Performance Evaluation of Mobile Ad Hoc Network Routing Protocols for Real Time Applications Support

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Abstract

The need for wireless communication between mobile terminals in environments where no fixed network infrastructure is available, has led to the design of Mobile Ad-hoc Networks (MANETs). In such networks the distance between two nodes may exceed the transmission range of their wireless devices, thus requiring the routing of information through intermediate nodes. Several routing protocols have been designed to provide reliable multi-hop communication, and face the difficulties imposed by mobility, limited bandwidth, and the energy constraints of the mobile hosts. The work presented in this paper evaluates the performance of the DSDV, AODV, DSR and TORA ad hoc routing protocols, focusing on their suitability to support real time applications. Simulation results are obtained with the aid of the $ns-2$ network simulator over a wide range of mobility and traffic scenarios.

1 Introduction

A Mobile Ad-hoc Network (MANET) is a network consisting of wireless mobile terminals, communicating without the support of any fixed network infrastructure. The initial idea was that such networks would be required in disaster recovery situations or military applications. Today there is a growing interest for commercial applications of MANETs, e.g. in university campuses, hospitals, airports. Recent advances in wireless networking technology offer transmission speeds of several Mbps, making possible the support of multimedia applications and real-time communications in MANETs. Since the area that must be covered may exceed the transmission range of the wireless devices, suitable routing protocols must be used to permit multi-hop communication, where as a hop is considered each wireless device. The characteristics of ad hoc networks, such as limited bandwidth, frequent topology changes and the energy constraints of the mobile hosts, make conventional routing protocols for wired networks inappropriate for MANETs. Therefore, new routing protocols have been designed for the highly dynamic environment of MANETs. These protocols are classified as either proactive or reactive. The proactive (or table-driven) protocols continuously determine the available routes in the network, and maintain routing tables with paths to all possible destinations. On the other hand, the reactive (or on-demand) protocols search for an appropriate route only when a specific connection must be established. The proactive approach provides faster response to route requests, but consumes more bandwidth since the network connectivity information must be continuously updated to reflect topology changes.

Although several ad hoc routing protocols have been proposed, very few performance analyses comparing these protocols appear in the literature, regarding mainly the transmission of datagrams, non time-critical traffic [1] [2]. The work presented in this paper, evaluates the performance of various routing protocols for MANETs, when both real time and datagram traffic is transmitted over the network. Simulation results are obtained for four protocols relying on different routing algorithms, namely the DSDV, AODV, DSR and TORA ad hoc routing protocols. The Physical and MAC layers of the IEEE802.11 network are considered as the underlying layer protocols.

DSDV (Destination Sequenced Distance Vector) is a proactive distance vector protocol, which assigns sequence numbers to each route to guarantee loop freedom [3]. The other three protocols use the reactive approach: AODV (Ad hoc On demand Distance Vector) [4] is a reactive version of DSDV, while DSR (Dynamic Source Routing) [5] is based on the concept of source routing. Finally, TORA (Temporally-Ordered Routing Algorithm) [6] uses a link reversal algorithm and is designed for highly dynamic networks where topology changes continuously.

2 Routing in Mobile Ad hoc Networks

2.1 Traditional routing algorithms

Many MANET routing protocols rely on traditional routing algorithms, with certain modifications that improve their performance in dynamic environments. In *link-state routing* [7], each node forms a local view of the network topology and maintains routing tables with costs assigned to each link for its neighboring nodes. Each node broadcasts its link-state information periodically. Upon receiving the broadcasted information, the nodes compute the preferable neighbor for reaching other nodes using a shortest path algorithm, such as the “shortest path first” (SPF) algorithm. As the network topology changes, some nodes may use out-dated link-state information and routing loops may be formed. However, these loops are short-lived since they are repaired when updated routing information is transmitted.

In *distance-vector* routing algorithms, like the Distributed Bellman-Ford (DBF) algorithm [8], the nodes calculate the distance to each destination through each one of their neighbors. To reduce the amount of information transmitted to the network, the nodes periodically advertise only the shortest distance information instead of their complete link-state information. In distance-vector routing, the lack of a detailed view of the network topology can lead to the formation of long-lived loops.

In *source routing* algorithms the decision about the complete path that packets must follow to reach their destination is made at the source. Using this method, the processing requirements of the intermediate nodes is minimized, and the looping problem is avoided. The main disadvantage is that each packet must carry the complete routing information in its header, thus consuming more bandwidth.

2.2 Destination Sequenced Distance Vector Protocol (DSDV)

The DSDV protocol [3] is based on the classical Bellman-Ford algorithm, modified appropriately to avoid the formation of routing loops and to provide faster response to topology changes. Routing tables are stored at each node and contain information about all available destinations. Each node broadcasts its routing information periodically. Each route table entry is assigned a sequence number, which is originated by the destination station. When data packets have to be forwarded by an intermediate node, it selects the route with the more recent sequence number. Using this procedure, older routes, which may have been broken, are excluded, and thus the formation of routing loops is avoided. If paths with the same sequence number exist, those with the smallest metric are used.

Broken links, caused as a result of the movement of network nodes, may be detected by the layer-2 protocol, or may be determined by DSDV if no packets have been received from a former neighbor for some time. When a link has been broken, any route through that next hop is assigned an infinite metric and a sequence number, which is greater than its previous one. The modified routes are immediately transmitted, as the information about broken links is regarded as an important topology change. When a node receives a route with an infinite metric and it has a later sequence number with a finite metric, it sends a route update packet to propagate the new information about that route.

2.3 Ad hoc On-demand Distance Vector Routing Protocol (AODV)

AODV [4] is based on the distance-vector routing algorithm, like DSDV. The main difference between the two protocols is that AODV takes the reactive approach, trying to minimize the number of broadcasts by creating routes on-demand, instead of maintaining a list of routes for every possible destination. AODV uses a sequence number for each route entry, created by the destination when it sends routing information to requesting nodes. When two or more routes to a destination are available, the transmitting node selects the one with the greatest sequence number to ensure loop freedom. AODV uses three message types: Route Requests (RREQs), Route Replies (RREPs), and Route Errors (RERRs).

When a source node wants to send a packet to a destination, it broadcasts a RREQ to find a route to that destination. A route is found when the RREQ reaches either the destination itself, or an intermediate node with a route to the destination whose sequence number is at least as great as that contained in the RREQ. The route is made available by sending a RREP packet to the source of the RREQ. When a node forwards a RREQ packet to its neighbors, it also records the node from which the request came, in order to be able to return the RREP to the source node.

When a node detects that a link to a neighbor has been broken, it sends a Route Error message to notify all other nodes that the link is no longer valid. This message propagates through the network and reaches the source nodes of the broken routes, which may repeat the route discovery procedure to find a new route to the destination. Link failures are detected either by the underlying MAC layer protocol or by AODV itself. In the latter case, each node periodically broadcasts a RREP packet (called Hello message) and listens for Hello messages from its neighbors. If it receives no such messages for a certain time, it assumes that the link to this neighbor is broken.

2.4 Dynamic Source Routing Protocol (DSR)

The DSR protocol [5] is a source-routing reactive protocol. The two major mechanisms of the protocol are route discovery and route maintenance. When a node needs to communicate with a destination node, it looks up its routing table for a route to the destination. If the node does not have such a route, it sends a Route Request packet containing the address of the source and the destination, and a unique identification number. If an intermediate node does not know a route to the destination, it appends its address to the route record of the packet and forwards the packet to its neighbors.

A Route Reply packet is generated when either the destination or an intermediate node with current information about the destination receives the Route Request. A Route Request packet contains in its route record, the sequence of hops taken from the source to this node. If the Route Reply is generated by the destination, then it places the route record from the Route Request packet into the Route Reply. On the other hand, if the node generating the Route Reply is an intermediate node, then it merges its known route to the destination with the route record of the Route Request packet, forming a complete path from source to destination, and places that information into the Route Reply packet.

The route maintenance mechanism of DSR uses two types of packets: Route Error packets and Acknowledgements. When a node detects a link breakage, it notifies its neighbors with a Route Error packet. Acknowledgment packets are used to verify the correct operation of the route links. This also includes passive acknowledgments in which a node hears the next hop forwarding the packet along the route.

2.5 Temporally Ordered Routing Algorithm (TORA)

TORA [6] is a source-initiated reactive routing protocol, designed for highly dynamic mobile ad hoc wireless networks. The basic routing algorithm used by TORA belongs to the family of link reversal algorithms. It guarantees loop-freedom and maintains multiple routes from a source node to a destination node. The protocol tries to reduce routing overhead by restricting the propagation of control messages to a small area near the occurrence of a topological change.

TORA consists of three basic functions: Route creation, route maintenance, and route erasure. When a source needs to establish a connection to a destination, it sends a Query packet identifying the destination for which the route is requested. The destination, or a node that has a valid route to it, responds by sending an Update packet containing its “height” with respect to the destination. Nodes receiving the Update set a greater value to their height, thus forming a directed graph from the source to the destination. When the next-hop link towards a destination has been broken, the node sets its height to be a local maximum compared to the heights of its neighbors and transmits an Update packet.

TORA is designed to function above the Internet MANET Encapsulation Protocol (IMEP) [9]. The responsibilities of IMEP are to provide a neighbor discovery mechanism, reliable delivery of control messages, and network layer address resolution. Moreover, IMEP sends several control messages in a single packet to minimize routing overhead.

3 The Simulation Environment

The simulator used in this work is the $ns-2$ network simulator developed by the University of California at Berkeley [10]. $ns-2$ is a discrete event simulator providing support for simulation of TCP, routing, and multicast protocols over wired and wireless (local and satellite) networks. Mobility support was an extension to ns, developed at the Carnegie Mellon University in the framework of the Monarch Project [11]. The extension provides models of the ad hoc network routing protocols DSDV, AODV, DSR and TORA, and also provides realistic implementations of the underlying layers: radio devices including the properties of antenna gain, receiver sensitivity and transmission power, a physical layer that models propagation delay, capture effects and carrier sense, and the Distributed Coordination Function (DCF) of the IEEE 802.11 Medium Access Control (MAC) protocol [12]. The extension also implements the Address Resolution Protocol (ARP) [13], to provide the translation of IP addresses (used by the routing protocols) to data link layer addresses.

3.1 Implementation of Protocols

The specifications of the studied protocols provide alternative approaches for some mechanisms, such as the detection of broken links. It is up to the implementation to select which option to use, based on the services supported by the underlying layer protocols and on performance issues. An important decision for all protocols is whether to rely on the data-link layer for notifications about broken links, or to use their internal mechanisms. Moreover, suitable values must be assigned to the parameters that specify the behavior of each protocol, such as retransmission retries, timer expiration values, etc. Early experimentations proved that the choices made in [1] by the developers of the $ns-2$ mobility extension worked well under our scenarios, too, and most of them are used in this work.

In the implementation of DSDV two approaches can be applied, concerning the conditions in order to transmit an immediate update of its routing tables. The first variation is that only the receipt of a new metric should result in an immediate update, and the second is that the receipt of a new sequence number for a destination should also cause the transmission of an immediate update. The second approach provides faster response to topological changes, but results in additional routing overhead. In section 4.3 we present a comparison between the two variations, showing that the first performs better when the traffic and mobility is high, while the second achieves better results for lighter traffic and mobility conditions. In the rest of this work, the first DSDV approach is considered.

Another important decision concerns the link breakage detection mechanism. In DSDV the decision that a link is broken is made when three periodic updates have not been received by a neighbor. The interval between periodic route updates is set to 15 secs. The other three protocols obtain link breakage information from the MAC layer. In AODV, the time for retransmission of a RREQ (when RREP has not been received) is 1 sec, and the maximum number of retransmissions is set to 3 secs. In DSR the first retransmission of a RREQ occurs after 500 msec, and an exponential back-off scheme is used for subsequent retransmissions. In TORA the most important decision is to send Update packets without waiting for aggregation by IMEP, to provide faster response in topological changes.

3.2 Traffic and Movement Scenarios

In our simulations we consider a rectangular area of 1000 x 500 meters with 50 wireless mobile nodes. Simulation time is 900 seconds. We consider two kinds of traffic being transmitted to the network: Real-time traffic (requiring packet delivery under certain timing constraints), and non-time critical (datagram) traffic. Several traffic and node movement scenarios are applied to the four protocols to measure their performance.

The traffic sources used in our simulations are constant bit rate (CBR) sources. The use of CBR sources guarantees that not only the total amount of traffic inserted to the network will be the same for all protocols, but that even the exact time that each packet is sent will also be the same, permitting the comparison of the protocols under a common traffic pattern. The use of TCP sources would result in packets sent at different times for each protocol, as TCP schedules packet transmissions according to the network's performance.

In each simulation an equal number of real-time and datagram CBR sources generates traffic to the network. We have chosen a packet size of 512 bytes for the real-time sources, and 128 bytes for the datagram sources, considering that real-time applications typically require the exchange of large amounts of data. Each source sends data to a certain destination for 200 seconds. The time at which a source begins its transmission is randomly chosen between 0 and 700 seconds, so that all the packets will be sent within the 900 seconds of simulation time. To measure the performance of the protocols under medium load conditions, we used traffic scenarios with a total number of 20, 40 and 60 CBR sources, with a sending rate of 4 packets/sec for each source. We also studied a heavy-load scenario, where real-time traffic is generated by a stationary Base Station located at the center of the simulation area, increasing the sending rate of real-time connections to 16 packets/sec.

The node movement scenarios used in our simulations are based on the succession of movement and pause intervals. All nodes are considered to remain stationary for a "pause time" interval after the beginning of the simulation. Then, they start moving towards a randomly chosen destination point in the simulation area, and when they reach their destination they stop again for *pause time.* We studied the performance of these four protocols for pause times of 0, 50, 100, 300, 600 and 900 seconds, representing a range of mobility from continuous movement (pause time of 0 seconds) to an entirely static network (pause time of 900 seconds). The second parameter that characterizes the movement model is the node speed, which is selected randomly (following a uniform distribution) between 0 and a maximum value. Simulation results are obtained for maximum speeds of 2, 5, 10, 15 and 20 m/sec. As different movement scenarios can lead to significantly different results, we used five different movement patterns for each set of the movement parameters (pause time and speed) to increase the reliability of our measurements.

4 Simulation Results

4.1 Medium load scenario

To determine the suitability of the studied protocols for real-time applications support, we use two metrics. The first is the average delay between the time a packet is sent and the time it arrives at its destination, and the second is the percentage of packets delivered successfully within a certain timing constraint. Simulations for 20, 40 and 60 traffic sources showed that the performance of DSDV, AODV and DSR is not affected significantly by the load offered to the network. On the other hand, TORA fails to converge in the case of 60 sources. The reason for this behavior is that when control messages are lost or delayed due to increased traffic, TORA and its underlying counterpart, IMEP, insist on retransmitting them, leading the network to a congestion loop [1]. In this discussion, we focus on the simulation results obtained for 40 traffic sources.

4.1.1 Delay

Figure 1 presents the performance of the four protocols in terms of the average packet delay as a function of pause time, and Figure 2 displays the effect of node speed to packet delay for 50 sec pause time. We observe that when mobility is low (pause time > 600 sec) the performance of the protocols is not significantly different. When mobility increases, DSR achieves the best results (max. delay 37.3 msec), followed by TORA, DSDV and AODV (max. delay 62, 76 and 225 msec respectively).

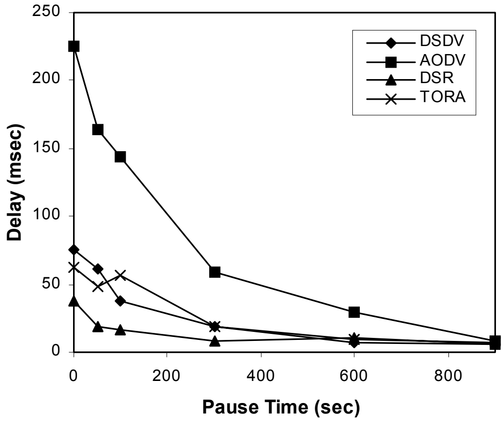

Figure 1. Comparison of the four protocols in terms of packet delay as a function of pause time for 20 m/sec node speed.

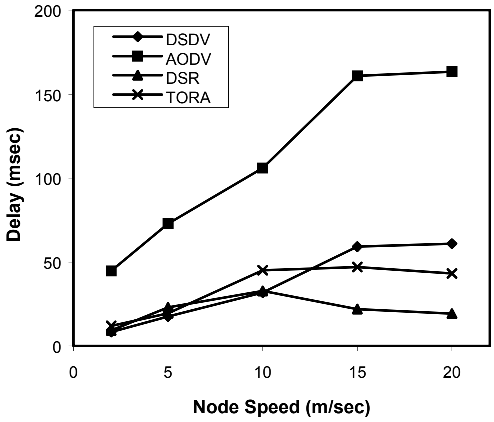

Figure 2. Average packet delay as a function of node speed for 50 sec pause time.

4.1.2 Delay Jitter

To obtain a more detailed perception of the delay performance of the studied protocols, the distribution of delay was measured over 5 msec intervals. Results for 40 traffic sources, 50 sec pause time and 20 m/sec node speed are presented in Figure 3.

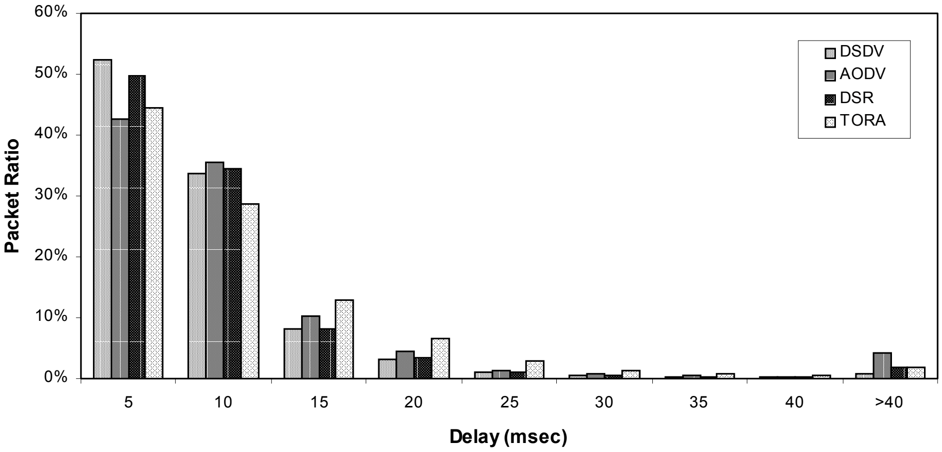

Figure 3. Delay distribution for 50 sec pause time, 20 m/sec node speed.

4.1.3 In-time Packet Delivery Ratio

In time-critical applications, it is essential that data be delivered within a certain time interval to their destination. Packets exceeding such a limit are useless to the application and can be considered "lost", just like packets that never reach their destination due to lack of a valid path, buffer overflow at the intermediate nodes, etc. When real-time voice transmission is concerned, a typical value of the maximum end-to-end acceptable delay is 200 msec, when echo cancellation is used. The performance of the four protocols in terms of the percentage of packets successfully delivered within the 200 msec constraint, as a function of pause time and node speed, is presented in Figures 4 and 5 respectively (for 40 traffic sources).

AODV, DSR and TORA achieve delivery ratios above 95%, while DSDV has lower performance, especially in high mobility scenarios (pause time 0-100 sec, node speed > 10 m/sec). This seems to be in contradiction with the measurements of section 4.1.1, where the average delay of DSDV was close to that of DSR and TORA. The reason is that delay is calculated over the packets that actually arrive to their destination, while in this section we also take into account the packets being dropped at intermediate nodes. In fact, most packets considered "delayed" for DSDV were actually dropped packets. We also observe that while DSDV, AODV and DSR show better performance as mobility decreases, TORA performs better in high mobility scenarios. This confirms the goal of its designers for a protocol optimized for highly dynamic wireless networks.

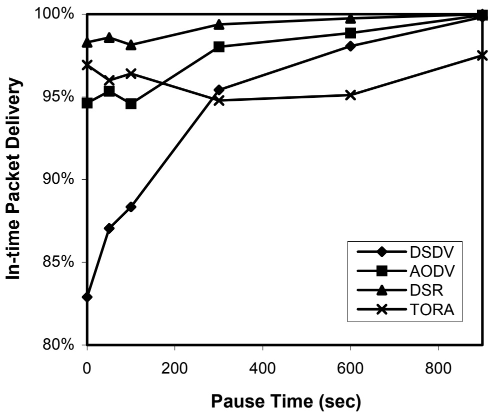

Figure 4. Number of packets delivered within 200 msec, as a function of pause time (node speed = 20 m/sec).

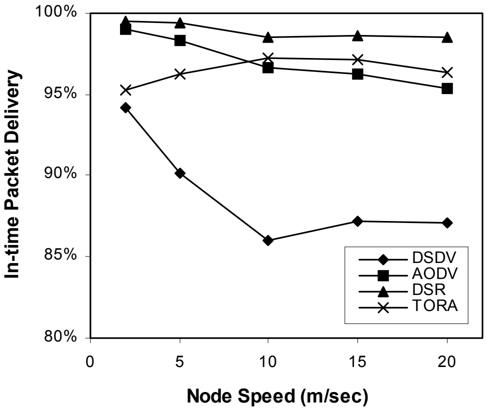

Figure 5. Number of packets delivered within 200msec, as a function of node speed (pause time = 50 sec).

4.2 Heavy-Load Scenario with Fixed Base Station

In this section we study the performance of the protocols under heavy-load conditions. Besides the 50 mobile nodes, we consider a stationary Base Station (possibly a file server, an Internet gateway or a multimedia services access point) located at the center of the simulation area and sending real-time data to several mobile nodes concurrently. The packet size remains 512 bytes, but the sending rate is increased to 16 packets/sec for each connection, which is sufficient to support, for example, an uncompressed voice channel, as the typical voice sampling rate is 8 kbytes/sec. Twenty data connections having the characteristics described in section 3.2 (packet size 128 bytes, sending rate 4 packets/sec) are also established among mobile nodes. The total load offered to the network under this scenario is calculated in Table 1 and is compared to the scenario studied in section 4.1.

Figures 6 and 7 show the packet delay and in-time packet delivery ratio as a function of pause time for DSDV, AODV and DSR (node speed is 20 m/sec). Again, TORA was not able to provide packet delivery due to very high routing overhead. AODV and DSR achieved very good performance, while DSDV had lower performance, especially when mobility was increased. In Figure 8 the delay jitter is presented for 50 sec pause time.

	Heavy Load Scenario			**Medium Load Scenario**		
	Real-time	**Data**	**Totals**	**Real-time**	**Data**	**Totals**
Num. of sources	20	20		20	20	
Data rate (pack/s)	16	4		4	4	
Duration (s)	200	200		200	200	
Total # of packets	64000	16000	**80000**	16000	16000	**32000**
Packet size	512	128		512	128	
Total # of Mbytes	32	2	**34**	8	2	**10**

Table 1. Traffic details for the two load scenarios.

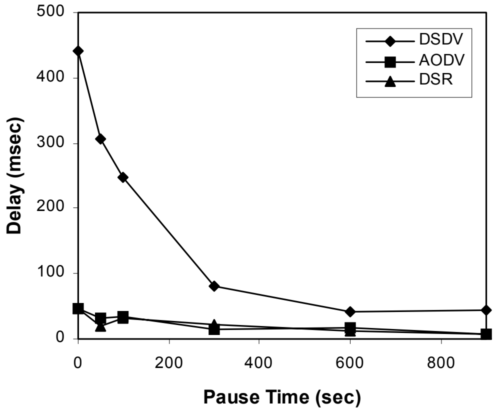

Figure 6. Delay as a function of pause time, under the heavy load scenario.

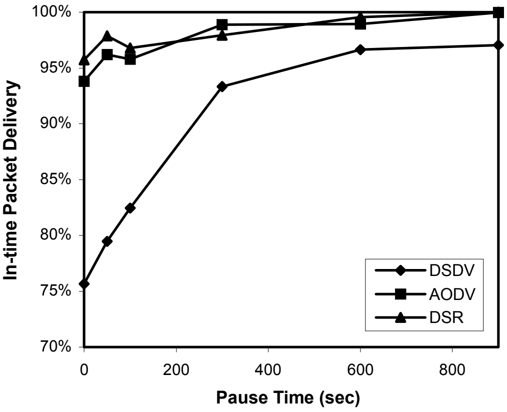

Figure 7. Number of packets delivered within 200msec of sending time, under the heavy load scenario.

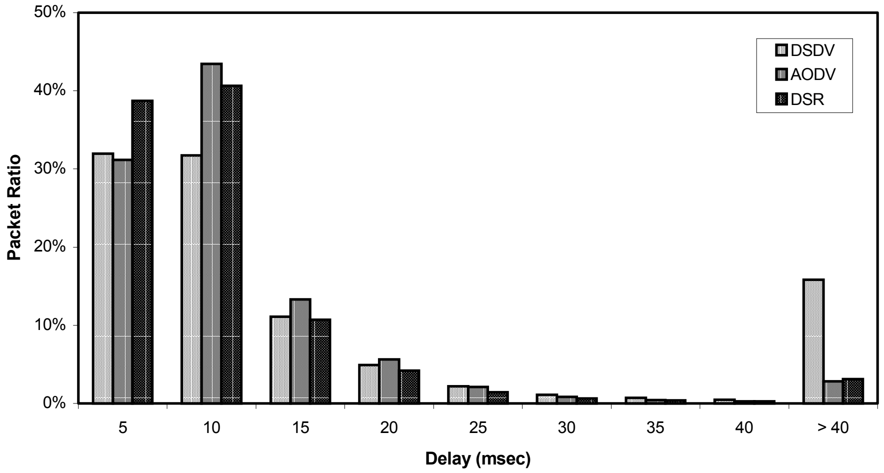

Figure 8. Delay distribution under the heavy load scenario.

4.3 Comparison of the two DSDV variations

As mentioned in section 3.1, two approaches can be applied concerning the transmission of immediate routing updates in DSDV. We define as DSDV-m the protocol's version of sending an immediate update only on the receipt of a new metric, while DSDV-sq is defined as the protocol's version of sending an immediate update even at the receipt of a new sequence number for a destination. Figures 9 - 12 present the packet delay and in-time packet delivery ratio performance of the two variations of the protocol, for the two traffic scenarios described in section 3.2. We observe that under low traffic and mobility conditions DSDV-sq achieves better results, as it reacts faster to the detection of broken links. However, when the traffic and mobility is increased, the avoidance of congestion becomes more important than the sensitivity to topological changes. Thus, the reduced overhead of DSDV-m results in better performance.

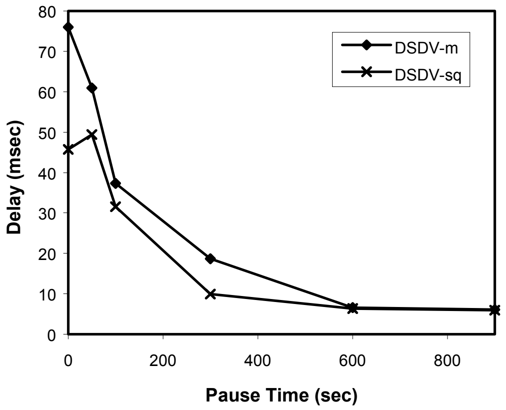

Figure 9. Delay performance of the two versions of DSDV (medium load scenario).

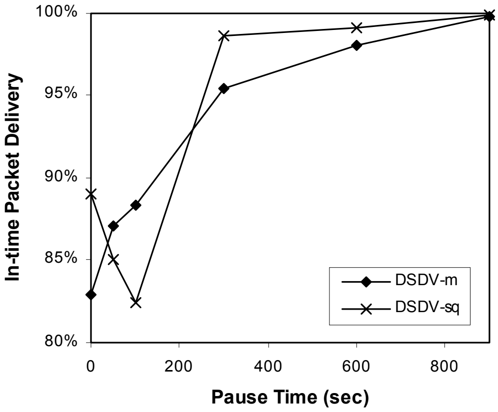

Figure 10. In-time Packet Delivery performance of the two versions of DSDV (medium load scenario).

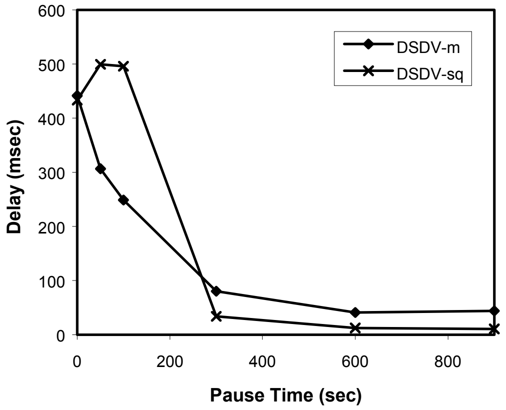

Figure 11. Delay performance of the two versions of DSDV (heavy load scenario).

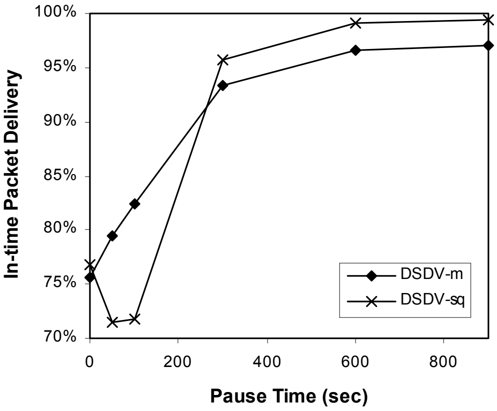

Figure 12. In-time Packet Delivery performance of the two versions of DSDV (heavy load scenario).

5 Conclusions

The aim of this work was to evaluate the suitability of several Mobile Ad Hoc Network (MANET) routing protocols for supporting time-critical applications. To achieve this, we focused on the analysis of the delay characteristics of the protocols, as well as on their ability to deliver real-time data to their destination within certain timing constraints. The studied protocols are DSDV, AODV, DSR and TORA, which rely on different routing algorithms and feature a variety of design techniques. We observed that the performance of the protocols is highly affected by the mobility and traffic conditions. All protocols achieve good results when mobility and traffic are low. As mobility increases, the performance of DSDV degrades significantly, while the other three protocols handle mobility more efficiently, maintaining a packet delivery ratio over 93%. When traffic is increased TORA fails to converge, as the network becomes overloaded by control messages. The performance of DSR and AODV remains very good even under high mobility and traffic conditions, thus these two protocols are the more suitable to support real-time applications for MANETs.

Acknowledgements

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