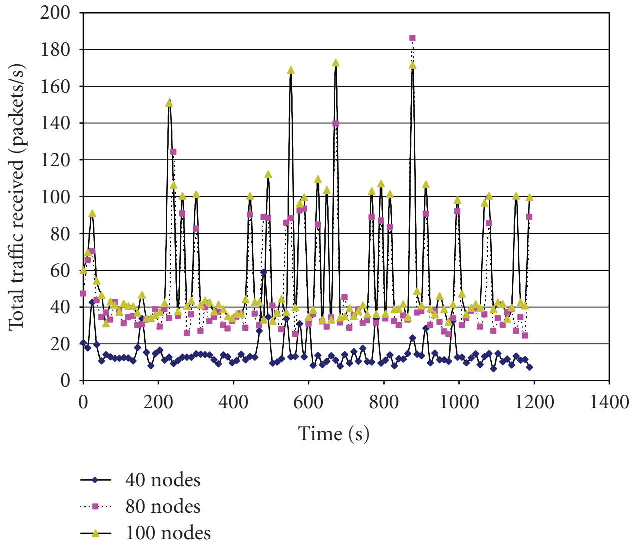

Figure 20: Total traffic received for TORA protocols under various loads.

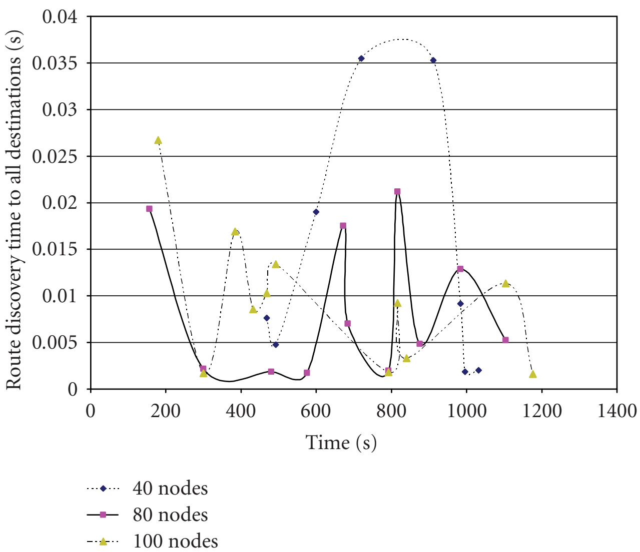

Figure 19: Route discovery time for DSR protocols under various loads.

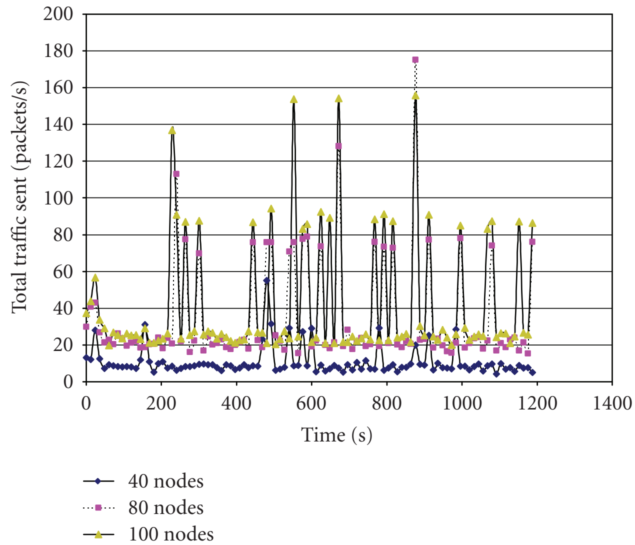

Figure 21: Total traffic sent for TORA protocols under various loads.

and 25 show AODV performance of routing traffic sent and routing traffic received, for different loads, respectively. We observe that the number of packets received and sent per second increases with incremental load increase. This is due to the route cache AODV uses for creating and maintaining routes. AODV keeps a large amount of data in routing cache, which increases with the increase in the number of nodes in a network. However, at the beginning all networks, regardless of load, take a few moments to set up the network before starting routing traffic. Therefore, we see almost zero performance for all loads in the initial time period.

Figure 26 shows AODV protocol performance for route discovery time (in packets/sec) for different loads. None of the networks show any similar characteristics. This is due to the algorithm AODV uses for routing. Since AODV uses the joint algorithm of DSR and DSDV, it takes hop-by-hop routing from DSDV. Usage of the Bellman-Ford algorithm in DSDV [13] ensures that each router provides its routing information to its neighbors. For any network size, the receiving router picks the routing information which has the lowest cost in terms of the shortest path and rebroadcasts it. This algorithm works efficiently no matter how large the network is. Hence, we do not find any dependence of route discovery time on the number of loads.

Figure 27 shows the performance of the AODV protocol in terms of the number of hops per route as a function of

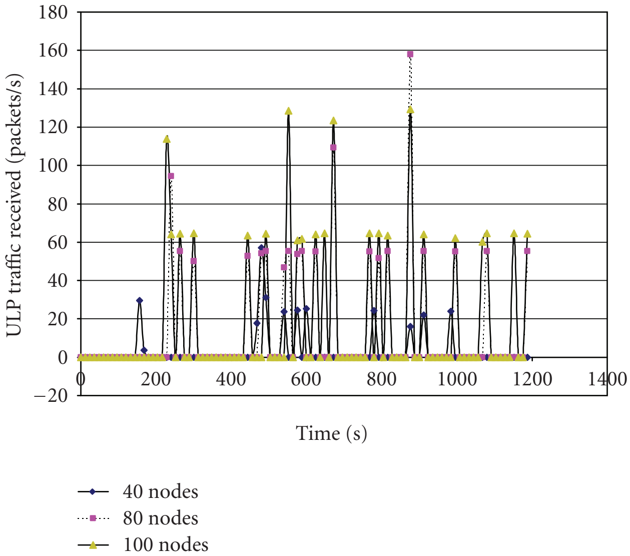

FIGURE 22: ULP traffic received for TORA protocols under various loads.

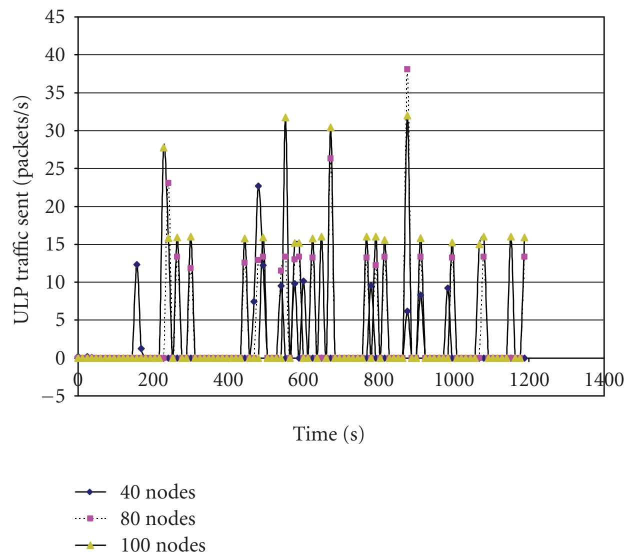

FIGURE 23: ULP traffic sent for TORA protocols under various loads.

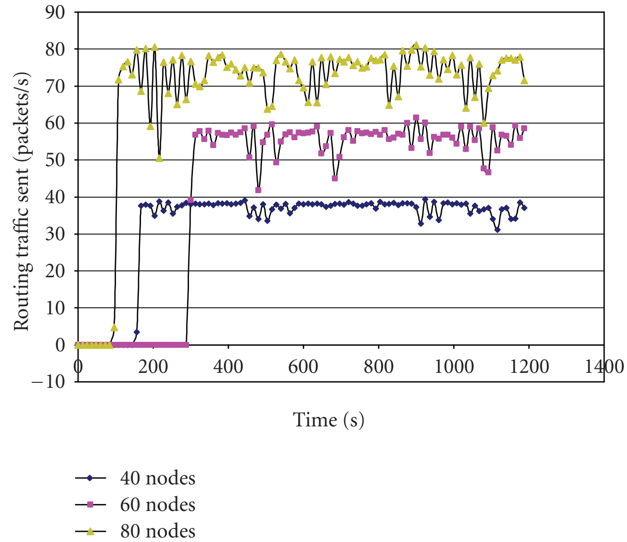

FIGURE 24: Routing traffic sent for AODV protocols under various loads.

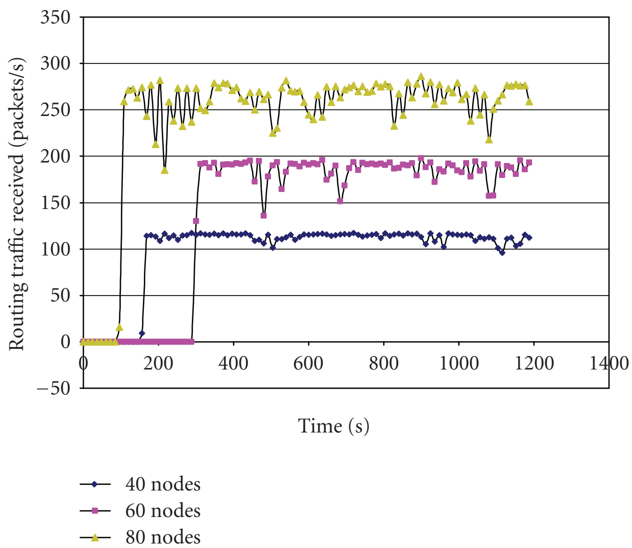

FIGURE 25: Routing traffic received for AODV protocols under various loads.

time for different loads. It is clear that none of the different sized networks have significantly different characteristics. It is due to the hop count entry used in each AODV route table. With each route table entry, AODV keeps the information on the number of hops required to reach destination, as well as, the next valid hop which increases with the increment of number of loads in the network.

6. CONCLUSION

This work is the first attempt towards a comprehensive performance evaluation of three commonly used mobile ad hoc routing protocols (DSR, TORA, and AODV). Over the past few years, new standards have been introduced to enhance the capabilities of ad hoc routing protocols. As a result, ad hoc networking has been receiving much attention from the wireless research community.

In this paper, using the latest simulation environment (OPNET Modeler 10.5), we evaluated the performance of three widely used ad hoc network routing protocols using packet-level simulation. The simulation characteristics used in this research, that is, the control traffic received and sent, data traffic received, throughput, retransmission attempts, utilization, average power, route discovery time, and ULP

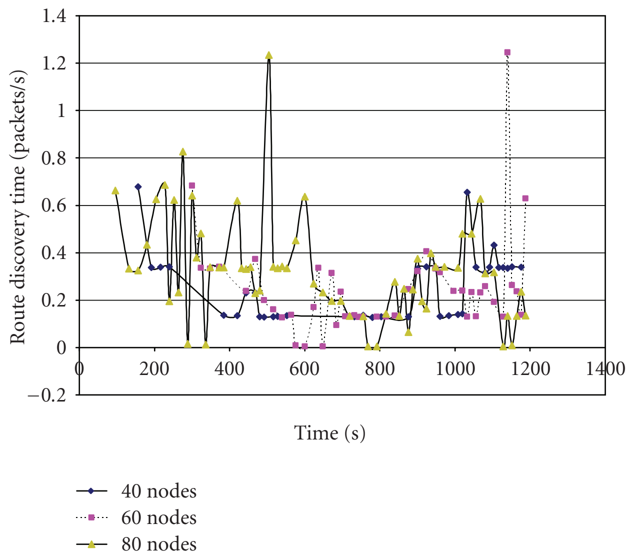

Figure 26: Route discovery time for AODV protocols under various loads.

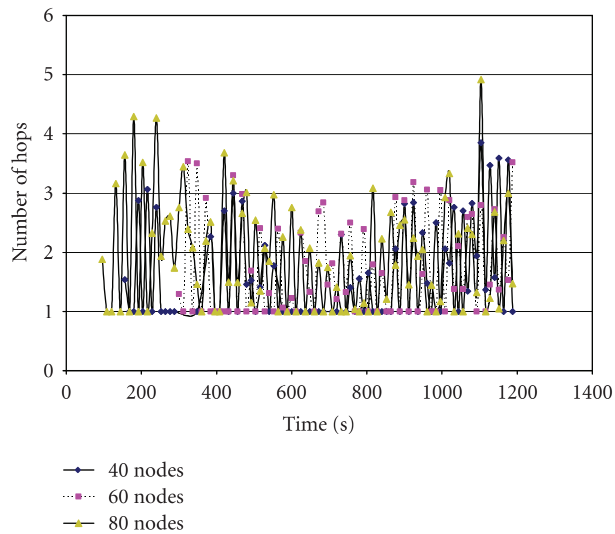

Figure 27: Number of hops per route for AODV protocols under various loads.

traffic received, are unique in nature, and are very important for detailed performance evaluation of any networking protocol.

Performance evaluation results for some ad hoc network protocols were previously reported [1, 14], which primarily covered the impact of the fraction of packets delivered, end-to-end delay, routing load, successful packet delivery, and control packets overhead. In our work, we perform a thorough analysis that includes additional important performance parameters.

For comparative performance analysis, we first simulated each protocol for ad hoc networks with 40 nodes. In case of wireless LAN, TORA shows good performance for the control traffic received, control traffic sent, and data traffic sent. However, AODV shows better performance for data traffic received and throughput. DSR and AODV show poor performance as compared to TORA for the control traffic sent and throughput. However, TORA and AODV show an average level of performance for the data traffic received and data traffic sent, respectively.

In case of radio receiver performance evaluation, TORA shows better performance for successful transmission of packets, while AODV shows better channel utilization. DSR shows an average level of performance in both power and channel utilization over time. AODV shows average results in case of throughput performance. For radio transmitter, TORA shows better performance for both utilization and throughput measure, whereas AODV shows average performance, and DSR shows poor performance. To determine how different protocols perform under increased loads, we tested all protocols for three different scenarios (40, 80, and 100 nodes). For DSR, the number of packets in routing traffic received and sent, as well as the number of packets in total traffic received and sent, increase with increasing load. However, for route discovery time and the number of hops per route, the performance depends primarily on the algorithm rather than on the load. For TORA, the number of packets in control traffic received and sent, as well as in ULP traffic received and sent, increases with the increment of loads. In the case of AODV, varying the number of nodes has no effect on the number of hops per route or route discovery time. However, it is a significant factor for routing traffic received and routing traffic sent.

Ad hoc network routing is a new area of research, and recommended standards are published almost every month. Recommendations for future studies that can improve the reliability of this kind of work include the following.

(i) We only studied a network of moderate size due to limitations of the simulator. Increasing loads up to a few hundreds of nodes could provide strength in terms of real-life applications.

(ii) This study included only one mobility model throughout the simulation. Different mobility models may give different results for ad hoc routing protocols. Future studies should measure performance parameters based upon different mobility models.

(iii) A simulation model that includes performance relative to security issues could provide future researchers, as well as ad hoc network protocol users, a well-deserved criterion for choosing a reliable and safe protocol.

(iv) Since we used OPNET Modeler 10.5, our simulation was confined to three protocols, DSR, AODV, and TORA. Additional ad hoc network protocols, such as DSDV and ZRP, could be added in OPNET for comprehensive performance evaluation.

REFERENCES

[1] E. Celebi, "Performance evaluation of wireless multi-hop adhoc network routing protocols," http://cis.poly.edu/~ecelebi/esim.pdf.

[2] J. Broch, D. A. Maltz, D. B. Johnson, Y. C. Hu, and J. Jetcheva, “A performance comparison of multi-hop wireless ad-hoc network routing protocols,” in *Proceedings of the 4th Annual ACM/IEEE International Conference on Mobile Computing and Network (MobiCom ’98)*, pp. 85–97, Dallas, Tex, USA, October 1998.

[3] V. D. Park and M. S. Corson, “A highly adaptive distributed routing algorithm for mobile wireless network,” in *Proceedings of 16th IEEE Conference on Computer and Communications Societies (INFOCOM ’97)*, vol. 3, pp. 1405–1413, Kobe, Japan, April 1997.

[4] V. D. Park and S. Corson, “Temporarily-ordered routing algorithm (TORA) version 1 functional specification,” corson-draft-ietf-manet.tora-spec-00.txt, IETF, Internet draft, 1997.

[5] M. S. Corson, S. Papademetriou, P. Papadopolous, V. D. Park, and A. Qayyum, “An Internet MANET Encapsulation Protocol (IMEP) Specification,” Internet draft, draft-ietf-manet-imep-spec01.txt, August 1998.

[6] V. Park and S. Corson, Internet draft, March 2004, http://www.ietf.org/proceedings/02mar/I-D/draft-ietf-manet-tora-spec-04.txt.

[7] D. B. Johnson and D. A. Maltz, “Dynamic source routing in ad-hoc wireless networks,” in *Mobile Computing*, T. Imielinski and H. Korth, Eds., chapter 5, pp. 153–181, Kluwer Academic, Hingham, Mass, USA, 1996.

[8] D. B. Johnson and D. A. Maltz, “Protocols for adaptive wireless and mobile computing,” *IEEE Personal Communications*, vol. 3, no. 1, 1996.

[9] T. Larsson and N. Hedman, “Routing protocols in wireless adhoc network—a simulation study,” Lulea University of Technology, Stockholm, Sweden, 1998.

[10] D. Bertsekas and R. Gallager, *Data Network*, Prentice Hall, Englewood Cliffs, NJ, USA, 2nd edition, 1992.

[11] J. Hoebeke, B. Latre, I. Moerman, B. Dhoedt, and P. Demeester, “Routing in mobile ad-hoc networks,” March 2004, http://www.ibcn.intec.ugent.be/css_design/research/topics/2003/FTW_PhD30_Jeroen.pdf.

[12] C. Perkins and S. Das, “Ad-hoc on-demand distance vector (AODV) routing,” Network Working Group, RFC: 3561, July 2003, http://rfc3561.x42.com.

[13] C. E. Perkins and P. Bhagwat, “Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers,” in *Proceedings of the ACM Special Interest Group on Data Communications (SIGCOM ’94)*, vol. 24, pp. 234–244, London, UK, August-September 1994.

[14] S. R. Das, R. Castaneda, J. Yan, and R. Sengupta, “Comparative performance evaluation of routing protocols for mobile, ad hoc networks,” in *Proceedings of 7th International Conference on Computer Communications and Networks (IC3N ’98)*, pp. 153–161, Lafayette, La, USA, October 1998.

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