Al-Maashri, A. and Ould-Khaoua, M. (2006) Performance analysis of MANET routing protocols in the presence of self-similar traffic. In, *Proceedings of the 31st IEEE Conference on Local Computer Networks, 2006, 14-16 November 2006*, pages pp. 801-807, Tampa, Florida, USA.

http://eprints.gla.ac.uk/3545/

Al-Maashri, A. and Ould-Khaoua, M. (2006) Performance analysis of MANET routing protocols in the presence of self-similar traffic. In, *Proceedings of the 31st IEEE Conference on Local Computer Networks, 2006, 14-16 November 2006*, pages pp. 801-807, Tampa, Florida, USA.

Al-Maashri, A. and Ould-Khaoua, M. (2006) Performance analysis of MANET routing protocols in the presence of self-similar traffic. In, *Proceedings of the 31st IEEE Conference on Local Computer Networks, 2006, 14-16 November 2006*, pages pp. 801-807, Tampa, Florida, USA.

http://eprints.gla.ac.uk/3545/

Performance Analysis of MANET Routing Protocols in the Presence of Self-Similar Traffic

Ahmed Al-Maashri Mohamed Ould-Khaoua

Dept. of Electrical & Computer Engineering
Sultan Qaboos University
Sultanate of Oman
{amaashari,mok}@squ.edu.om

Abstract

A number of measurement studies have convincingly demonstrated that network traffic can exhibit a noticeable self-similar nature, which has a considerable impact on queuing performance. However, many routing protocols developed for MANETs over the past few years have been primarily designed and analyzed under the assumptions of either CBR or Poisson traffic models, which are inherently unable to capture traffic self-similarity. It is crucial to re-examine the performance properties of MANETs in the context of more realistic traffic models before practical implementation show their potential performance limitations. In an effort towards this end, this paper evaluates the performance of three well-known and widely investigated MANET routing protocols, notably DSR, AODV and OLSR, in the presence of the bursty self-similar traffic. Different performance aspects are investigated including, delivery ratio, routing overhead, throughput and end-to-end delay. Our simulation results indicate that DSR routing protocol performs well with bursty traffic models compared to AODV and OLSR in terms of delivery ratio, throughput and end-to-end delay. On the other hand, OLSR performed poorly in the presence of self-similar traffic at high mobility especially in terms of data packet delivery ratio, routing overhead and delay. As for AODV routing protocol, the results show an average performance, yet a remarkably low and stable end-to-end delay.

Keywords

Mobile Ad Hoc Network, Self-Similarity, Performance Analysis, NS-2 Simulation, Latency, Throughput.

1. Introduction

A significant number of research efforts have been devoted to investigate Mobile Ad Hoc Networks (MANETs) over the past few years [5, 6, 16]. Interest in MANETs is due to their promising ubiquitous connectivity beyond that is currently being provided by the Internet. Firstly, MANETs are easily deployed allowing a plug-and-communicate method of networking. Secondly, MANETs need no infrastructure [7]. Eliminating the need for an infrastructure reduces the cost for establishing the network. Moreover, such networks can be useful in disaster recovery where there is not enough time or resources to install and configure an infrastructure. Thirdly, MANETs also do not need central management. Hence, they are used in military operations where units are moving around the battle field and a central unit can not be used for synchronization [7]. Nodes forming and Ad Hoc network are required to have the ability to double up as a client, a server, and a router simultaneously [7]. Moreover, these nodes should also have the ability to connect to and automatically configure to start transmitting data over the network. It is impractical to expect a MANET to be fully connected, where a node can directly communicate with every other node in the network. Typically, nodes are obliged to use a multi-hop path for transmission, and a packet may pass through multiple nodes before being delivered to its intended destination.

A number of MANET routing protocols were proposed in the last decade. These protocols can be classified according to the "routing strategy" that they follow to find a path "route" to the destination. These protocols perform variously depending on type of traffic, number of nodes, rate of mobility, etc…

1-4244-0419-3/06/$20.00 ©2006 IEEE

Extensive measurements have revealed that traffic follows a self-similar behavior. As a consequence, networks often experience long periods of bursty traffic. The self-similar nature of network traffic was first noted in Ethernet traffic in 1994 [1]. Since then, more evidences have been gathered to support the work of [2], which showed that WWW traffic has a self-similar behavior and that of [3] which proved the failure of Poisson model in WAN environments.

There have been a lot of research activities on developing efficient routing protocols for MANETs [10, 11, 15]. Such protocols have been primarily designed and analyzed under the assumptions of either CBR or Poisson traffic models, which are inherently unable to capture traffic self-similarity. One of the main goals of this study is to re-visit the relative performance merits of the existing routing protocols in the context of self-similar traffic. Such an investigation may shed new light on the performance behavior of MANETs routing in the presence of bursty correlated traffic. The routing protocols selected for the present evaluation study include Dynamic Source Routing (DSR), Ad hoc On-Demand Vector Routing (AODV) and Optimized Link State Routing (OLSR). These have been selected because they have been widely investigated in the literature over the past few years [4, 5, 6, 7, 19].

In the remainder of the paper, Section 2 describes self-similarity in network traffic. Section 3 provides a brief discussion of the routing protocols considered in this evaluation study. Section 4 describes the simulation scenarios in the evaluation, while Section 5 analyzes the performance results. Finally, Section 6 concludes this paper.

2. Self-Similar Traffic

Recent evidences show that data traffic is being statistically self-similar [1, 2, 3]. This implies that data traffic will maintain bursty characteristics. A bursty traffic is a traffic that is generated randomly, with peak rates exceeding average rates by factors of eight to ten. Let,

$$X = (X_i : i = 0,1,2...) \quad (1)$$

being a stochastic process with a constant mean, finite variance and an autocorrelation functions as in:

$$\alpha = E[X_i] \quad (2)$$

$$\sigma^2 = E[(X_i - \alpha)^2] \quad (3)$$

$$r(k) = E[(X_i - \alpha)(X_{i+k} - \alpha) / E[(X_i - \alpha)^2], \quad (i = 0,1,2,\ldots) \quad (4)$$

Assuming X has an autocorrelation function of the form:

$$r(k) \sim k^{-\beta} L_1(k), \ k \rightarrow \infty, 0 < \beta < 1 \quad (5)$$

Let,

$$X^{(m)} = (X_k^m : k = 1,2,3,...) \ , m = 1,2,3,... \quad (6)$$

$$X_k^{(m)} = 1/m(X_{km-m+1} + ... + X_{km}), k = 1, 2, 3,\ldots \quad (7)$$

For each m, the aggregated time series $X^{(m)}$ is a wide-sense stationary process; and $r^{(m)}$ is the autocorrelation function of it. The process X is called second-order self-similar [1, 2, 4].

The degree of burstiness is measured by a parameter called Hurst (H) Parameter, where

$$H = 1 - \beta / 2 \quad (8)$$

Hurst parameter is typically a function of the overall utilization of the network. The higher H is the burstier is data traffic. Hurst parameter for a statistically self-similar traffic is in the range ($0.5 < H < 1$).

In a simulation environment, Self-similar traffic can be produced by multiplexing ON/OFF sources that have a fixed rate in the ON periods and ON/OFF period lengths that are heavy-tailed [3] (e.g. Pareto traffic).

3. Routing protocols in MANETs

Three routing protocols were studied in this paper, namely; DSR, AODV and OLSR. Below is a brief description of the protocols.

DSR [15]: Dynamic Source Routing protocol is a reactive routing protocol, which means that nodes request routing information only when needed. DSR is based on source routing concept, where the sender constructs a source route in the packet's header. This source route lists all the addresses of the intermediate nodes responsible of forwarding the packet to the destination. When a sender wants to communicate with another node (destination), it checks its *route cache* to see if there is any routing information related to that destination. If *route cache* contains no such information, then the sender will initiate a *route discovery* process by broadcasting a *route request.* If the *route discovery* is successful, the initiating host receives a *route reply* packet listing a sequence of network hops through which it may reach the target. Nodes may reply to requests even if they are not the destination to reduce traffic and delay. It is also possible that intermediate nodes which relay the packets can *overhear* the routes by parsing the packet and thus learning about routes to certain destinations.

DSR also utilizes a *route maintenance* scheme. This scheme, however, uses the data link layer acknowledgments to learn of any lost links. If any lost link was detected, a route error control packet is sent to the originating node. Consequently, the node will remove that hop in error from the host's *route cache*, and all routes that contain this hop must be truncated at that point.

AODV [11]: Ad Hoc On-Demand Distance Vector routing protocol uses broadcast discovery mechanism, similar to but modified of that of DSR. To ensure that routing information is up-to-date, a sequence number is used. The *path discovery* is established whenever a node wishes to communicate with another, provided that it has no routing information of the destination in its routing table. *Path discovery* is initiated by broadcasting a route request control message "*RREQ*" that propagates in the forward path. If a neighbor knows the route to the destination, it replies with a route reply control message "*RREP*" that propagates through the reverse path. Otherwise, the neighbor will re-broadcast the *RREQ*. The process will not continue indefinitely, however, authors of the protocol proposed a mechanism known as "*Expanding Ring Search*" used by Originating nodes to set limits on *RREQ* dissemination.

AODV maintains paths by using control messages called *Hello* messages, used to detect that neighbors are still in range of connectivity. If for any reason a link was lost (e.g. nodes moved away from range of connectivity) the node immediately engages a *route maintenance* scheme by initiating route request control messages. The node might learn of a lost link from its neighbors through route error control messages "*RERR*". Reference [12] indicates that *Hello* messages are sent on an interval of 1 second, while nodes can tolerate a loss of 2 *Hello* messages before declaring a lost link.

OLSR [10]: Optimized Link State Routing protocol is a proactive routing protocol. It performs hop-by-hop routing, where each node uses its most recent routing information to route packets. Each node in the topology selects a set of nodes from its one hop neighbors to act as *Multipoint Relays* "*MPR's*". The selection is made in a way that it covers all nodes that are two hops away (i.e. neighbors of the neighbors). This set of nodes it responsible of retransmitting OLSR control messages, hence reducing number of messages forwarded by all neighbors as in other flooding techniques.

A node senses and selects its *MPR's* by means of control messages called *HELLO* messages that are used to ensure a bidirectional link with the neighbor. *HELLO* messages are emitted at a certain interval. Nodes broadcast control messages called *Topology control* "*TC*", used to declare its *MPR* selection. These are also emitted at certain intervals. Each node is set with a certain level of "*willingness*", which is a measure of how much is the node willing to act as a *MPR* for neighboring nodes.

4. Simulation setup

Extensive simulations were conducted using NS-2. While the implementation of DSR and AODV routing protocols is provided by [8], however, OLSR implementation is provided by [17]. The simulated network consisted of 50 nodes randomly scattered in a 300x600m area at the beginning of the simulation. The tool *setdest* [14] was used to produce mobility scenarios, where nodes are moving at six different uniform speeds ranging between 0 to 20 m/s with a margin of ±1 and a uniform pause time of 10s [4, 9].

We simulated the steady-state conditions of the network with three types of traffic models; namely CBR, Pareto and Exponential [4, 5, 6]. These were generated using the tool *cbrgen.tcl* [14], with the following parameters:

CBR: Constant Bit Rate traffic model. This was generated at a deterministic rate with some randomizing dither enabled on the interpacket departure interval. Packets size was set to 64 bytes generated at a constant rate of 2 kb/s. The packet interarrival time is 600ms and the holding time of the model follows a Pareto distribution with a mean of 300s and a shape parameter of 2.5.

Exponential: The exponential traffic model is an ON/OFF model with an exponential distribution. During ON period, the traffic is generated at 2 kb/s. Average ON, OFF periods are 315ms and 325ms respectively. The holding time follows an exponential distribution with a mean of 300s.

Pareto: The Pareto model is also composed of ON/OFF periods. However, these periods follow a Pareto distribution, where traffic is generated at 2 kb/s during ON periods. Average ON, OFF periods are 315ms and 325ms respectively. The holding time follows a Pareto distribution with a mean of 300s and a shape parameter of 2.5.

It must be noted, however, that the packet transmission starts 1000 seconds after nodes start to move to reduce the variability in the simulation results [4, 6]. The traffic models generator was properly seeded to generate around 30 source connections, which will aggregate more data traffic towards the end of simulation causing a burstier traffic to occur. Hence, self-similarity can be achieved.

For each speed with a certain traffic model, 10 simulation runs were conducted to achieve higher confidence in the obtained results. Table 1 summarizes the simulated network area topology and mobility parameters, while Table 2 summarizes the data traffic scenarios used in the simulation.

Table 1. Area topology and node's mobility

Parameter	Value
Topology Area	300 x 600m
Number of Nodes	50
Nodes Transmission range	100m
Foot Print*	17.45%
Total Simulation time	1000s
Bandwidth	2 Mb/s
Pause Time (Uniform)	10 seconds
Speed (Uniform)	0, (1, 5, 10, 15, 20) ± 1 m/s

Table 2. Summary of traffic models' parameters

CBR Parameters	Distribution	Mean Value
Packet Size	Constant	64 bytes
Rate	Constant	2 kb/s
Holding time	Pareto	300s
Pareto Parameters	**Distribution**	**Mean Value**
Packet Size	Constant	64 bytes
Rate	Constant	2 kb/s
Burst time	Pareto	315 ms
Idle time	Pareto	325 ms
Holding time	Pareto	300 s
Shape (α)	Constant	2.5
Exponential Parameters	**Distribution**	**Mean Value**
Packet Size	Constant	64 bytes
Rate	Constant	2 kb/s
Burst time	Exponential	315 ms
Idle time	Exponential	325 ms
Holding time	Exponential	300s

5. Results and discussion

In this paper we have considered several metrics in analyzing the performance of routing protocols. These metrics are as follows.

- **Data packet delivery ratio**: Total number of delivered data packets divided by total number of data packets transmitted by all nodes. This performance metric will give us an idea of how well the protocol is performing in terms of packet delivery at different speeds using different traffic models.
- **Normalized Protocol Overhead**: Total number of routing packets divided by total number of delivered data packets. Here, we analyze the average number of routing packets required to deliver a single data packet. This metric gives an idea of the extra bandwidth consumed by overhead to deliver data traffic.
- **Normalized Protocol Overhead (bytes)**: Total number of routing packets (in bytes) divided by total number of delivered data packets. Here, we analyze the average number of routing packets in bytes needed to deliver a single data packet. This is needed because the size of routing packets may vary.
- **Throughput (messages/second)**: Total number of delivered data packets divided by the total duration of simulation time. We analyze the throughput of the protocol in terms of number of messages delivered per one second.
- **Average End-to-End delay (seconds):** The average time it takes a data packet to reach the destination. This metric is calculated by subtracting "time at which first packet was transmitted by source" from "time at which first data packet arrived to destination". This includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, propagation and transfer times [16]. This metric is crucial in understanding the delay introduced by path discovery.

The simulation traces were analyzed, the following are the observations noted.

Data packet delivery ratio: Figure 1 shows Data packet delivery ratio versus speed for the studied protocols. It is clear that packet delivery ratio is very close to 1 at speed 0 m/s for all protocols. However, as speed increases, the ratio decreases dramatically.

It was observed that the data packet delivery ratios of AODV and OLSR were close to each other throughout the six speeds with a relatively higher ratio exhibited by AODV. Compared to the other two protocols, DSR has maintained good delivery performance when mobile nodes are moving at speeds less than 10 m/s. However, the performance degraded as speed exceeds 10 m/s reaching 0.4 for Pareto traffic at speed 20 m/s. The performance achieved by DSR is due to the use of data link acknowledgments which enable the mobile nodes to learn quickly about any lost links immediately and act accordingly. In addition, the *overhearing* property allows intermediate nodes to learn about routes to destinations, hence caching these routes for future use.

On the other hand, the presence of Pareto traffic model does not exhibit any major difference in terms of packet delivery ratio compared to Exponential or CBR traffic models.

Normalized Protocol Overhead: Figure 2 shows the routing overhead required to deliver a single data packet versus speed. OLSR exhibited the highest overhead compared to the other protocols. This is expected since OLSR is a proactive protocol, which requires sending periodic *HELLO* and *TC* messages. OLSR routing overhead continues to increase

---

* Percentage of the simulation area covered by a node's transmission range

dramatically beyond the speed 1 m/s reaching 73 routing packets per a single data packet for the CBR traffic at the speed 20 m/s.

On the other hand, DSR maintained the lowest routing overhead at speeds below 10 m/s. However, the routing overhead increases dramatically after the speed 10 m/s. It was observed that at speed 15 m/s, DSR produces higher overhead than AODV. The reason behind this dramatic increase is that the *route cache* property is useless when mobile nodes are moving at higher speeds and links are lost more frequently. Consequently, intermediate mobile nodes need to keep on engaging *path discovery*, which causes the dramatic increase in routing overhead.

AODV has maintained a remarkably low and stable overhead throughout the six speeds. The stability in number of routing packets per data packet was due to that fact that AODV engages a *Path Discovery* only when necessary. Necessity is determined by the use of *Hello* messages that allow nodes to learn of any lost link and immediately inform all active nodes on that path.

On the overall, the routing overhead in the three protocols was the lowest in the presence of Pareto traffic model. This was observed in the three protocols, but can be clearly identified in OLSR.

Normalized Protocol overhead (bytes): Figure 3 shows the routing overhead in bytes required to deliver a single data packet versus speed. Similar observations were noted as in figure 2. It is apparent that OLSR required almost 9000 bytes of routing packets to deliver a single data packet when using CBR traffic at the speed of 20 m/s.

Throughput (messages/second): Figure 4 shows the throughput of the protocols measured in messages/second versus speed. DSR has maintained a high throughput at speeds less than 10 m/s. Once again this was due to the use of *route cache* and *overhearing* properties of DSR routing protocol.

On the other hand, the throughput observed when using the Pareto traffic model was higher than of that in the case of CBR and Exponential traffic models.

Average End-to-End delay: Figure 5 illustrates end-to-end delay versus speed. AODV has remarkably maintained a low end-to-end delay throughout the six speeds, with a slight increase in delay at speed 20 m/s. This is because AODV can immediately use any routing information that it receives from intermediate nodes and it can update that information with a better one if received later. DSR has maintained a low delay as well for speeds less than 10 m/s. However, a dramatic increase in delay was observed at higher speeds. As for OLSR routing protocol, the delay was higher compared to AODV and DSR. The reason is that at high mobility, a *MPR* might move away from the connectivity range and a link to a currently used path to destination might be lost. Hence, the process of selecting a replacement *MPR* and determining a new path to destination introduces a significant amount of delay that severely affects the performance of the OLSR protocol.

It was observed that at higher speeds, the presence of Pareto traffic in the three routing protocols introduces a relatively higher delay compared to CBR and Exponential traffic models.

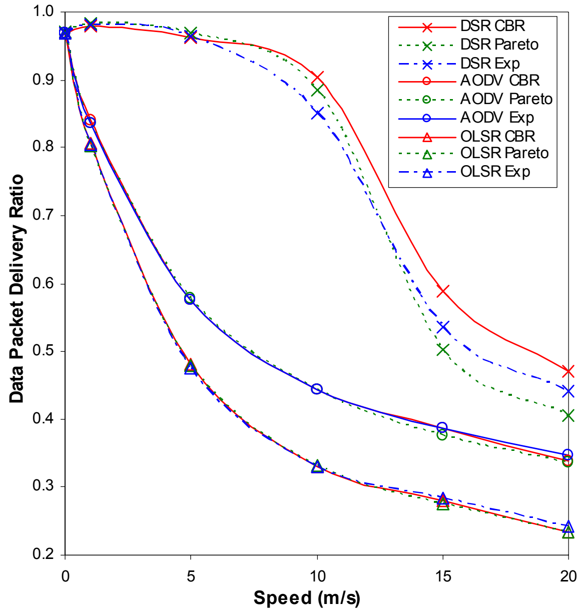

Figure 1. Data packet delivery ratio vs. speed

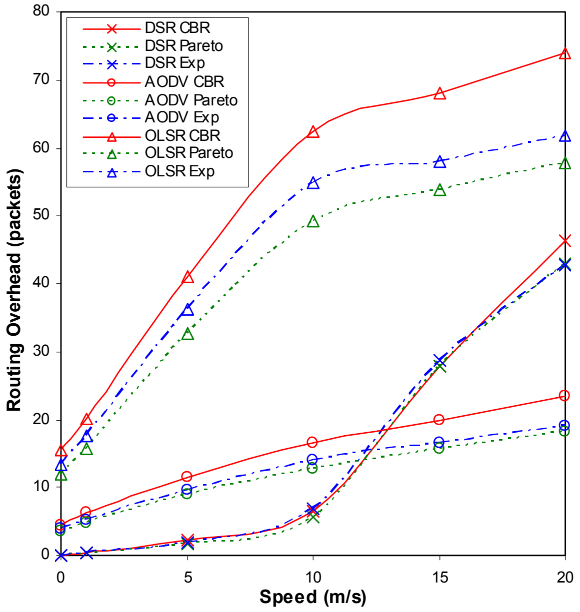

Figure 2. Routing protocol overhead vs. speed

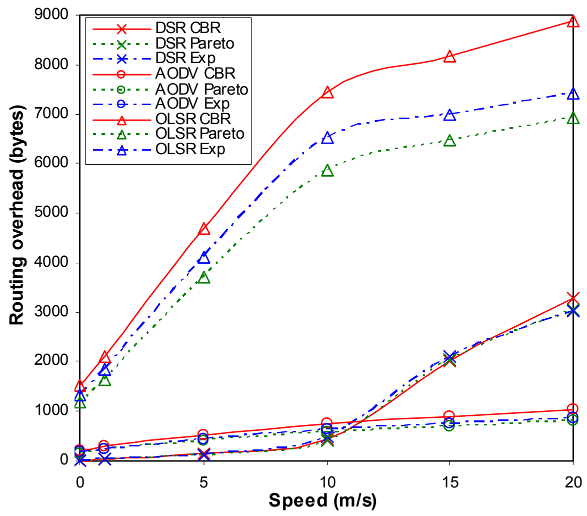

Figure 3. Routing protocol overhead (bytes) vs. speed

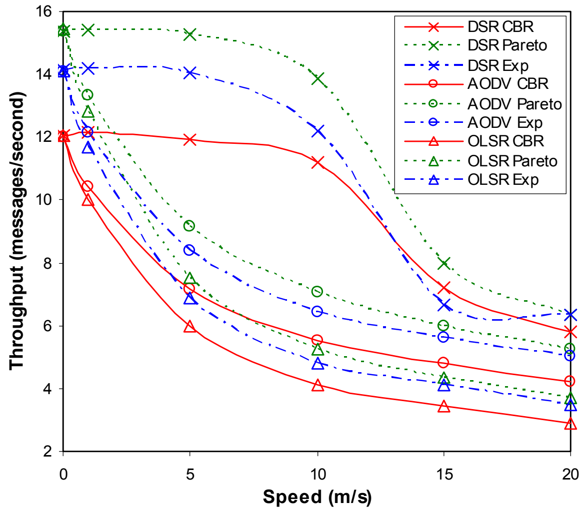

Figure 4. Throughput vs. speed

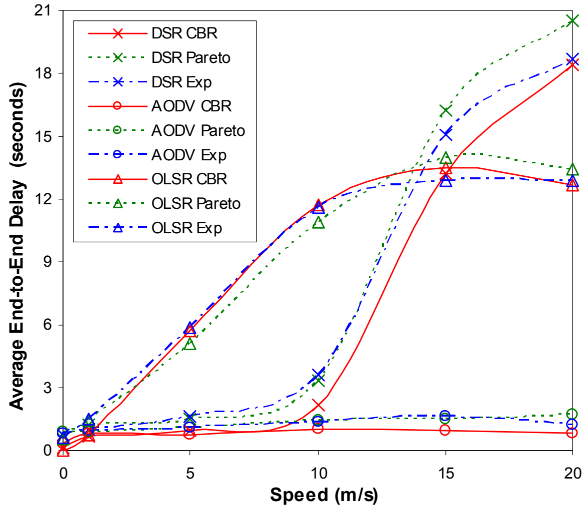

Figure 5. Average End-to-End Delay vs. speed

6. Conclusions

This paper resembles an effort to re-examine three popular routing protocols in the presence of statistically self-similar traffic model. We have analyzed the performance of DSR, AODV and OLSR routing protocols by simulation using NS-2, with nodes moving at speeds ranging from 0 to 20 m/s. In order to mimic traffic models that are statistically self-similar, a number of Pareto traffic connections were aggregated yielding an ever bursty traffic model.

The DSR routing protocol has exhibited superior performance in terms of data packet delivery ratio, throughput and end-to-end delay at speeds less than 10 m/s compared to AODV and OLSR. On the other hand, OLSR performed poorly in the presence of a statistically self-similar traffic at high mobility especially in terms of data packet delivery ratio, overhead and delay. As for AODV routing protocols, the results show an average performance, yet a notably stable and low end-to-end delay was observed.

As a continuation of this research work, it would be very interesting to evaluate other protocols that have been suggested for important operations in MANETs such as those for performing multicast and broadcast communication.

Acknowledgment

The authors would like to thank Francisco J. Ros and Pedro M. Ruiz for their help and support in the implementation of OLSR routing protocol for the NS-2 environment.

7. References

[1] W. E. Leland, M. S. Taqqu, W. Willinger, and D. V. Wilson, "On the Self-Similar Nature of Ethernet Traffic (Extended Version)," in IEEE/ACM Transactions on Networking. Vol. 2, No. 1, 1994.

[2] M. E. Crovella, and A. Bestavros, "Self-Similarity in World Wide Web Traffic: Evidence and Possible Causes," in Proceedings of the 1996 ACM SIGMETRICS International Conference on Measurement and Modeling of Computer Systems. pp. 160-169, October 1995.

[3] V. Paxon, and S. Floyd, "Wide-Area Traffic: The Failure of Poisson Modeling," in IEEE/ACM Transactions on Networking 3(3), pp. 226-244, June 1995.

[4] H. AhleHagh, and W. R. Michalson, "Statistical Characteristics of Wireless Network Traffic and Its Impact on Ad Hoc Network Performance," in Advanced simulation Technologies Conference, Orlando, USA, pp. 66-71, April 2003

[5] J. Borch, D. A. Maltz, D. B. Jognson, Y. Hu, and J. Jetcheva, "A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols," in Proceedings of the 4th ACM/IEEE international conference on Mobile computing and networking, Dallas, Texas, USA, pp. 85-97, 1998

[6] T. Camp, J. Boleng, B. Williams, L. Wilcox, and W. Navidi, "Performance Comparison of Two Location Based Routing Protocols for Ad Hoc Networks," in Proceedings of the IEEE INFOCOM 2002, The 21st Annual Joint Conference of the IEEE Computer and communications Societies, New York, USA, June 2002

[7] S. Lee, J. Hsu, R. Hayashida, M. Gerla, and R. Bagrodia, "Selecting a Routing Strategy for Your Ad Hoc Network," Computer Communications, special issue on Advances in Computer Communications and Networks: Algorithms and Applications, vol. 26, no. 7, pp. 723-733, May 2003

[8] The Network Simulator, NS-2, Available from www.isi.edu/nsnam/ns, 2006

[9] T. Clausen, and P. Jacquet, "Optimized Link State Routing Protocol (OLSR)". IETF RFC3626, Available from http://menetou.inria.fr/olsr/rfc3626.txt, October 2003.

[10] P. Jacquet, P. Muhlethaler, T. Clausen, A. Laouiti, A. Qayyum, and L. Viennot, "Optimized Link State Routing Protocol for Ad-Hoc Networks," in Proceedings of the 5th IEEE Multi Topic Conference (INMIC 2001), 2001

[11] C. E. Perkins, and E. M. Royer, "Ad-Hoc On-Demand Distance Vector Routing," in Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications, New Orleans, LA, pp. 90-100, February 1999

[12] C. Perkins, E. Belding-Royer, and S. Das, "Ad Hoc On-Demand Distance Vector (AODV) Routing". IETF RFC3561, Available from http://www.ietf.org/rfc/rfc3561.txt?number=3561, July 2003

[13] Maria Papadopouli, and Henning Schulzrinne, "Network Connection Sharing in an Ad Hoc Wireless Network among Collaborative Hosts," *NOSSDAV*, June 24th-26th, 1999, Bell Labs, New Jersey

[14] CMU Monarch Group, "CMU Monarch extensions to the NS-2 simulator." Available from http://www.monarch.cs.cmu.edu/cmu-ns.html, 2006

[15] David B. Johnson, David A. Maltz, and Josh Broch, "DSR: The Dynamic Source Routing Protocol for Multi-Hop Wireless Ad Hoc Networks," in Ad Hoc Networking, edited by Charles E. Perkins, Chapter 5, pp. 139-172, Addison-Wesley, 2001.

[16] S. R. Das, C. E. Perkins, E. M. Royer and M. K. Marina, "Performance Comparison of Two On-demand Routing Protocols for Ad Hoc Networks," in IEEE Personal Communications Magazine, special issue on Mobile Ad Hoc Networks, Vol. 8, No. 1, pp. 16-29, Feb 2001

[17] MANET Simulation and Implementation at the University of Murcia, Available from http://masimum.dif.um.es/, 2006

[18] S. Kurkowski, T. Camp, and M. Colagrosso, "MANET Simulation Studies: The Incredibles," in ACM's Mobile Computing and Communications Review, vol. 9, no. 4, pp. 50-61, October 2005

[19] Thomas D. Dyer, Rajendra V. Boppana, "A comparison of TCP performance over three routing protocols for mobile ad hoc networks," MobiHoc 2001: 56-66, 2001