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Quality of Service Evaluations of On Demand Mobile Ad-Hoc Routing Protocols

Hetal Jasani, Ph. D.
Department of Computer Science
Northern Kentucky University
Highland Heights, KY, USA, 41099
jasanih1@nku.edu

***Abstract*— A mobile ad hoc network (MANET) is a set of wireless mobile nodes that can communicate with each other without using any fixed infrastructure. It is also necessary for MANET devices to communicate in a seamless manner. There are multiple routing protocols that have been developed for MANETs. There is a need to support real time and multimedia applications in MANETs as they gain popularity. MANETs require an efficient routing protocol and quality of service (QoS) mechanism in order to support multimedia applications such as voice and video. Such applications have strict quality of service requirements such as bandwidth, delay, and jitter. Design and development of routing algorithms with QoS support is experiencing increased research interest. This paper evaluates the QoS performance of MANETs by comparing the results of using AODV and DSR routing protocols. Using the OPNET Modeler, we have conducted an extensive set of performance experiments for these protocols with a wide variety of settings. The results show that DSR would be the best protocol to use with voice based traffic as long as mobility is kept to a minimum. As network size and mobility increases, AODV is the better choice due to the on-demand nature allowing for much higher mobility because of the non-caching nature of the routes. However, when resource intensive applications such as voice and video are introduced, the on-demand nature of AODV severely hampers network performance. Even with QoS, AODVs route discovery cannot keep up with the requirements of these applications and this is where DSR's route caching truly shines.**

Keywords: OPNET, Modeling and Simulation, QoS, Mobile Ad Hoc Networks, VoIP, DSR, AODV.

I. Introduction

Mobile ad hoc networks (MANETs) are created on the fly quickly where infrastructure is not available. All mobile nodes will help each other to forward packets to other mobile nodes in the network that may not be within immediate wireless transmission range of each other. These MANETs are characterized by frequently changing network topology, multi-hop wireless connectivity, and the need for efficient dynamic routing protocols [1]. The design of trustworthy and proficient routing protocols in MANETs is a challenging subject. On-demand routing protocols are widely used because they use much lower routing overhead than proactive protocols [10]. Two most widely studied on-demand ad hoc routing protocols are Ad Hoc on-demand Distance Vector (AODV) [3] and Dynamic Source Routing (DSR) [4]. They both construct and depend on a uni-path route for data communications. They need to initiate a new route discovery process whenever there is a link break on the route. This results in a high routing process overhead. On-demand multipath routing protocols can alleviate these problems by establishing multiple routes between the source node and destination node during one route discovery process. A new route discovery is initiated only when all the paths failed or only one path is available.

Because of the rising popularity of voice and video applications in the commercial setting, QoS support in MANETs has become a significant area of research. The QoS requirements generally include high bandwidth availability, high packet delivery ratio and low delay rate. This paper presents QoS comparative study results of these two MANET routing protocols. This research allows us for better understanding of frameworks that offer the best QoS in terms of performance, reliability, usability, caring capacity, stability and ease of maintenance.

II. AODV and DSR

This section provides a quick overview of AODV [3-5] and DSR [9-11]. For complete details see the original papers.

A. Ad-hoc On-demand Distance Vector (AODV)

The Ad-hoc On-demand Distance Vector (AODV) routing algorithm is a routing protocol designed for mobile ad hoc networks. AODV is an on-demand algorithm, meaning that it builds routes between nodes only as desired by source nodes. It maintains these routes as long as the source nodes need them. AODV uses sequence numbers to ensure the freshness of routes. It is loop-free, self-starting, and scales to large numbers of mobile nodes.

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AODV builds routes using a Route Request (RREQ) and Route Reply (RREP) query cycle. When a source node desires a route to a destination for which it does not already have a route, it broadcasts a RREQ packet across the network. Nodes receiving this packet update their information for the source node and set up backwards pointers to the source node in the route tables. In addition to the source node's IP address, current sequence number, and broadcast ID, the RREQ also contains the most recent sequence number for the destination of which the source node is aware. A node receiving the RREQ may send a RREP if it is either the destination or if it has a route to the destination with corresponding sequence number greater than or equal to that contained in the RREQ. If this is the case, it unicasts a RREP back to the source. Otherwise, it rebroadcasts the RREQ. Nodes keep track of the RREQ's source IP address and broadcast ID. They discard the RREQ and do not forward it if they receive a RREQ, which have already been processed by them.

Nodes set up forward pointers to the destination as the RREP propagates back to the source. Source node may begin to forward data packets to the destination once it receives the RREP. Source node may update its routing information for that destination and begin using the better route if it later receives a RREP containing a greater sequence number or contains the same sequence number with a smaller hop count. Route would be maintained as long as it remains active. A route is considered active as long as data packets are sent periodically from the source node to the destination along that path. If the source node stops sending data packets, the links will time out and eventually be deleted from the intermediate node routing tables. If a link break occurs while the route is active, the node upstream of the break propagates a route error (RERR) message to the source node to inform it of the unreachable destination(s). After receiving the RERR, if the source node still desires the route, it can reinitiate route Discovery. Because the network nodes are mobile, it is likely that many link breakages along a route will occur during the lifetime of that route. AODV allows mobile nodes to respond to link breakages and changes in network topology in a timely manner.

B. Dynamic Source Routing (DSR)

The Dynamic Source Routing protocol (DSR) is a reactive (on-demand) routing protocol that is based on the well-known concept of source routing [6-10]. The protocol includes two major operational components: Route Discovery and Route Maintenance, and three types of route control messages, i.e., Route Request (RREQ), Route Reply (RREP), and Route Error (RERR). When a source node in the mobile ad hoc network attempts to send a packet to a destination but it does not have a route to that destination in its route cache, it initiates a route discovery process by broadcasting a Route Request packet (RREQ). This route request packet contains the source node address, the destination node address, unique sequence number, and an empty route record. Each intermediate node, upon receiving a route request for the first time, will check its own route cache. If it has no route to the destination, the intermediate node will add its own address to the route record and rebroadcast the RREQ. If it has a route to the destination in its route cache, the intermediate node will append the cached route to the route record and initiate a Route Reply (RREP) back to the source node. The RREP contains the complete route record from the source to the destination. The intermediate node ignores the late arrival of the same route request by examining the sequence number. If the node receiving the route request is the destination node, it will copy the route record contained in the route request and send a RREP back to the source. In most simulation implementations, the destination node will reply to all the route requests received, since DSR is capable of caching multiple paths to a certain destination. Moreover, the replies from the destination reflect the up-to-date communication topology the most accurately.

Due to the node movement, the routes discovered may no longer be valid over time. The route maintenance mechanism is accomplished by sending route error packets (RERR). If a link break occurs while the route is active, the node upstream of the break propagates a RERR to the source node to inform it of the unreachable destination(s). Each node, upon receiving the RERR, removes all the routes that contain the broken link from its cache. Consequently, if the source node still desires the route, it can reinitiate route discovery. In DSR, each node transmitting the packet is responsible for confirming that the packet has been received by the next hop along the source route. This can be done by either a link layer acknowledgement (as in IEEE 802.11), or a passive acknowledgement (in which the first transmitting node confirms the receipt at the second node by overhearing the second node transmitting the packet to the third node). It can also be achieved by a DSR-specific software acknowledgement returned by the next hop. Once a route is entered into the cache, the failure of the route can only be detected when it is actually used to transmit a packet but fails to confirm the receipt by the next hop.

III. Related Work

Four ad hoc routing protocols including AODV and DSR have been evaluated in [11]. They used 50 node models with similar mobility and traffic scenarios that we used. Packet delivery fraction, number of routing packets and distribution of path lengths were used as performance metrics. An earlier version of AODV was used without the query control optimizations. DSR demonstrated vastly superior routing load performance, and somewhat superior packet delivery and route length performance.

Other papers have compared performance of these two on-demand protocols, including [12]. However, the simulation environment was rather limited, with no link or physical layer models. The routing protocol models also did not include many useful optimizations. This work doesn't consider QoS requirement for real-time applications such as VoIP, video.

There are few finding on required QoS in traditional wireless and mobile networks, but they are not complete and suitable for MANETs. There are various technical challenges for delivering real-time audio/video over the MANETs. In [13], a flexible QoS model for mobile ad-hoc networks (FQMM) is presented, which is a hybrid service model and based on IntServ and Diffserv model. This protocol addresses the basic problem appeared by QoS frameworks [14]. But it cannot solve other problems such as, decision upon traffic classification, allotment of per flow or aggregated service for the given flow, amount of traffic belonging to per flow service, and scheduling or forwarding of the traffic by the intermediate nodes. Reference [15] describes a packet scheduling approach for QoS provisioning in multi-hop wireless networks. Besides the minimum throughput and delay bounds for each flow, the scheduling disciplines seek to achieve fair and maximum allocation of the shared wireless channel bandwidth. The coordination of the adaptation between the different layers of the network in order to solve the problems introduced by scarce and dynamic network resources is described in [16]. Network feedback based on link and acceptable throughput measurements were made to support higher layer and soft quality of service. However, these schemes do not consider the inherent characteristics (changing network topology, limited resource availability, and error-prone shared radio channel) of MANETs and drawbacks of integrated services and differentiated services [17]. In past, researchers have evaluated and compared the performance of AODV, DSR and some other routing protocols. However, they have not studied QoS parameters. Even recently, there are some attempts to evaluate the performance of AODV and DSR and compare the performance parameters [18, 19]. Both have not considered the QoS parameters such as Voice jitter, Voice End-to-End Delay. Another group of researchers [20] has evaluated ZRP (Zonal Routing Protocol) for MANETs using QualNet. They have only considered throughput, end-to-end delay and total bytes received as parameters to compare ZRP with AODV and DSR. We have evaluated these parameters in addition to Video end-to-end delay, HTTP object response time, Voice Delay, etc.

IV. Performance Metrics/Parameters

We carry out the performance evaluation of the two ad hoc routing protocols, AOVD and DSR, to determine which is more efficient in different network settings including real-time applications such as VoIP and video. We have used OPNET Modeler to model ad hoc network that implement the DSR protocol and another node that implements AODV that do not interact with one another. We evaluate the Quality of Service performance that focuses on end-to-end throughput, delay, dropped packets, and average number of data bits transmitted/delivered.

We have run simulations with optimal settings for both AODV and DSR network setups. We test a variety of parameters. These parameters are listed below with the description. Network size - we will focus on how end-to-end delay increase as the number of nodes in the network increases. Topology Change - how is performance impacted as the environment changes the topology or the devices shift locations. Traffic Patterns - this is a deeper focus on the route pattern based on a given type of protocol and network topology. Mobility - how well does the performance of the network deal with movement of the nodes over time.

Focus is placed on key elements to compare between AODV and DSR. The key elements that we compare are: Route Requests sent - How many route discovery request are sent, Delay - Time that it takes for the data to be sent across the network, Page response time - HTTP Response time, Object response time - FTP file response time, Video - Video data that is transmitted across the network, ETE delay - End-to-end delay across the total route, Voice - Voice data that is transmitted across the network, Jitter - The variation in data flow across the network in a given amount of time.

V. Performance Evaluations

A. Base Case Scenario

The baseline testing environment that used to evaluate the performance of DSR and AODV ad-hoc routing protocols is shown in Figure 1. The topology of the network is generated by randomly distributing the nodes in a given region. In OPNET Modeler, we configured a mobility profile, application definition and application profile. We have multiple nodes, some nodes create multimedia traffic, others create VoIP, and remaining nodes create FTP and HTTP traffic.

In Figure 2, the result shows the comparison between DSR and AODV and the number of request made. AODV has a lower number of route requests where as DSR has a higher number of route request sent because it is more dynamic and repairs routes more often. AODV only creates a route when one is requested, thus in comparison to DSR, AODV has a lower number of requests. However, in the beginning for very little period, AODV has higher number of route requests.

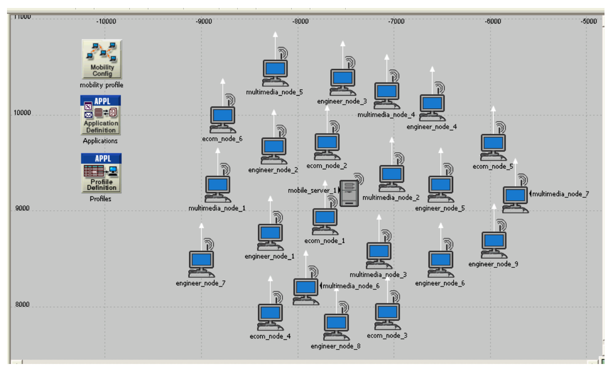

Figure 1. Base Scenario

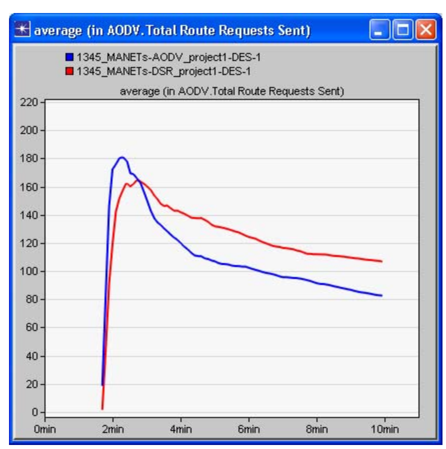

Figure 2. Route Request Sent

Another important parameter in MANETs to end-users is delay. Delay is caused and altered by many factors. Some of the factors include size of network, movement, and data transfer type. In Figure 3, DSR has a larger amount of delay as it may only keep certain routes, because of this, multiple nodes may use the same route increasing traffic and delay. In AODV, the routes are made on demand and allow for better route selection and lower delay overall. The overhead from route discovery is limited in terms of performance with using the same routes over and over.

Figure 4 shows the HTTP page response time; this time is critical in quality of service perceptive. In the graph, AODV has a generalized trend. There is the same response time because it must discover the route each time. This would be consistent with the results we got (where it flat lines after http traffic starts up). DSR has a more unpredictable nature in response time because it has cached routes and thus, sometimes, response time is better than others. There are few flat levels at different point of time. Refilling the cached route table with new routes may have caused the spike.

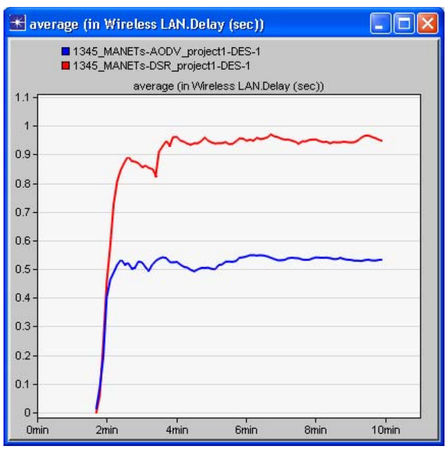

Figure 3. Delay

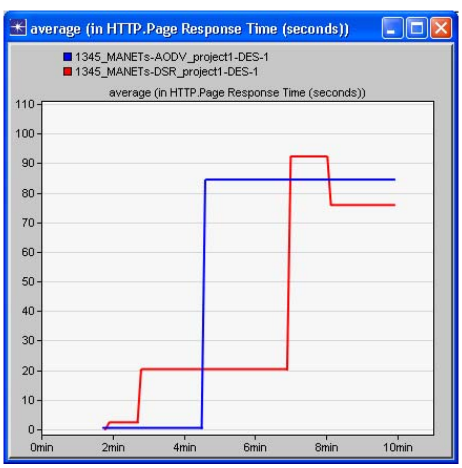

Figure 4. HTTP Page Response Time

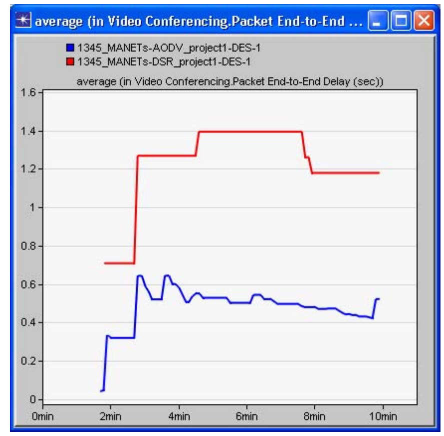

Figure 5. Video End-to-End Delay

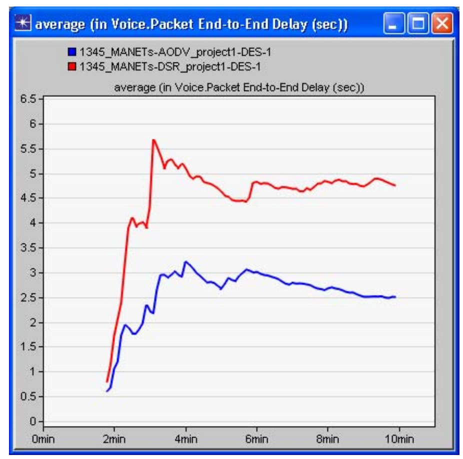

Figure 6. Voice End-To-End Delay

One multimedia task that each protocol needs to be tested against is that of video conferencing. Figure 5 shows difference in video end-to-end delay. AODV had significantly lower delay form source to destination. This is because new routes are always changing and we can get a better route on demand if needed. DSR, its delay is much higher because it has cached routes and may be more prone to errors due to mobility and outdated routes. This may create retransmissions and increased delay.

Figure 6 shows the comparison of AODV Vs. DSR with voice data end-to-end delay. In this case, AODV has a lower delay because if a new route becomes available it will then use it on the next transmission. DSR has a higher delay because there is more a possibility that there will be errors, retransmissions or routes that need to be cleared from the cache. In terms of Quality of Service with Voice data, AODV is better as a dynamic routing protocol to allow for the best network. Jitter plays an important role in Quality of Service. In a network that is ever changing, one can see a clear difference. As shown in Figure 7, AODV has overall less jitter because it creates new routes and not using the same route that may become crowed or congested. DSR has an increasing rate due to the fact that more nodes may use the cached route.

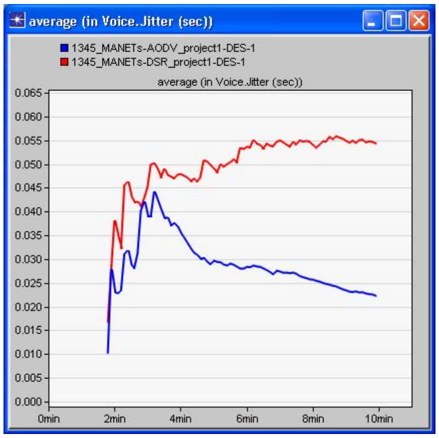

Figure 7. Voice Jitter

B. QoS Scenario

We have simulated QoS scenarios using default QoS traffic priorities in same network configurations.

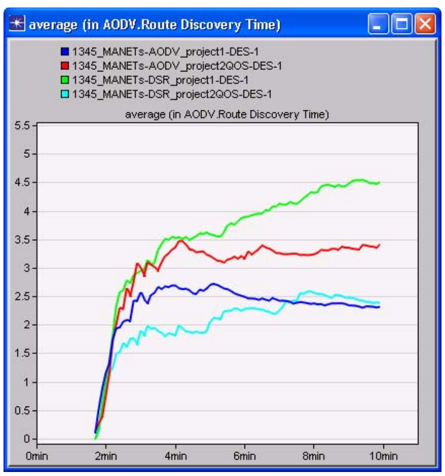

Figure 8. Route Discovery

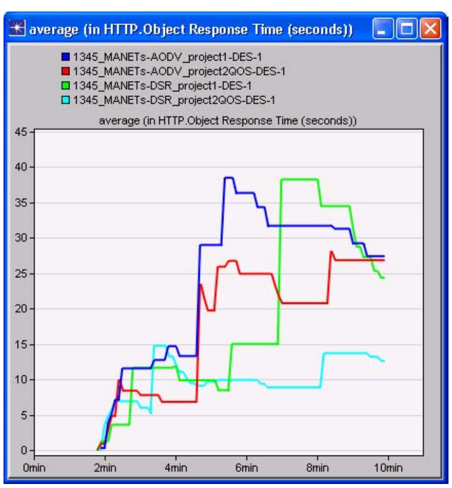

Figure 9. HTTP-Object Response Time

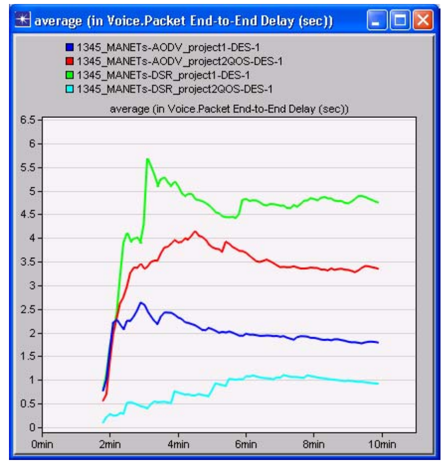

Figure 10. Voice End-To-End Delay

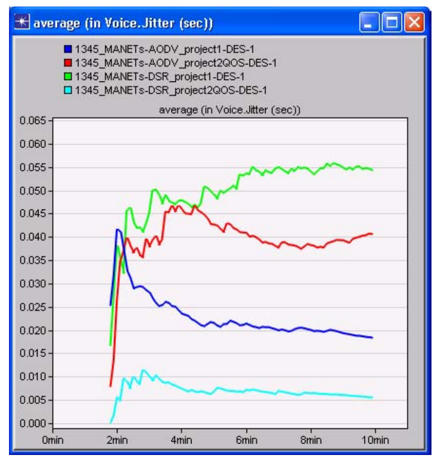

Figure 11. Voice Jitter

Figure 8 shows that the QoS enabled DSR has much lower route discovery time. AODV has a higher route discovery because the network layer handles the routes and QoS is handled on the lower levels. This would create a longer delay of route discovery time. However, you can see that AODV takes less time in the first set of simulations.

With Quality of Service enabled there is significant difference in the application response time. Figure 9 shows the HTTP Object response time. The Quality of Service affects DSR the most by creating routes in the lower levels of the OSI model. This allows for route to be cached more effectively. In the original graphs one is able to ascertain that both AODV and DSR have very similar graphs such that they both increase and then begin to decrease after initial route discovery. Quality of Service enabled created a noticeable difference in DSR such that the response time for HTTP data was much better.

Figure 10 shows the Voice End-to-End delay. There is a clear difference among the two protocols and two different scenarios. The original comparison showed that AODV was more efficient than that of DSR. However, with QoS enabled DSR grabbed wonderful performance gain as it creates the routes and caches routes. In situations that require voice data, it would then be recommended to use DSR with QoS. Figure 11 shows voice jitter. It was a great comparison to enhance the fact that DSR should be used in a time where voice data is required in a mobile ad hoc network.

VI. Conclusions

As a result of creating simulations for both Dynamic Source Routing and Ad hoc On Demand Distance Vector, the study is able to capture initial data for a base line comparison. The first set of results is done to create a baseline that is used to compare against the QoS results of second set. By looking at just the baseline results, AODV would be the choice of protocol to use in most if not all situations. The reason for this is that AODV creates the routes on demand. Thus, there would be less chance of a route error and retransmission time. However, the downside to AODV would be the increased network traffic by constantly creating routes when source requests a route and the destination sends the route response packet.

The second set of simulations was created to implement Quality of Service for both protocols. The results were based on QoS in the same scenarios that were tested in the baseline study. The results show that DSR would be the better protocol to use with Voice based traffic. There were significant performance gains with lower delays and lower number of hops. The results show based on the comparison between the baseline and the Quality of Service studies that in the case where voice data is needed and required as a vital part of the network such as disaster recovery. Therefore, DSR with Quality of Service is a better choice when constant high voice data is needed.

In small ad-hoc networks with minimal traffic and low mobility, DSR would definitely be the better choice of routing protocol. As long as mobility is kept to a minimum, DSR can still be an applicable protocol for routing but eventually routing tables will simply get too large or too out of date. As network size and mobility increases, AODV is the better choice due to the on-demand nature allowing for much higher mobility because of the non-caching nature of the routes.

However, when resource intensive applications such as voice and video are introduced, the on-demand nature of AODV severely hampers network performance. Even with QoS, AODVs route discovery cannot keep up with the requirements of these applications and this is where DSR's route caching truly shines.

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