A Comparative Study of Multi-Hop Wireless Ad-Hoc Network Routing Protocols in MANET

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Abstract

Mobile Ad-Hoc Network (MANET) is a collection of wireless mobile hosts forming a temporary network without the aid of any stand-alone infrastructure or centralized administration. Most of the proposed MANET protocols do not address security issues. In MANETs routing algorithm is necessary to find specific routes between source and destination. The primary goal of any ad-hoc network routing protocol is to meet the challenges of the dynamically changing topology and establish an efficient route between any two nodes with minimum routing overhead and bandwidth consumption. The existing routing security is not enough for routing protocols. An ad-hoc network environment introduces new challenges that are not present in fixed networks. A several protocols are introduced for improving the routing mechanism to find route between any source and destination host across the network. In this paper present a logical survey on routing protocols and compare the performance of AODV, DSR and TORA.

Keywords: *DSR, AODV, TORA, MANET.*

1. Introduction

Wireless networking is an emerging technology that allows users to access information and services electronically, regardless of their geographic position. Wireless networks have become increasingly popular in the computing industry. The applications of the ad hoc networks are vast [9]. Mobile Ad hoc network (MANET) is a self-organized network because it is an infrastructure less feature of networks. MANET is a collection of nodes. Each node can connect by wireless communication links, without any fixed station such as base station. In MANET each node can act as a router and connectivity is achieved in the form of multihop graph between the nodes [8].

A routing is a core problem in network for sending data from one node to another. Several protocols have been developed under the authority of Mobile Ad hoc networking group. MANET is a charter of Internet Engineering Task Force (IETF). Lots of research has also been done about the performance of ad hoc networks under varying scenarios. Different kind of metrics or Characteristics may be used to analyze the performance of an ad hoc network [7, 9].

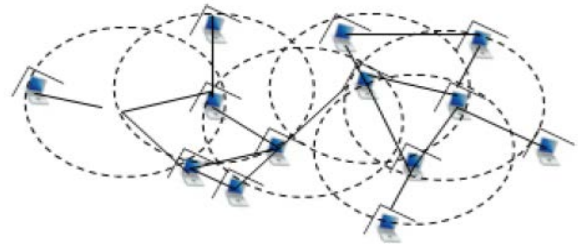

Fig. 1 Wireless Network Structures (Infrastructure less Networks)

1.1 Characteristics of MANET

- Dynamic Topology*:*
  Nodes can move arbitrarily with respect to other nodes in the network.
- Bandwidth-Constrained:
  MANET's nodes are mobile, so they are using radio links that have far lower capacity than hardwired link could use. In practice the realized throughput of a wireless network is less than a radio's theoretical maximum rate.
- Energy Constrained Operation:
  Mobile nodes are likely to relay on batteries, that is why the primary design criteria may sometimes be energy conservation.
- Limited Physical Security:
  Normally, radio networks are vulnerable to physical security threats compared to fixed networks. The possibility of eavesdropping, spoofing and Denial of Service attacks is higher. Existing link security techniques can be applied. However, a single point failure in an ad hoc network is not as crucial as in more centralised networks.
- Unpredictable Link Properties:
  Wireless media is very unpredictable. Packet collision is intrinsic to wireless network. Signal propagation faces difficulties such as signal fading, interference and multi-path cancellation. All these properties make the measures, such as

bandwidth and delay of a wireless link, unpredictable.

- Hidden and Exposed Terminal Problems:
  In the MAC layer with the traditional carrier sense multiple access (CSMA) protocol, multi-hop packet relaying introduces the "hidden terminal" and "exposed terminal" problems. The hidden terminal problem happens when signals of two, say B and C, which are out of the transmission range of each other, collide at a common receiver, say node A. An exposed terminal is created when a node A, is within range of and between two other nodes B and C, which are out of range of each other. When A wants to transmit to one of them, node B for example, the other node, C in this case, is still able to transmit to a fourth node, D which is in C's range (but out of the range of node A). Here A is an exposed terminal to C but can still transmit to B.

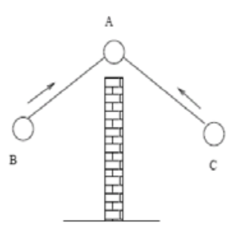

Fig.2: Hidden Terminal Problem

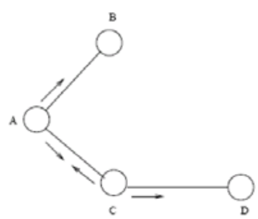

Fig.3: Exposed Terminal Problem

- Route Maintenance:
  The dynamic nature of the network topology and the changing behavior of the communication medium make the precise maintenance of network state information very difficult. Thus the routing algorithms in ad hoc networks have to operate with inherently imprecise information. Furthermore, in ad hoc networking environments, nodes can join or leave anytime. The established routing paths may be broken even during the process of data transfer. So, need for maintenance and reconstruction of routing paths with minimal overhead and delay.
  QoS-aware routing would require reservation of resources at the routers (intermediate nodes). However, with the changes in topology the intermediate nodes also change and new paths are created. Thus the reservation maintenance with the updates in the routing path becomes cumbersome.

1.2 Issues in MANETs:

- Multicasting:
  This is the ability to send packets to multiple nodes at once. This is similar to broadcasting except the fact that the broadcasting is done to all the nodes in the network. This is important as it takes less time to transfer data to multiple nodes.
- Loop Free:
  A path taken by a packet never transits the same intermediate node twice before it arrives at the destination. To improve the overall, we want the routing protocol to guarantee that the routes supplied are loop-free. This avoids any waste of bandwidth or CPU consumption.
- Multiple routes:
  If one route gets broken due to some disaster, then the data could be sent through some other route. Thus the protocol should allow creating multiple routes.
- Distributed Operation:
  The protocol should of course be distributed. It should not be dependent on a centralized node.
- *Reactive:*
  It means that the routes are discovered between a source and destination only when the need arises to send data. Some protocols are reactive while others are proactive which means that the route is discovered to various nodes without waiting for the need.
- Unidirectional Link Support:
  The radio environment can cause the formation of unidirectional links. Utilization of these links and not only the bi-directional links improves the routing protocol performance.
- Power Conservation:
  The nodes in an ad-hoc network can be laptops and thin clients, such as PDAs that are very limited in battery power and therefore use some sort of stand-by mode to save power. It is therefore important that the routing protocol has support for these sleep-modes.
- Proactive Operation:
  This is opposite to demand based operation. If additional delays that occur in demand based operation are unacceptable, proactive approach can be used especially when energy and bandwidth capacities support the use of proactive operation.
- Security:
  Ad hoc routing protocols are exposed too much kind of attacks. Maintaining link layer security is in practice harder with ad hoc networks than with fixed networks. Sufficient routing protocols security is desirable. Sufficient within

this context covers prohibiting disruption or modification of protocol operation.

- "Sleep" Period Operation:
  Since nodes in ad hoc networks may have energy constraints or because of some other need, nodes may want to stop sending and/or receiving data from arbitrary time periods. A routing protocol should be able handle such "sleep" periods without overly unfavourable consequences.

1.3 Applications of MANET:

- Sensor Networks for environmental monitoring.
- Rescue operations in remote areas.
- Remote construction sites and Personal Area Networking.
- Emergency operations.
- Military battlefield.
- Civilian environments.
- Law enforcement activities.
- Commercial projects.
- Educational Class rooms.

2. MANET Routing Protocol

MANET protocols are used to create routes between multiple nodes in mobile ad-hoc networks. IETF (Internet Engineering Task Force) MANET working group is responsible to analyze the problems in the ad-hoc networks and to observe their performance [7, 9]. There are different criteria for designing and classifying routing protocols for wireless ad-hoc networks. The MANET protocols are classified into three huge groups, namely Proactive (Table-Driven), Reactive (On-Demand) routing protocol and hybrid routing protocols [1, 2]. The following figure shows the classification of protocols.

Proactive (Table-Driven) routing protocol: - In proactive routing protocol perform consistent and up-to-date routing information to all the nodes is maintained at each node.

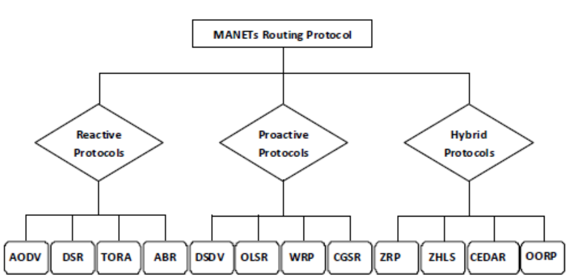

Fig.4 Different type of routing protocols in wireless Ad-hoc network

Reactive (On-Demand) routing protocol: - This type of protocols find route on demand by flooding the network with Route Request packets

2.1. Proactive vs. Reactive Routing

Proactive Schemes determine the routes to various nodes in the network in advance, so that the route is already present whenever needed. Route Discovery overheads are larger in such schemes as one has to discover all routes. Examples of such schemes are the conventional routing schemes, Destination Sequenced Distance Vector (DSDV). Reactive Schemes determine the route when needed. Therefore they have smaller Route Discovery overheads. Examples for such schemes are Ad Hoc On-Demand Distance Vector (AODV) routing protocol.

2.2. Single-Path vs. Multi-Path

There are several criteria for comparing single-path routing and multi-path routing in ad-hoc networks. First, the overhead of route discovery in multi-path routing is much more than that of single-path routing. On the other hand, the frequency of route discovery is much less in a network which uses multi-path routing, since the system can still operate even if one or a few of the multiple paths between a source and a destination fail. Second, it is commonly believed that using multi-path routing results in a higher throughput. Third, multi-path networks are fault tolerant when dynamic routing is used, and some routing protocols, such as OSPF (Open Shortest Path First), can balance the load of network traffic across multiple paths with the same metric value [2, 6, 10].

2.3. Proactive vs. Source Initiated

A proactive (Table-Driven) routing protocols are maintaining up-to-date information of both source and destination nodes. It is not only maintained a single node's information, it can maintain information of each and every nodes across the network. The changes in network topology are then propagated in the entire network by means of updates. Some protocols are used to discover routes when they have demands for data transmission between any source nodes to any destination nodes in network, such protocol as DSDV(.Destination Sequenced Distance Vector) routing protocol. These processes are called initiated on-demand routing. Examples include DSR (Dynamic Source Routing) and AODV (Ad-hoc On Demand Distance Vector) routing protocols [2].

3. AD-HOC on Demand Vector Protocol (AODV)

AODV combines some properties of both DSR and DSDV. It uses route discovery process to cope with routes *on-demand* basis. It uses routing tables for maintaining route information. It is reactive protocol; it doesn't need to maintain routes to nodes that are not communicating. AODV handles route discovery process with *Route Request (RREQ)* messages. *RREQ* message is broadcasted to neighbour nodes. The message floods through the network until the desired destination or a node knowing fresh route is reached. Sequence numbers are used to guarantee *loop freedom*. *RREQ* message cause bypassed node to allocate route table entries for reverse route. The destination node unicasts a *Route Reply (RREP)* back to the source node. Node transmitting a *RREP* message creates routing table entries for forward route [14].

For route maintenance nodes periodically send *HELLO* messages to neighbour nodes. If a node fails to receive three consecutive *HELLO* messages from a neighbour, it concludes that link to that specific node is down. A node that detects a broken link sends a *Route Error (RERR)* message to any upstream node. When a node receives a *RERR* message it will indicate a new source discovery process [5, 14].

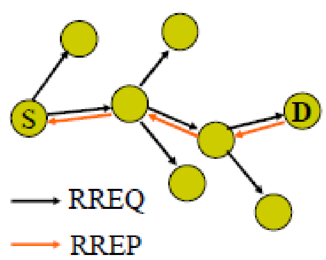

Fig. 5 AODV routing protocol with RREQ and RREP message

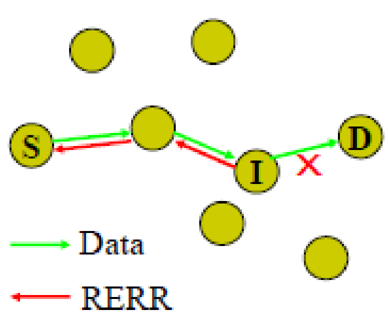

Fig 6 AODV routing protocol with RERR message

4. Dynamic Source Routing (DSR)

The Dynamic Source Routing Protocol (DSR) is a reactive routing protocol .By the means of this protocol each node can discover dynamically a source route to any destination in the network over multiple hops. It is trivially loop free owing to the fact that a complete, ordered list of the nodes through which the packet must pass is included in each packet header. The two main mechanisms of DSR are Route Discovery and Route Maintenance, which work together to discover and maintain source routes to arbitrary destinations in the network [1, 5]. The following figure shows the route discovery method.

Salvaging: An intermediate node can use an alternate route from its own cache, when a data packet meets a failed link on its source rout e.

Gratuitous route repair: A source node receiving a RERR packet piggybacks the RERR in the following RREQ. This helps clean up the caches of other nodes in the network that may have the failed link in one of the cached source routes.

Promiscuous listening: When a node overhears a packet not addressed to it, it checks if the packet could be routed via itself to gain a shorter route. If so the node sends a gratuitous RREP to the source of the route with this new, better route. Aside from this, promiscuous listening helps a node to learn different routes without directly participating in the routing process [5, 6].

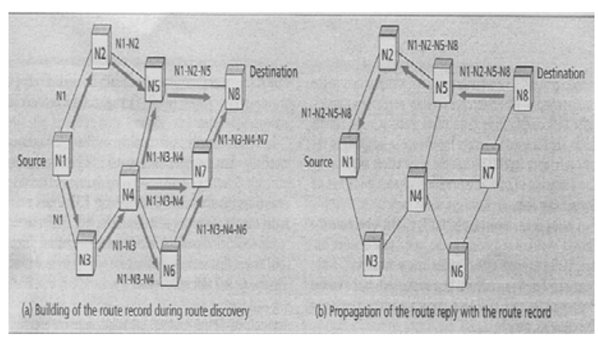

Fig.7 Creation of the route record in DSR

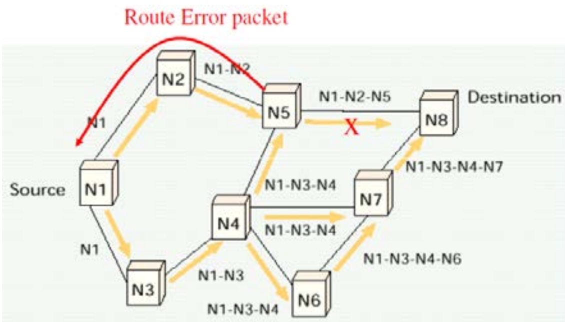

Fig. 8 Building of the route record during route discovery

5. Temporary Ordered Routing Algorithm (TORA)

The Temporary Ordered Routing Algorithm (TORA) is a highly adaptive, efficient and scalable distributed routing algorithm based on the concept of link reversal. TORA is proposed for highly dynamic mobile, multi-hop wireless networks. It is a source-initiated on-demand routing protocol. TORA finds multiple routes between source node and destination node. The main feature of TORA is that the control messages are localized to a very small set of nodes near the occurrence of a topological change. To achieve this, the nodes maintain routing information about adjacent nodes. The protocol has three basic functions:

- Route Creation,
- Route Maintenance and
- Route Erasure.

TORA can suffer from unbounded worst-case convergence time for very stressful scenarios. TORA has a unique feature of maintaining multiple routes to the destination so that topological changes do not require any reaction at all. The protocol reacts only when all routes to the destination are lost. In the event of network partitions the protocol is able to detect a partition and erase all invalid routes [19, 20].

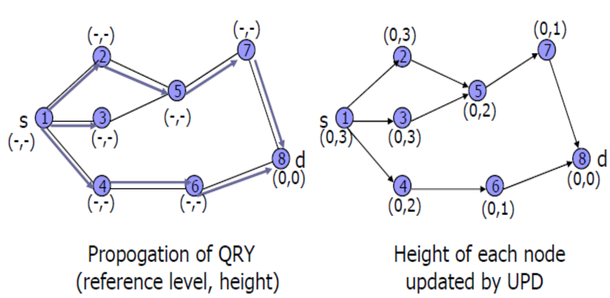

Fig. 9: Route Creation of TORA

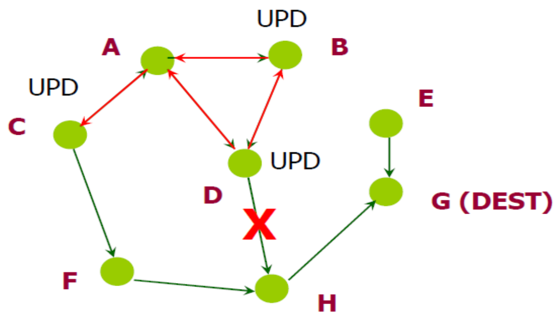

Fig. 10: Route Maintenance

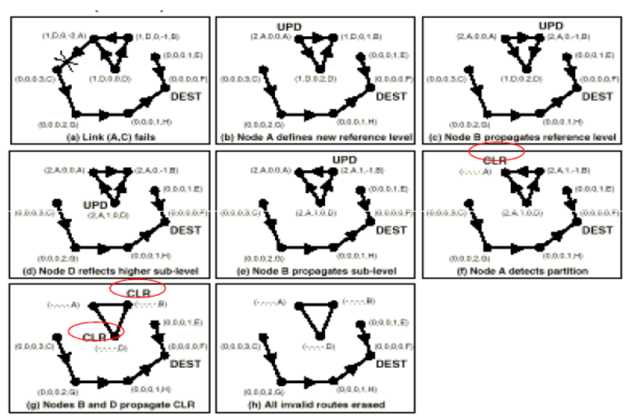

Fig. 11: Erase Invalid Routes after a failure which Partitions the network

6. Simulation

The simulations were performed using Network Simulator 2 (Ns-2), particularly popular in the ad hoc networking community. The traffic sources are CBR (continuous bit –rate). The source-destination pairs are spread randomly over the network. The mobility model uses 'random waypoint model' in a rectangular filed of 500m x 500m with 50 nodes. During the simulation, each node starts its journey from a random spot to a random chosen destination. Once the destination is reached, the node takes a rest period of time in second and another random destination is chosen after that pause time. This process repeats throughout the simulation, causing continuous changes in the topology of the underlying network. Different network scenario for different number of nodes and pause times are generated [18].

Table 1: Simulation Parameters

SL.NO.	***PARAMETER***	***VALUE***
1.	Simulator	ns-2

2.	Protocols studied	AODV, DSR and TORA
3.	Simulation time	200 sec
4.	Simulation area	500×500
5.	Transmission range	250 m
6.	Node movement model	Random waypoint
7.	Bandwidth	2 Mbps
8.	Traffic type	CBR
9.	Data payload	Bytes/packet

7. Metrics for Performance Analysis

- Throughput: Ratio of the packets delivered to the total number of packets sent.
- Packet Delivery: Packet Delivery Ratio in this simulation is defined as the ratio between the number of packets sent by constant bit sources (CBR) and numbers of packets received by CBR sink at destination.

$$PktDelivery\% = \frac{\sum_{1}^{n} CBRrecv}{\sum_{1}^{n} CBRrecv} \times 100 ......Equation1$$

- Minimum Delay: Minimum Time taken for the packets to reach the next node.
- Maximum Delay: Maximum Time taken for the packets to reach the next node.
- Average End-to-End Delay: Time taken for the packets to reach the destination.

$$Avg\_End-to-End\_Delay = \frac{\sum_{1}^{n}(CBRsentTime - CBRrecvTime\_)}{\sum_{1}^{n} CBRrec} ......Equation2$$

- Simulation Time: The time for which simulations will be run i.e. time between the starting of simulation and when the simulation ends.
- Network size: It determines the number of nodes and size of area that nodes are moving within. Network size basically determines the connectivity. Very lesser nodes in the same area mean fewer neighbours to send request to, but also smaller probability of collision.
- Number of Nodes: This is constant during the simulation. We used 50 nodes for simulations.
- Pause time: Node will stop a “pause time” amount before moving to another destination point.
- Jitter: Jitter describes standard deviation of packet delay between all nodes.
- Power Consumption: The total consumed energy divided by the number of delivered packet.
- Average Packet Delay: It is the sum of the times taken by the successful data packets to travel from their sources to destination divided by the total number of successful packet. The average packet delay is measured in seconds.
- Average Hop Count: It is sum of the times taken by the successful data packets to travel from their sources to destination divided by the total number of successful packets. The average hop count is measured in number of hops.
- Node Expiration time (NET)**:** it is the time for which a node has been alive before it must halt transmission due to battery reduction. The node expiration is plotted as number of nodes alive at a given time, for different point in time during the simulation.

8. Result Analysis

8.1. Packet Delivery Fraction (PDF) or Throughput

- TORA performs buffer at high mobility but in other cases it shows to have lower throughput.
- As per result AODV have the best overall performance.
- On-Demand protocols (DSR and DSDV) drop a considerable number of packets during the route discovery phase; a route acquisition takes time proportional to the distance between the source and destination.
- Packet drops are fewer with proactive protocols as alternate routing table entries can always be assigned in response to link failures.
- TORA can be quite sensitive to the loss of routing packets compared to the other protocols.
- Buffering of data packets while route discovery in progress, has a great potential of improving DSR, AODV and TORA performance.
- AODV has a slightly lower packet delivery performance than DSR because of higher drop rates.
- AODV uses route expiry, dropping some packets when a route expires and a new route must be

found

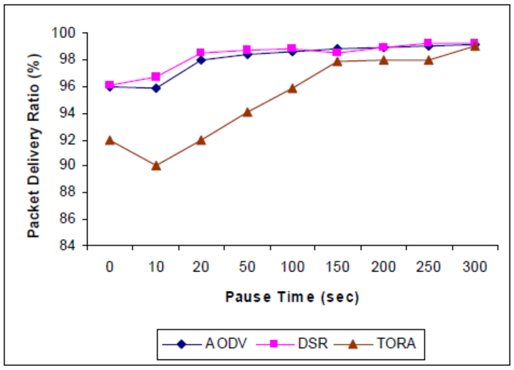

Fig.12: Packet delivery fraction vs. Pause time for 50-nodes with 10 sources.

9.	Provide Loop-Free Routers	YES	YES	YES
10	Route Optimization	YES	YES	YES
11.	Scalability	YES	YES	YES
12.	Route Reconfiguration	Erase Route Notify Source	Erase Route Notify Source	Link Reversed Route Repair
13.	Proactive	NO	NO	YES
14.	Routing Philosophy	FLAT	FLAT	FLAT

8.2. End-to-End Delay

- AODV and DSR show poor delay characteristics as their routes are typically not the shortest over a period of time due to node mobility.
- AODV performs a little better delay-wise and can possibly do even better with some fine-tuning of this timeout period by making it a function of node mobility.
- TORA too has the worst delay characteristics because of the loss of distance information with progress.
- TORA route construction may not occur quickly.
- In DSR Route Discovery is fast, therefore shows a better delay performance than the other reactive protocols at low pause time (high mobility).

- In case of congestion (high traffic) DSR control messages get loss thus eliminating its advantage of fast establishing new route.
- Without any periodic hello messages, DSR outperforms the other protocols in terms of overhead.
- In most cases, both the packet overhead and the byte overhead of DSR are less than a quarter of AODV's overhead.
- The excellent routing load performance of DSR is due to the optimizations possible by virtue of source routing.
- TORA's performance is not very competitive with the distance vector and on-demand protocols.
- TORA shows a better performance for large

Sl.No	Protocol Property	AODV	DSR	TORA
1.	Multi-Cost Routes	NO	YES	YES
2.	Distributed	YES	YES	YES
3.	Unidirectional Link	NO	YES	YES
4.	Multicast	YES	NO	NO
5.	Periodic Broadcast	YES	NO	YES
6.	QoS Support	NO	NO	YES
7.	Routes Information Maintained in	Route Table	Route Cache	Adjacent Routers(One-Hop-Knowledge)
8.	Reactive	YES	YES	YES

networks with low mobility rate.

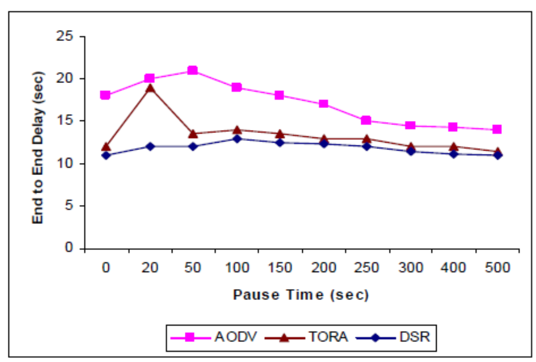

Fig.13: End- to -End Delay vs. Pause time for 50-node model with 10 sources.

Table 2: Comparison between AODV, DSR and TORA

9. Conclusion

This work is an attempt towards a comprehensive performance evaluation of three commonly used mobile ad hoc routing protocols (DSR, TORA and AODV). Over the past few years, new standards have been introduced to enhance the capabilities of ad hoc routing protocols. As a result, ad hoc networking has been receiving much attention from the wireless research community. In this paper, using the latest simulation environment NS 2, we evaluated the performance of three widely used ad hoc network routing protocols using packet-level simulation. The simulation characteristics used in this research, that is, packet delivery fraction and end-to-end delay are unique in nature, and are very important for detailed performance evaluation of any networking protocol. We can summarize our final conclusion from our experimental results as

- Increase in the density of nodes yields to an increase in the mean End-to-End delay.
- Increase in the pause time leads to a decrease in the mean End-to-End delay.
- Increase in the number of nodes will cause increase in the mean time for loop detection.

In short, AODV has the best all round performance. DSR is suitable for networks with moderate mobility rate. It has low overhead that makes it suitable for low bandwidth and low power network. TORA is suitable for operation in large mobile networks having dense population of nodes. The major benefit is its excellent support for multiple routes and multicasting.

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