Assessing the Performance of Mobile Ad-Hoc Network (MANET) Routing Protocols

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***Abstract* — This paper focuses on evaluating some of the routing protocols for the Mobile Ad-Hoc Network (MANET) and discusses their abilities to provide advanced Quality of Service (QoS) support in spite of their dynamic nature. Two routing protocols have been extracted to be studied extensively and compared against each other in terms of their performance: the on-demand Dynamic Source Routing (DSR) along with the table-driven Destination-Sequenced Victor (DSDV) routing protocol. The performances are analyzed according to various factors such as network load, mobility, and network size using a set of parameters. The evaluation shows that an on-demand routing protocol is preferable in all routing conditions.**

Keywords: MANET; Routing Protocols; Packet Delivery Fraction Ratio; Normalized Routing Load.

I. INTRODUCTION

The increased importance of wireless networks is increasingly evident since the demand to access information from any part of the globe has overwhelmed supply. Reduction in cost and time taken to build wired infrastructure has become the ultimate objective for networks designers. Wireless networks can be classified into two categories: "infrastructure" networks and "Infrastructureless" networks. Infrastructure networks usually have fixed and wired gateways and mobile nodes communicate with the network through a base station. The mobile nodes can continue communication with the network even if out of range by connecting with a new fixed base station or access point. The other classification of networks is Infrastructureless, also known as ad-hoc networks. This type of network has no fixed infrastructure or routers; all nodes within the network are mobile and able to move freely to different locations, they can connect dynamically in an arbitrary manner. Each node within ad-hoc network acts as a host and router at the same time. Fig. 1 gives a simplified overview of an ad-hoc network. This figure shows how different heterogeneous hosts are communicating without any infrastructure (Soldiers, tanks, vehicles, satellites).

The biggest problem facing the ad-hoc networks is that it consists of wireless hosts, which have the ability to move in an unpredictable fashion. The movement of these nodes creates many complex issues resulting in changes in routes and addresses, which requires some new mechanisms for planning suitable routing protocols and other configurations.

So far, network simulations, using simulation software, have been done on both the DSR and DSDV protocols and the results have been taken. Results have shown that the on-demand routing protocols are more efficient in solving the routing problem in a mobile environment than the table-driven protocols. Therefore, the comparison between the ad-hoc protocols is a continuous concern, due to the importance of these protocols in a wireless world.

The objective of this work is to undertake the most important issues regarding ad-hoc networks, evaluate their performance based on their properties and their ability to provide QoS and follow with an overview comparison between some selected protocols. Simulation environments are used to compare the performance of DSR and DSDV to examine the impact of the mobility of nodes on the behavior of these protocols regarding packet delivery, delay and routing load. The simulation results show that DSR outperforms DSDV in select scenarios.

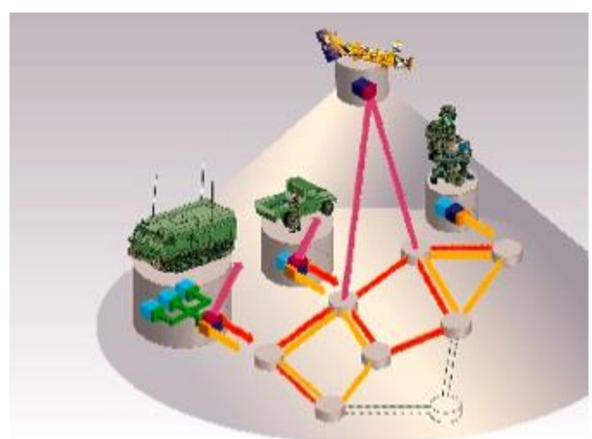

Figure 1. A simplified overview of MANET

The rest of this paper is organized as follows. Section II addresses some related study. Section III describes the MANET routing protocols in general, and then specifically describes the two main protocols under comparison; DSR and DSDV. Section IV introduces the simulation environment.

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Section V discusses the simulation results. Section VI outlines the conclusion of this paper.

II. RELATED WORK

Due to the importance of ad-hoc wireless networks, many routing protocols have been proposed and developed. Each one of these protocols has been designed for special applications. Therefore, differences between them are a point of contention.

Continued work on performance evaluation and comparisons between ad-hoc routing protocols has been conducted by different researchers, using different methods of evaluation, such as simulations, algorithms, and mathematical analyses. In one study, a comparison between different types of protocols in term of control traffic overhead and loop-free properties based on theoretical analysis and discussion is made [1]. Other comparisons between the main categories of ad-hoc protocols have taken place based on Quality of Service [2]. Another study used simulations to compare three ad-hoc protocols [3]. Multiple studies comparing the performance between three ad-hoc protocols have also been done, with the performance comparison as their main issue [4], [5].

III. MANET ROUTING PROTOCOLS

Routing is a process of forwarding packets from source to destination; the path from source to destination should meet the QoS requirements such as: packet delay, delay jitter, bandwidth and packet loss [6]. The dynamic nature of the nodes in an ad-hoc network makes it difficult to sustain the precise link information that meets the QoS routing. Some of the MANET protocols properties, such as dynamic topology, multiple wireless links, physical security, power constrained, and limited resources heighten the pressure on routing protocols that can adapt with these characteristics, which are not met by traditional routing protocols [7],[8]. Therefore, the need for special routing protocols with certain properties is highly essential to meet the ad-hoc nature. Some desired characteristics of these protocols are: distributed, on demand operations, secure, loop free, bi-directional/uni-directional, QoS, energy and bandwidth reservation, and entering/departing nodes [9]. To meet the desirable properties above, many protocols have been proposed by the IETF MANET group [10] for the ad-hoc networks. These protocols can be classified into the following categories: table-driven, on-demands and hybrid protocols [11]. Table 1 shows general differences between on-demand and table-driven based routing protocols as stated in [12].

Table-driven, also called proactive, protocols are based on updating the information in the routing table periodically. This will enable the ad-hoc node to operate in steady fashion and up-to-date routing table. These protocols identify the network topology before any forward packet happens. Examples of these protocols are Destination-Sequenced Distance Vector (DSDV), Wireless Routing Protocol (WRP) and Source Tree Adaptive Routing (STAR) [13].

On-demand, also called reactive, protocols, a complete routing table is not required; Instead, hosts establish routes when they need that. Examples of these protocols are: AODV (Ad-hoc On-Demand Distance Vector protocol), DSR (Dynamic Source Routing Protocol), TORA (Temporally Order Routing Algorithm) and ABR (Associated Based Routing). For this study, the DSR and DSDV from each type were selected for further discussion, analysis and performance evaluation. These protocols have been used for different applications ranging from small networks with low mobility, to large networks with high mobility. None of these protocols is suitable for the whole ad-hoc application; each one has its own characteristics to suit a specific application.

TABLE 1. GENERAL DIFFERENCES BETWEEN ON-DEMAND AND TABLE-DRIVEN

Parameters	On-demand	Table-driven
Availability of Routing Information	Available when needed	Always available regardless of need
Routing Philosophy	Flat	Mostly flat
Periodic Rout update	Not required	Required
Coping with mobility	Using localized route discovery	Inform other nodes to achieve consistent routing table
Signalling traffic generated	Grown with increasing mobility of active routes as in ABR	Greater than that of on-demand routing
Quality of Service	Some can support QoS	Mainly Shortest Path as QoS metric

A. DSR

DSR [14] is an on-demand routing protocol. It uses the source routing mechanism to discover routes. The sender knows the complete route (hop-by-hop) to the destination. These routes are stored in a route cache and the data packet carry the source route are in the packet header.

As seen in Fig. 2, Node A is discovering a route to node D. Each node forwards the *ROUTE REQUEST* from A, adding its own address to the list in the packet; the combination of the initiator address (A), the target address (D), and the request identifier (2) assigned by node A uniquely identifies this Route Discovery [15].

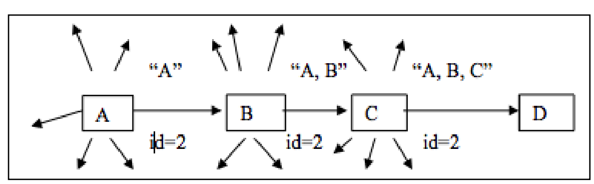

Figure 2. Route Discovery in DSR

B. DSDV

DSDV [16] is a table-driven routing protocol that has been designed to ad-hoc networks as a modification to Bellman-Ford algorithm [17].

It is a hop-by-hop distance vector routing that requires every node to continually broadcast routing updates. Each node maintains a routing table. This routing table contains the next hop to be accessed from this node, and the distance to that hop. Each route in the routing table is marked with a sequence number that reflects the freshness of the route [16]. This sequence number is originated at the destination node. Whenever an update is required, each node broadcasts an increasing sequence number for itself to all of its neighbors. When a node adjusts a route, it broadcasts an update with a sequence number greater than its sequence number for that route [16]. When a node receives a limitlessness metric with a later sequence number, it will prompt a route update broadcast to disseminate the news. The DSDV then, updates routes when faces a route failure as shown in Fig. 3.

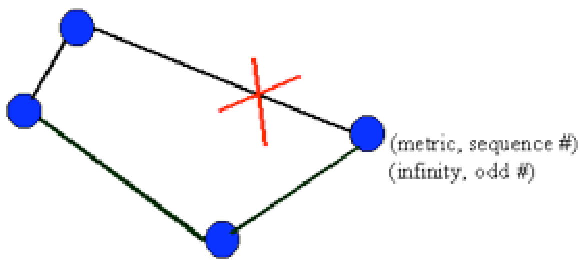

Figure 3. DSDV updates routes when faces a route failure

The above two protocols' performance are then assessed using the Network Simulator tool with predefined performance metrics as explained below.

IV. SIMULATION ENVIRONEMNT

In this study, the Network Simulator (ns-2) from Berkley was used [18]. Fig. 4 shows a simplified user's view of NS. This figure shows that for C++ objects that have an OTcl linkage forming a hierarchy, there is a matching OTcl object hierarchy very similar to that of C++ [18]. This simulation is used to study a performance comparison between the two ad-hoc protocols (DSDV and DSR). The simulation models all the control message exchanges at the MAC layer and network layer.

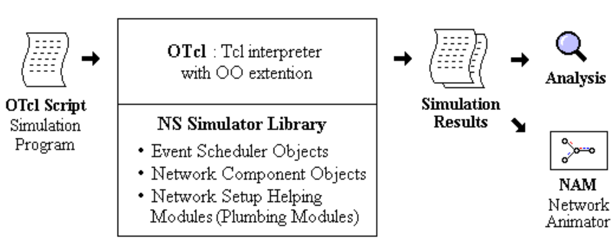

Figure 4. Simplified overview of NS

C. Simulation Setup and Parameters

The IEEE 802.11 at 2 Mbps was used in this simulation as physical, data link, and MAC layer protocols. The *random way-point* was used as the mobility model. The area used is 600m X 600m with fixed 50 nodes. The maximum speed for the mobile node is 20 m/s (0-20m/s). 20 sources are used, each source sends four 512-byte data packets per networks. Complete setup is explained in the simulation parameters in in Table 2 below. These parameters are used for both protocols (DSR and DSDV).

TABLE 2. SIMULATION PARAMETERS

Total Number of Nodes	50
Size of simulation area	600m X 600m
Movement model used	Random way-point
Pause time used	0, 10, 20, 40, 100, 200 seconds
Total simulation time	200 sec
Traffic type	CBR (Constant (Continuous) bit rate
Packet size	512 bytes
Data rate	4 packets/second
Interface queue size	50 packets
Nodes movement speed	0-20m\s
Ratio model used	Lucent's wave LAN
MAC protocol	IEEE 802.11 distribute coordination function (DCF)
Send buffer	64 packets
Type of link	Bi-directional

As shown in above table, the parameters used in this simulation are:

- Total number of nodes. 50 nodes.
- Size of simulation. 600m X 600m.
- Movement Model used. The mobility model used for the nodes is the "random way-point" model [19]. In this model, the movements of mobile nodes are broken into repeating pause and motion period. A mobile node first stays at a location for a certain time then it moves to a new random-chosen destination a speed uniformly distributed between [0, max speed]. Here, each packet starts its movement from a random location to a random destination with a random chosen speed (0-20m\s). Once the destination is reached, another random destination is targeted after a pause.
- Pause time: the time a node stays at a position before moving to the next random position. Different pause times were used in this simulation 0,10,20,40,100, and 200 seconds. A 0-second pause time indicates that nodes are continuously moving while a 200-second

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pause time means that nodes are at rest for the entire simulation.

- Total simulation time. In this simulation a 200 seconds total simulation time is used.
- Traffic type. Constant (Continuous) bit rate (CBR) traffic sources are used in this simulation with packet size 512 bytes and packet sending rate in each pair is set to 4 packets / second. The CBR is used as traffic here and not the TCP because the main object is to evaluate the performance of the two protocols to see how they behave toward the selected metrics.
- Interface queue size. The interface queue has a maximum size of 50 packets. It is a drop-tail priority queue with two priorities each served in FIFO.
- Nodes movement speed. Nodes move at speeds between 0 and 20m\sec.
- Radio model used. The ratio model uses characteristics similar to the radio interface, Lucent's WaveLAN card. WaveLAN is modelled as a shared-media with nominal bit rate of 2Mb\s and a nominal ratio range of 250m.
- MAC protocol. The distribution coordination function (DCF) of IEEE 802.11 for WLAN is used as the MAC layer protocol; with unslotted carrier senses multiple access techniques with collision avoidance (CSMA\CA).
- Send buffer. The protocols maintain a send buffer of 64 packets. That means network layer a 64 packets send buffer is used for storing packets waiting for routing, such as packets for which route discovery has started, but no reply has arrived yet.
- Bi-Directional link. Each node sends data to other nodes and visa versa.

D. Performance Metrics

There are several metrics that can be used to assess the routing protocols. In this simulation the following metrics are used to assess the performance of the two routing protocols [15].

- *Packet Delivery Fraction (PDF)*. The fraction of originated data packets that are successfully delivered to their planned destination nodes. This metric is most important for best-efforts traffic. This can be calculated from the following formula:

*PDF = (received packets \ sent packets) *100* (1)

- *Average end –to–end delay*. This includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at MAC, and propagation, and transfer times. It can be derived from the formula:

Average End-to-end delay=(time pkts received destination)- (time the pkts generated) (2)

- *Normalized routing load (NRL)*. The number of routing packets transmitted per data packets delivered at the destination. Each hop-wise transmission of routing packet is counted as one transmission. It is the total number of overhead packets used by the routing protocol (DSDV / DSR). The formula used to evaluate this metric is:

NRL = routing packet sent/ received (3)

E. Methodology

Fig. 5 is an overview of the implementation and simulation design used starting from writing the script, generating the required scenarios and then getting the simulation output. This figure shows that, main OTcl application script is used to connect all components together to complete the simulation.

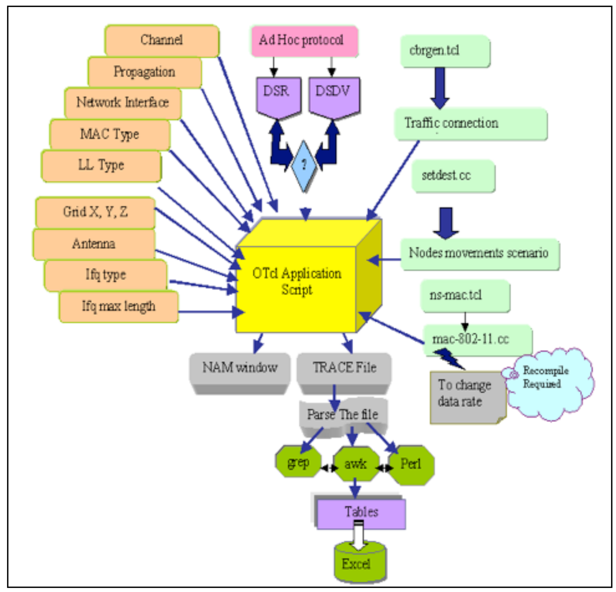

Figure 5. Simulation design overview

The OTcl script is used to setup the network configuration and components, the nodes links, send data between the nodes, etc. Fig. 6 shows the script used to define the network model components. This part o fthe script defines how the mobile nodes are configured. Communication between mobile nodes generates a necessity for a random traffic connection. Either TCP or CBR can be setup between mobile nodes using a traffic-scenario generator script. This script is used to generate CBR and TCP traffics connections between mobile nodes. So, we define the type of traffic (CBR or TCP), the number of nodes, the maximum number of connections to be setup between them, a random seed and in case of CBR connections, a rate whose inverse value is used to compute the interval time between the CBR packets. CBR connection file is created between 50 nodes having maximum connection of 20 connections, with a seed value 1.0 and a rate 4.0.

```
set val(prop)     Propagation/TwoRayGround          ;# channel type
set val(netif)    Phy/WirelesTPhy             ;# radio propagation model
set val(mac)      Mac/802_11                               ;# mac type
set val(ifq)Queue/DropTail/PriQueue           ;#Interface queue type
set val(ll)          LL                                   ;#Link layer type
set val(ant)       Antenna/OmniAntenna                ;#Antenna type
set val(x)          600                      ;# X dimension of the topography
set val(y)          600                      ;# Y dimension of the topography

set val(ifqlen)               50                         ;# max packet in ifq
set val(seed)                0.0                            ;# the seed value
set val(tr)          tracefile.tr                               ;# trace fil

set val(nm)              tracenam.nam          ;# the nam for visualization

set val(adhocRouting)       DSDV|DSR    ;#the ad-hoc protocol used
set val(nn)                    50                              ;# simulated nodes
set val(cp)          "../scenarios/cbr-50-5-4"                   ;# the traffic
connection file generated

set val(sc)          "../scenarios/scen-50-20-0"       ; # the scenario file
generated

set val(stop)             200.0                           ;# simulation time
```

Figure 6. Mobile Node Configuration in Otcl

The Otcl script is also used to create Traffic connection either TCP or CBR and node movement. – *Not shown here due to space limitations.*

F. Analyizng the simulation output

The simulation results can be analyzed using the two methods, the NAM file, and the trace file. The NAM file is used to visualize the simulation output as shown in Fig. 7. The trace file needs to be parsed in order to extract the required information.

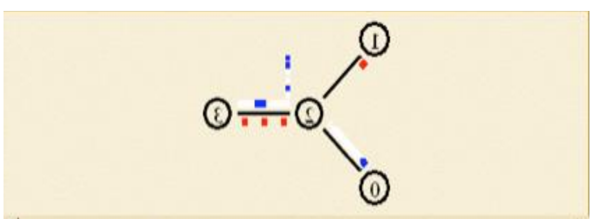

Figure 7. The NAM window

G. Packet Delivery Fracton Ratio

Fig. 8 shows the PDF for the two protocols after plotting the data from the trace files generated. From this figure, it is clear that DSR performed better than DSDV. In DSR most of the originated data was delivered successfully even when the mobility is high, more than 95% of data was delivered effectively.

Fig 8 shows that, DSDV has shown to lack productivity; almost 77% of packets were delivered, that means it has dropped around 23% of data generated. So, when mobility is high (pause time is 0 seconds), DSR outperformed DSDV with number of data delivered from the total that originated.

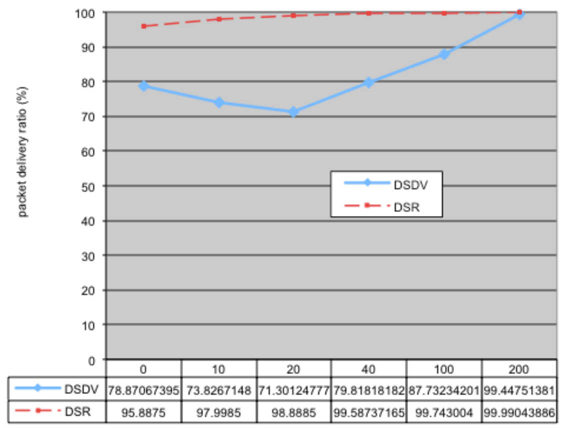

Figure 8. Packet Delivery Ratio

When the pause time is 200 second (the nodes are not moving), both protocols performed well almost all of the generated data has been delivered successfully for DSR and DSDV.

H. Normalized Routing Load

As shown in Fig. 9, there was a significant low routing load for the DSR regardless of mobility. It is fluctuating between 0.01 and 0.07; the highest routing load for DSR was when pause time is 20 seconds (medium mobility), and the lowest when pause time is 200 seconds (no mobility). Overall, DSR has a low routing load in all cases.

DSDV recorded higher routing load routing from 0.93 to 1.26. The highest routing load achieved when pause time is 40 seconds (moderate mobility), and the lowest when mobility is high (pause time is 0).

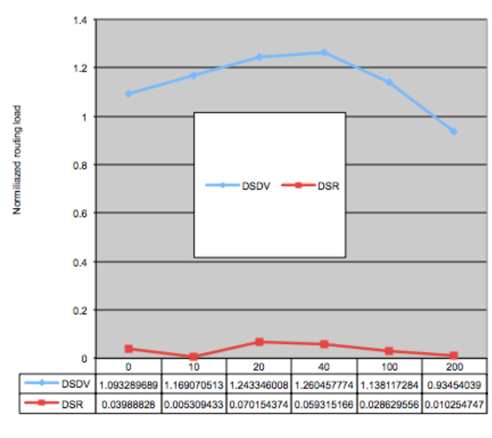

Figure 9. Normalized Routing Load

Overall, DSR outperforms the DSDV, since it has lower routing load. The reasons for these readings will be discussed in the next section.

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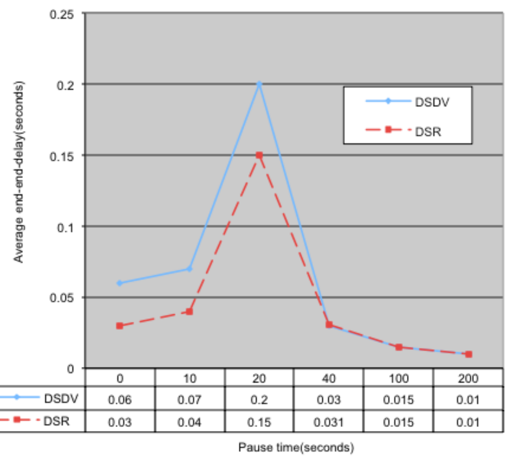
I. End –to-End Delay

The average end-to-end delay is higher in case of DSDV. The DSR protocol outperform the DSDV in all mobility cases as shown in Fig. 10, it however is not a big difference, when the mobility is the highest (0second pause time), the delay on DSR is, almost, 0.03 seconds, and for DSDV 0.05 seconds.



	0	10	20	40	100	200
DSDV	0.06	0.07	0.2	0.03	0.015	0.01
DSR	0.03	0.04	0.15	0.031	0.015	0.01

Figure 10. End-to-End Delay

This delay increases with decreasing the mobility to reach the highest for both protocols when the pause time 20 seconds. Still, at this stage DSR performs better. This increasing of average delay goes down again with decreasing mobility when pause time equals 40 sec. Until the end of pause time 100, and 200 seconds, both protocols, almost behave the same. The minimum delay was recorded when the mobility reached the lowest level (pause time is 200 seconds). In this case, both protocols performed well.

V. RESULTS AND DISCUSION

The same simulation model was used for both protocols, in order to compare the two protocols under the same circumstances to evaluate their behavior. The main objective is to evaluate the performance of those two protocols when changing mobility. Therefore, the same movement model was used. The number of nodes is set to 50, the maximum speed was set to 20m/s, and the pause time was varied between 0, 10,20,40,100, and 200 seconds. Varying the pause time will put the two protocols in different mobility conditions. The 0 seconds pause time means the highest mobility, while the 200 seconds pause time is the lowest (no motion).

After recording the results from the simulation, many observations may be identified.

The different mechanisms that the two routing protocols use to discover the route, affect their performance. The higher the mobility the more link failure occurs within the network. Therefore, a different reaction from both protocols will be used to deal with this failure. When no mobility (pause time is 200 seconds), both protocols performed well regarding the successful data delivered from the original. Whereas, when mobility is high (pause time is 0), DSDV performed poorly, and almost a quarter of the generated packets were dropped. The reason for the high number of dropped packets in DSDV is due to the mechanism that DSDV uses to build the routes.

As explained above, each node maintains a routing table for the whole network. Therefore, the dropped packets result from stalling the routing table's entry that directed and forwarded them over a broken link. In addition, the idea of DSDV having only one route for a specific destination with no alternative caused the MAC layer to drop the packets that were not delivered. This is because the route is broken, and no alternative is available.

The DSR performed well in all cases. Even with high mobility (pause time is 0), more than 95% of originated packets were delivered. In all mobility cases, between 96% and 100% of packets were delivered.

There is a notable difference between the two routing protocols regarding the average end-to-end delay time. In all cases, DSR performed better than DSDV. As mentioned before, the DSDV uses the table-driven approach to maintain the routing information. Therefore, to be able to adapt with updating these routing tables after any route changes, extra time is needed, causing a time delay. In contrast, DSR uses an on-demand approach that builds the route whenever needed. This makes it more adaptive to any routing changes, causing less time delay.

In case of normalized routing load, DSR performed very well and had lower routing load in all cases than DSDV. The reason is that DSR uses the cache routing strategy which means the route can be found in the route cache without the need for route discovery, so it is more likely to find the route within the cache than the routing table.

VI. CONCLUSION

A comparison has been made between two mobile ad-hoc routing protocols, DSDV (table-driven), and DSR (on-demand). The Network Simulator (ns2) was used in these simulations to evaluate the performance of these two protocols. Similar parameters were set for both protocols to evaluate their behaviors under the same conditions toward mobility.

The on-demand routing protocol, DSR, outperformed the table-driven protocol, DSDV, in all chosen metrics. In addition, DSR protocol uses the route cache mechanism to discover routes and *doesn't depend on any timer-based activity*. In addition, DSR uses two routes per destination. If the protocol faces any broken links in one of the routes, an alternative path for the route is already available. The only limitations that DSR has is that it employs an aggressive use of caching, and a lack of any mechanism to expire state routes or determine the freshness of routes when multiple choices are available. DSDV is a suitable protocol in cases of low mobility and no continuous changing of topology. In addition, it is the right solution when the network is small.

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The main conclusion that can be drawn from this evaluation is that on-demand routing protocols perform better than the table-driven protocols for the mobile ad-hoc networks. However, the main challenge in the ad-hoc network environment is designing a special mobile ad-hoc routing protocol that can deal with the heterogeneity of network resources, and be able to select routes based on the requirements of each node, to achieve a high scalability within the ad-hoc world. Therefore, comparison between these protocols is still a principal issue of researches. However, there are other research issues related to MANET still undergoing such as security, address auto-configuration and scalability that can be proposed as future work for this study.

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