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Performance Evaluation and Comparison of On-Demand Routing Protocols for Ad Hoc Networks: DSR, AODV, AOMDV, TORA

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ABSTRACT

Routing in mobile ad-hoc networks is an integral aspect of communication between devices. Routing is considered to be a challenging task in MANETs due to the drastic and unpredictable changes in network topologies as a result of the random and frequent movement of the nodes and due to the absence of any centralized control. Several routing protocols have been designed and developed to perform under various network environments. In this work a systematic simulation based performance study of the four prominent routing protocols: Ad hoc on Demand Multipath Routing Distance Vector (AOMDV), Dynamic Source Routing (DSR), Ad Hoc On Demand Distance Vector (AODV) and Temporarily Ordered Routing (TORA) protocols in the simulated networking environment under varying number of nodes in various scenarios is performed. These protocols use on-demand routing and have different protocol mechanisms leading to differences in performance. The performance is analyzed and evaluated based on end to end delay, packet delivery ratio, routing overheads and through-put done by varying network load, and the size of the network. Based on the observations, we make recommendations about the performance of the protocols.

Keywords**: Mobile ad hoc network, varying number of nodes, packet delivery fraction, average end-to-end delay, routing overhead.**

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1. INTRODUCTION

MANET: An mobile ad-hoc network is a group of mobile devices which are self organizing, self-controlled in a topologically ever changing network [1-6]. The main advantage of these networks is that they do not require on any pre-established infrastructure or centralized control. MANETs are autonomous networks with a number of mobile nodes each equipped with wireless interfaces to communicate with each other either directly or through intermediary nodes. MANETs use multi-hop communication in which each node plays the role of both the host as well as the router. The transmission range of the nodes in a MANET is limited thereby restricting the total area of coverage. MANETs work as individual separated groups and the applications require connection to the external network such as Internet or LAN to access external resources.

2. ROUTING PROTOCOLS IN MANETs

2.1 Routing

Routing is a fundamental engineering task on the internet. It is the process of finding a path from source to destination host. Various metrics decide the efficiency of the route in terms of number of hops, traffic, security etc. The primary objective of routing protocols is to have minimum delay in transmission, an increased network throughput, maximize network lifetime and maximize energy efficiency. The two important tasks of routing are to determine optimal routing path and the transfer of packets. Routing becomes complex as the size of the networks increase because of many potential intermediate destinations a packet might traverse before reaching its destination [6] increase and they are mobile. Ad-hoc networks use various techniques for tracking changes in the network topology, rediscover new routes when older paths break. Also since ad hoc networks have no infrastructure and these operations should be performed with collective cooperation of all nodes.

2.2 Classification of Routing Protocols for MANET

Based on the criteria of when the source node possesses a route to the destination, the routing protocols in MANETs are categorized into three main categories.

- Table driven/ Proactive
- Demand driven / Reactive
- Hybrid

Volume: 07 Issue: 02 Pages: 2666-2673 (2015) ISSN: 0975-0290

Many protocols already have been developed for MANET environment. They can be classified in many ways [6][7][8][9][10].

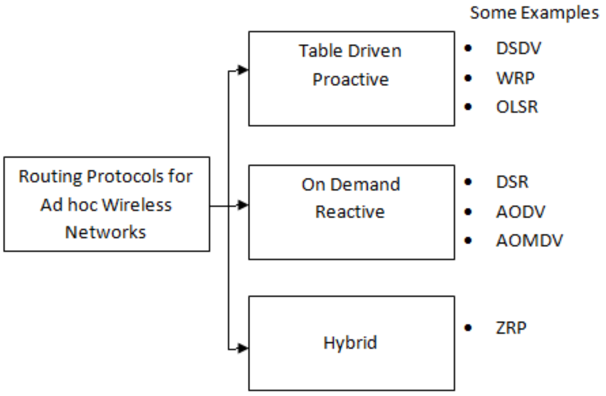


Fig 1: Classification of routing protocols

Flat Routing protocols for Mobile ad hoc networks can be classified into the following main categories:

2.2.1 Proactive Protocols

Proactive routing protocols endeavour to administer consistent, progressive routing information between every pair of nodes. Here route updates in the network are proactively propagated in fixed time intervals. These protocols are also known as table-driven protocols because information related to routing is stored in tables. The proactive routing approaches intended for ad hoc networks are inferred from the conventional routing protocols. The proactive approaches essentially ensure that each node in the network maintains a route to every other node in the network constantly. The advantage of proactive approaches is that routes are accessible the moment they are requested. To begin packet transmission and to send data packets to some destination, a source has to simply check its routing tables, as each node consistently maintains periodically updated routes to every other node in the network. However, the primary disadvantage of these protocols is that the control overhead can be critical in vast networks or in networks with rapidly moving nodes. Pro active driven protocols though are fast in getting path related information, the maintenance of the up to date network information is associated with large overhead traffic needing significant amount of bandwidth. Even if there is no data traffic, the process of maintaining the routes to the reachable nodes is continuously executed. Some of the proactive routing protocols are – DSDV: Destination-Sequenced Distance-Vector routing protocol, WRP: Wireless routing protocol, OLSR: Optimized Link State routing protocol and FSR: Fisheye State Routing.

2.2.2 Reactive Protocols

Wired networks change relatively less often, resources are abundant, connectivity patterns remain almost the same and maintaining full connectivity graphs is an advantage. The advantage of proactive routing is the instant availability of a route. However the constant need of maintaining routes from a node to every other node imposes additional overheads. Reactive routing is an approach where the routing process needs to discover a route only whenever packets have to be sent from a source to a destination. In reactive routing, each node has no pre-built routing table or global information from which routes can be determined. Given the node's mobility in a wireless network, finding and maintaining routes is an important process. Here the route discovery process happens more often, but the route discovery mechanism requires a much lower control overhead traffic in comparison to the control overhead traffic for updating routing tables of the nodes. The scalability is higher in reactive routing than in proactive routing. However the overall delay increases in a reactive routing technique because the source node needs to wait for the discovery process each time it attempts to send a message; (Abolhasan M et al, 2004; Eiman A and Biswanath M, 2012)

In an ad hoc network, however, link connectivity can change frequently and control overhead is expensive. Reactive routing techniques also known as on-demand routing, adopt a very different approach to routing than proactive protocols. The reactive routing approaches have took a departure from conventional Internet routing approaches as here, the routes are discovered only when they are actually need rather than maintaining a constant route between all pairs of network nodes [1]. Whenever a source node needs to send data packets to some destination, it checks its route table to figure out whether it has a route. If no route exists, a route discovery procedure is performed to find a path to the destination. Hence, route discovery becomes on-demand. The route discovery procedure commonly comprises of the network- wide flooding of a request message. To reduce overhead, the search area may be reduced by various advancements.

The benefit of this approach is that signalling overhead is liable to be reduced contrasted with the proactive approaches, especially in networks with low to moderate traffic loads. When the number of data sessions in the network increases, it could happen that the overhead generated by the route discoveries approaches may even surpass, that of the proactive approaches. Another drawback of the reactive approach is that when a route is needed by a source node, there is some finite latency in discovering the route, which is in contrast with the proactive approach i.e. routes are typically available the moment they are needed. Hence, there is a delay in beginning the data session in reactive routing.

Some of the popularly used reactive routing protocols are DSR: Dynamic Source Routing, AODV : Ad hoc On-demand Distance Vector, AOMDV : Ad hoc on Demand Multipath Routing Distance Vector, Temporally Ordered Routing Algorithm (TORA) protocols.

2.2.3 Hybrid Routing Protocols

Hybrid protocols present the combination of the proactive and reactive approaches. For e.g. Zone Routing Protocol (ZRP) is an example of Hybrid Routing Protocol which uses proactive mechanism for route establishment within the nodes neighbourhood, and reactive mechanism for communication amongst the neighbourhood [2].

Volume: 07 Issue: 02 Pages: 2666-2673 (2015) ISSN: 0975-0290

3. DYNAMIC SOURCE ROUTING PROTOCOL DSR [13, 14]

DSR [13][14] is a reactive routing protocol which is particularly designed for the nodes in a MANET. It dynamically discovers routes across from the source to destination in multiple hops. It doesn't need any existing network infrastructure or administration making these networks to be completely self-organizing and self-configuring. DSR uses On-Demand Routing; it verifies the best possible route only when packets need to be forwarded [5] and this process of finding the path is executed only when nodes require to send data. DSR is based on the Link-State Algorithms where each node is proficient to save the best way to a destination.

Routing in DSR is done using two phases:

1. Route discovery or construction: The optimum path for a communication between a source node and target node is determined by route discovery process.
2. Route maintenance: Route Maintenance ensures that the communication path remains optimum and loop-free even if there are changes in network conditions which require altering routes during a transmission.

The mobile nodes maintain route caches, which store all the routes known to that node. When a node comes to know of a new route it updates its own route cache. In DSR, which uses "source routing" each data packet carries the complete path through which it passes to reach the destination node. It allows the sender node to have a control on the routes used for sending its own packets and supports the use of multiple routes to any destination.

When a node wants to transmit data to a destination, it first consults its own route cache to check for an available route. If there is a route entry to that destination, the source uses that route to send the packets. If a source node doesn't have route to the destination, it initiates a Route Request. This Route Request packet is broadcast through the network and reaches all the nodes within the wireless transmission range. Each node upon receiving a Route Request packet re broadcasts it to its neighbors if, it has not forwarded it already or if, that node itself is not the destination node and provided the packets time to live (TTL) counter has not exceeded.

Every Route Request contains the source and the destination identities, a unique request identification given by the source, a record listing of the intermediary nodes through which the route discovery is going to take place. Initially the record listing at the source is just an empty list and it gets appended with node addresses along the path it traverses to reach the destination. As the other node receive this Route Request and if it happens to be the target of the Route Discovery, returns a "Route Reply" back to the source node which initiated the Route Discovery in the first place, along with the complete route record listing which has been accumulated with the path from the Route Request onwards; the source node on receiving this Route Reply caches this route in its Route Cache for sending subsequent packets to this destination. The unique request identification number on the packet is used to prevent loop formations and avoid multiple transmissions of the same Route Request by intermediate nodes that receive it through multiple paths. Thus, all nodes except the destination forward the Route Request packet during the route construction phase.

Every node which is the source node or a forwarding node along the discovered path to the destination is responsible for confirming that data can flow over the link from that node to the next hop. If any link on a source route is broken, RERR i.e. the route error packets are sent to the source node and it is notified of route break. Hence the source now removes the route using this link from its cache. The source node reinitiates a new route discovery process if this route is still needed. Route breaks are handled by implementing Route Maintenance procedures.

DSR makes very aggressive use of source routing and route caching, the forwarding nodes too cache the routes which they see while forwarding a packet, for possible future use.

Advantages and Limitations of DSR

It has an increased routing overhead because to send a packet the source must know the complete hop sequence it needs to traverse to the destination. This requires that the sequence of hops is included in each packet's header, thereby increasing the routing overhead.

However, one of the advantages of source routing is that intermediate nodes can learn routes available in the packets they are forwarding, avoiding the need for an update of routing information, thereby reducing costs in terms of time, bandwidth and energy.

Routing loops are avoided due to the availability of the complete route at a single node instead of making the decision hop-by-hop [14].

The routing packet overhead of DSR scales automatically to the requirement reacting to the changes in routes which are currently in use.

The protocol allows multiple routes to any destination, allowing the sender node to select and control the routes it uses to route packets this provides for load balancing and increased robustness [14].

It does not require hello packet transmissions, which are used by nodes to inform its neighbors of its presence.

4. ADHOC ON DEMAND DISTANCE VECTOR (AODV) ROUTING PROTOCOL [15], [3]

Distance vector routing is associated with two aspects: the *distance*, or metric, of a destination, and the *vector*, or direction to take to get there. AODV uses distance Vector Routing. Here each node knows the other nodes in the vicinity and the associated costs to reach them. AODV is a reactive routing protocol, which is collectively based on DSDV using the destination sequence numbers (Perkins CE and Bhagwat P, 1994) and the on demand route discovery techniques used by DSR to formulate loop -free, on-demand, single path, distance vector protocol. Sequence numbers in AODV play a key role in ensuring loop freedom; however AODV protocol uses hop-by-hop routing instead of DSRs source routing.

Volume: 07 Issue: 02 Pages: 2666-2673 (2015) ISSN: 0975-0290

AODV minimizes system-wide broadcasts and initiates route discovery processes only when there is a need for a source node to send data to the destination node and are maintained only as long as they are required. AODV performs well in low, moderate, and relatively high mobile rates, under a variety of data traffic loadings. However, it makes no provisions for security [3].

4.1 Working Principle of AODV:

When a node wants to send information to a destination node, the entries in route table are checked for current existent routes to the destination nodes. If a route is available then the data packets are forwarded through the appropriate hops in that route to reach the destination. If a route is not available then a route discovery process is initiated.

In the process of Route Discovery AODV uses three types of messaging: Route Request (RREQ), Route Reply (RREP), and Route Error (RERR) messages.

RREQ- AODV initiates a route discovery process using Route Request (RREQ), it is the source node which creates the RREQ packet. The RREQ packet contains the address of the source, a generated current sequence number, the address of the destination node, the destination's last sequence number. A broadcast ID is sent along with the RREQ. This broadcast ID is incremented for every initiation of RREQ. A time to live (TTL) value is carried by every route request which states the number of hops it has to be forwarded for. This value is first initialized at a predefined value at first transmission and afterwards it goes on incrementing at retransmissions. Retransmissions occur when there is no reply [4]. Every node is supposed to maintain two counters: node sequence number and broadcast id. Basically, the sequence numbers are used to determine the timeliness of each data packet. The broadcast ID together with the IP address of the source node forms a unique identifier for RREQ identifying each request. The requests are sent using RREQ message. The information in connection with creation of a route is sent back in RREP message.

The RREQs which have been broadcast by the source node are in turn broadcast to its neighbours who in turn forward it to their neighbours and so on so forth. The source node sets a timer and waits for a reply. If there is no reply within a certain discovery period, the next RREQ is broadcast with a TTL value increased by an increment value. Every node receiving a RREQ message stores the reverse route entry back to the source node in its route table which helps in forwarding a RREP to the source. Every reverse route entry has a lifetime is associated with it and if this entry is not used within this lifetime, the route information is deleted. In case a RREQ is lost during transmission, the source node is allowed to start again the using route discovery mechanism.

RREP- A route reply message is unicasted to the originator of the RREQ if the receiver either is the node in the requested address or is having a valid route to the requested address. As the RREP is routed back along the reverse path set up by the intermediary nodes, a forward path entry to the destination too is set up the routing tables of the intermediary nodes. As the RREP traverses along the network back to the source node, a route has been established from source to the destination and hence the source node can begin the data transmission.

RERR- A route discovered between a source node and destination node is maintained as long it is needed by the source node. For the routes which are active, nodes monitor and keep track of the links of the next hops. In case a breakage is detected in the active route, a RERR message is broadcast to the other nodes notifying about the loss of the link and to reach to their predecessor nodes. This process continues until the source node is reached. The source node on getting the RERR either stops sending the data or requests for the route discovery mechanism by issuing a new RREQ message. It can happen that source node itself moves during an active session as there is movement in mobile ad hoc network, the source node reinitiates route discovery mechanism to establish a new route to destination.

Advantages and Limitations of AODV

1. On-demand route is established with small delay.
2. Link breakages in active routes can be efficiently handled
3. Destination sequence numbers are used to find the latest route to the destination.
4. Connection set up delay is less
5. Intermediate routes can lead to inconsistent routes if the source sequence number is old.
6. Multiple RERR packets in response to single RREQ packet may lead to heavy control overhead.
7. Periodic beaconing leads to bandwidth consumption.

5. AOMDV

AOMDV (Marina M. K and Das. S. R, 2001) protocol is a denotation to the AODV protocol . It computes multiple loop-free paths. New route discoveries are passed up by maintaining a few multiple redundant paths. The protocol switches routes when an earlier path fails. In case of all paths failing route discovery is reinitiated.

AOMDV Route Discovery

AOMDV route discovery mechanism enables computation of multiple link disjoint routes between source destination pairs. Intermediate nodes in the route between source and destination may form multiple routes to the destination, making available many routes. AOMDV finds node-disjoint or link-disjoint routes. The route discovery procedure sets up a reverse path backwards back to the source with the understanding of the path the route request (RREQ) has taken.. To find node-disjoint routes, each node examines the duplicate RREQs before rejecting these duplicate RREQs. Each RREQs arriving via a different neighbour of the source defines a node-disjoint path. (Marina M. K and Das. S. R, 2001)

The condition to set up a reverse route is that the RREQs reaching the destination must come via disjoint routes. To ensure disjoint routes, the RREQs reaching a destination must take the first hops from S with different nodes as

Volume: 07 Issue: 02 Pages: 2666-2673 (2015) ISSN: 0975-0290

shown in Fig-2. If in the path from source to the destination, were there two paths meeting at a node, the copy arriving second will not be sent further. Thus, all possible paths of a RREQ between any pair of nodes having unique first hops are guaranteed to be disjoint. The first hop information is included in the RREQ packet.(Marina M. K and Das. S. R, 2001).

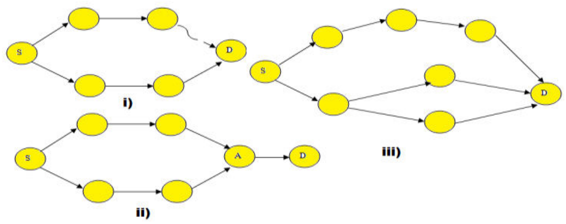


Fig 2: Node Disjointness

The reverse paths that have been created are used to send the multiple RREPs towards the source there by forming multiple forward paths. The destination nodes replies to the RREQ arriving via unique neighbours, disregarding the first hops of these RREQs which ensure that the links are disjoint at the first hop of the RREP as shown in Fig 3. With the first hop taken, the RREP takes the node disjoint reverse routes which were previously set up. Each RREP arriving at an intermediate node takes a different reverse route when multiple routes are already available and there is a possibility of RREPs crossing at an intermediate node.

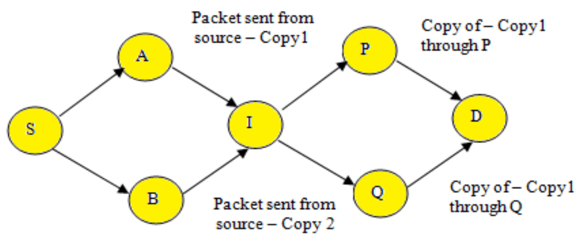


Fig 3: Link Disjointness

One of the advantages of using AOMDV is that it intermediate nodes in a route could also reply to RREQs, while still selecting disjoint paths. However these messages in the route discovery cause an increase in the overheads due to increased flooding. AOMDV being a multipath routing protocol, the destination too replies to the multiple RREQs it receives resulting in an increase in overhead [3]

Loops are prevented in case of the RREQs only the copy arriving first is forwarded further. But if intermediate nodes if choose to reply to RREP could cause loops. AOMDV uses sequence numbers to ensure freedom. The different routes identified for a destination will have different hop counts and the multiple next hops for that destination will have the same sequence number hence keeping track of a route. A route can be formed through an intermediate node only when this intermediate node advertises it. An advertised hop count is maintained for each destination by a node. Loop freedom is assured for a node by advertised hop counts. The advertised hop count is the maximum hop count for a particular destination. Each duplicate route advertisement received by a node defines an alternate path to the destination [9]. Alternative paths are only considered if they have less hop count than advertised hop count. Because the maximum hop count is used, the advertised hop count therefore does not change for the same sequence number. As route advertisements with a greater sequence number start to arrive for a destination, the next-hop list and the advertised hop count are reinitialized.

6. TEMPORARILY ORDERED ROUTING ALGORITHM (TORA)

Temporarily Ordered Routing Algorithm (TORA) is distributed, source initiated on demand routing protocol [16]. Link reversal algorithm is the basis for its implementation. As the topology changes the impact is on the routing protocol, TORA is designed to minimize the reactions to topological changes. The underlying design concept is that control messages will be typically localized to a very small set of nodes. TORA guarantees loop free routes and also provides multiple routes for any source/destination pair [9].

The routing activities associated with TORA can be identified as:

1. Creation of routes
2. Route Maintenance
3. Erasing routes.

Route creation activities basically assign directions to links in a network or portion of the network, thereby building and a directed acyclic graph rooted at the destination. Every node has an associated height in the network in TORA implementation. All the messages in the network flow downstream, from a node with higher height to the node with lower height. The query and update packets help in the identification of routes. When a node with no downstream links needs a route to destination, it will broadcast a query packet. The query packet will propagate through the network until it reaches the node that has route to destination or is destination itself [8]. Such a node will then broadcast update packet that contains the node height. Every node receiving this update packet will set its own height to a larger height which is specified in the update packet. The node will then broadcast its own update packet. Hence for a query there will be a number of directed links to the destination resulting in multiple routes. Each node maintains information about adjacent nodes and has capability to detect partitions because of which it performs well in highly dynamic networks.

When routes break and nodes understand that the routes to a certain destination no longer exist, it will adjust its height to a local maximum with respect to its neighbors after which it will transmit and UPDATE packet. If the neighbors of a node do not have finite height with respect to a destination, the node will attempt to rediscover a new route. When a node detects a partition, route erasure phase is necessary to be executed which is brought up by flooding a broadcast CLEAR packet throughout the network to erase the invalid route detected. When a node

Volume: 07 Issue: 02 Pages: 2666-2673 (2015) ISSN: 0975-0290

generates a CLEAR packet, there is a reset routing over the ad hoc network.

Benefits and Limitations of TORA

TORA supports multiple routes between any source and destination. If there are any failures in routes or removal of any nodes, it is quickly resolved without source intervention just by switching to an alternate route.

One of the limitations is that it depends on synchronized clocks among nodes in the ad hoc network. TORA depends on the intermediate lower layers for certain functionality presumes are all readily available.

7. EXPERIMENTAL RESULTS :

7.1 Performance Metrics

The metrics to evaluate the performance of ad-hoc routing protocols are:

Packet Delivery Fraction: Ratio of number of packets received by the destination from all the generated packets by the source. A higher Packet delivery fraction is desired by a network.

Average end-to-end Delay: It is the average delay time incurred when data packets are sent from the source to the destination which includes delay due to buffering, route discovery, transmission time, queuing time etc.

Throughput: It is the average rate of successful packets delivered per unit time.

Routing Overhead: is the number of routing packets generated for the data packets received. Nodes often change their location within network; some stale routes are generated in the routing table which leads to unnecessary routing overhead.

7.2 Evaluation scenario with varying network size

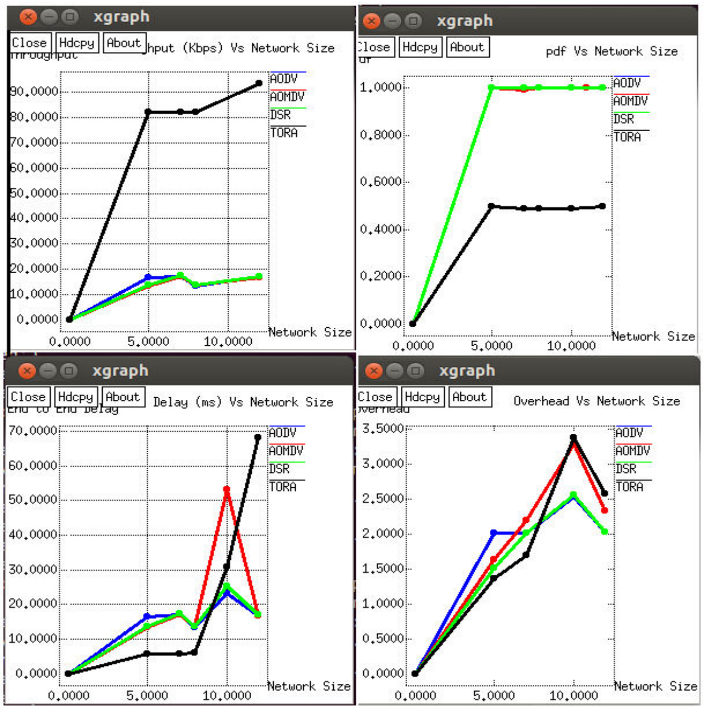
Simulation Results

In this section, the proposed method has been simulated in NS2.35 and the simulation results are presented.

Parameter	Value
1. Network Simulator	**Ns2.35**
2. Channel	**Wireless Channel**
3. Propagation Model	**Two Ray Ground**
4. Queue	**Drop Tail**
5. Antenna	**Omni-Directional**
6. Routing Protocol	**AODV, DSR ,AOMDV,TORA**
7. Energy Model	**Radio Energy Model**
8. Initial Energy	**100J**
9. Application	**FTP**
10. Transport	**TCP**
11. Protocols	**AODV, DSR, AOMDV,TORA**
12. Area Size	**800 X 800**
13. Packet Size	**512**
14. Queue Length	**50**

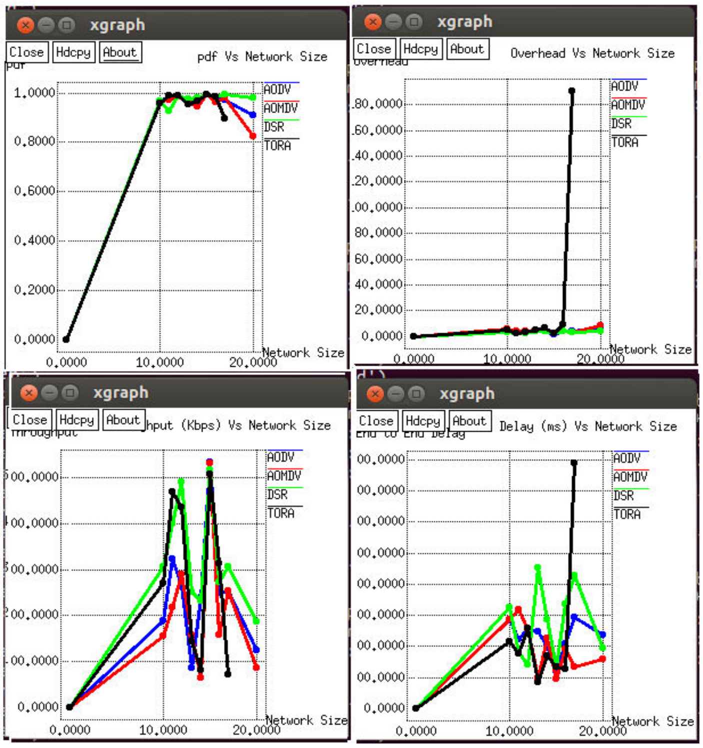
Table 1: Simulation Parameters

Scenario 1: Number of Nodes: 5 to 12

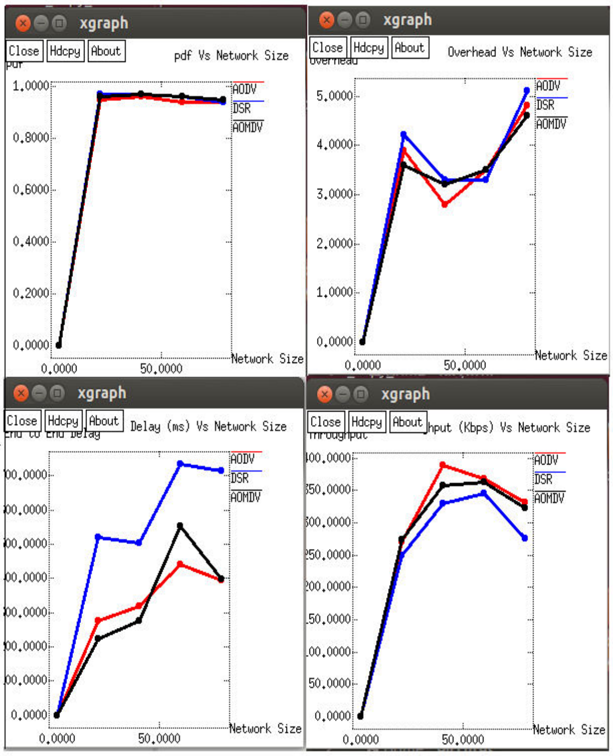


Volume: 07 Issue: 02 Pages: 2666-2673 (2015) ISSN: 0975-0290

Scenario 2: Number of Nodes: 5 to 20



Scenario 3

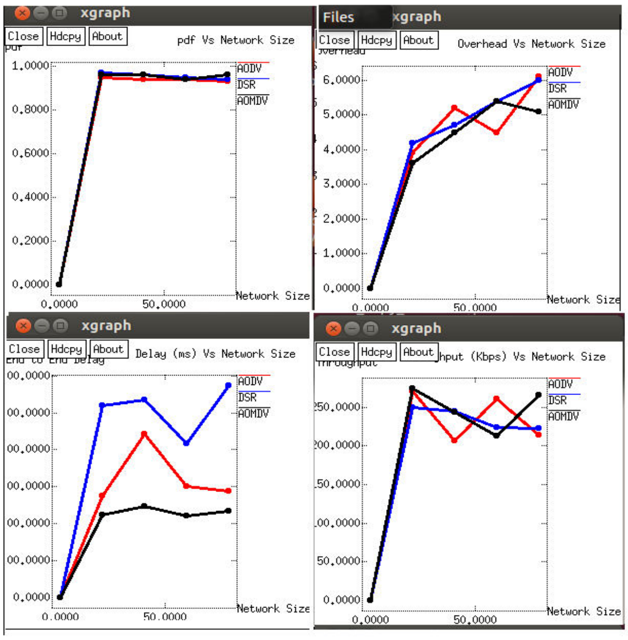


Scenario 3				
	Parameter	**AODV**	**DSR**	**AOMDV**
No. of Nodes 20	GoodPut	271	249	274
	End to End Delay	275	519	223
Active Connections: 5	Packet Delivery Fraction	.95	.97	.96
	Overheads	3.9	4.2	3.63
No. of Nodes 40	GoodPut	389	329	357
	End to End Delay	320	502	277
Active Connections: 10	Packet Delivery Fraction	.96	.97	.97
	Overheads	2.8	3.3	3.22
No. of Nodes 60	GoodPut	369	346	363
	End to End Delay	442	733	551
Active Connections: 15	Packet Delivery Fraction	.94	.96	.96
	Overheads	3.5	3.3	3.5
No. of Nodes 80	GoodPut	332	275	322
	End to End Delay	394	713	397
Active Connections: 20	Packet Delivery Fraction	.94	.94	.95
	Overheads	4.8	5.1	4.6

Scenario 4				
	Parameter	**AODV**	**DSR**	**AOMDV**
No. of Nodes: 20	GoodPut	271	249	274
	End to End Delay	275	519	223
Active Connections: 5	Packet Delivery	.95	.97	.96
	Overheads	3.9	4.2	3.63
No. of Nodes: 40	GoodPut	207	245	244
	End to End Delay	441	536	246
Active Connections : 5	Packet Delivery	.94	.96	.96
	Overheads	5.2	4.7	4.5
No. of Nodes : 60	GoodPut	261	224	213
	End to End Delay	300	416	221
Active Connections: 5	Packet Delivery	.94	.95	.94
	Overheads	4.5	5.4	5.4
No. of Nodes: 80	GoodPut	214	222	265
	End to End Delay	288	573	234
Active Connections: 5	Packet Delivery	.93	.94	.96
	Overheads	6.14	6.0	5.06

Volume: 07 Issue: 02 Pages: 2666-2673 (2015) ISSN: 0975-0290

Scenario 4



We have done comprehensive simulation, to determine average end-to-end delay, throughput, packet delivery ratio and routing overheads for the routing protocols DSR, AODV, AOMDV and TORA by varying network size and changing the active no. of connections time.

TORA has an extra requirement that all nodes must have synchronized clocks [17]. As the Number of nodes become large the performance of TORA decreases drastically. AOMDV has more message overheads during route discovery due to increased flooding and also it being a multipath routing protocol. To monitor link breakages in AODV, nodes intermittently exchanges hello messages with their neighbors, thereby incurring extra control traffic overhead.

In DSR the byte overhead in each packet will increase whenever network topology changes since DSR protocol uses source routing and route cache, hence has increased overheads. Both AODV and DSR protocols have illustrated similar characteristics and perform very well. AODV has less traffic overhead and is more scalable because of the size limitation of route record field. .

It is found that AODV has maximum throughput less end to end delay under low traffic. As network becomes dense DSR and AOMDV too perform well in terms of throughput.

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