Int. J. Communications, Network and System Sciences, 2010, 3, 511-522
doi:10.4236/ijcns.2010.36069 Published Online June 2010 (http://www.SciRP.org/journal/ijcns/).

An Empirical Examination of Routing Protocols in Mobile Ad Hoc Networks

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Received March 26, 2010; *revised April* 28, 2010; *accepted May* 29, 2010

Abstract

A Mobile Ad hoc NETwork (MANET) is a self-organizing, temporary, infrastructure-free, multi-hop, dynamic topology wireless network that contains collection of cooperative autonomous freely roaming mobile nodes. The nodes communicate with each other by wireless radio links with no human intervention. Each mobile node functions as a specialized router to forward information to other mobile nodes. In order to provide efficient end-to-end communication with the network of nodes, a routing protocol is used to discover the optimal routes between the nodes. The routing protocols meant for wired networks can not be used for MANETs because of the mobility of nodes. Routing in ad hoc networks is nontrivial due to highly dynamic nature of the nodes. Various routing protocols have been proposed and widely evaluated for efficient routing of packets. This research paper presents an overview on classification of wide range of routing protocols for mobile ad hoc wireless networks proposed in the literature and shows the performance evaluation of the routing protocols: DSDV, AODV, FSR, LAR, OLSR, STAR and ZRP using the network simulator *QualNet* 4.0 to determine which protocols may perform best in large networks. To judge the merit of a routing protocol, one needs performance metrics (throughput, end-to-end delay, jitter, packet delivery ratio, routing overhead) with which to measure its suitability and performance. Our simulation experiments show that the LAR protocol achieves relatively good performance compared to other routing protocols.

Keywords: Mobile Ad Hoc Networks, Routing Protocols, LAR, QualNet 4.0, Performance Metrics, Simulations, Performance Evaluation

1. Introduction

The advent of ubiquitous computing and the proliferation of portable computing devices have raised the importance of mobile and wireless networking. Wireless networking is an emerging technology that allows users to access information and services electronically, regardless of their geographic position. *Ad hoc* is a Latin word, which means "*for this purpose only*". The term "ad hoc" tends to imply "can take different forms" and "can be mobile, stand alone, or networked" [1]. Ad hoc networks have the ability to form "on the fly" and dynamically handle the joining or leaving of nodes in the network. Mobile nodes are autonomous units that are capable of roaming independently. Typical mobile ad hoc wireless nodes are Laptops, Personal Digital Assistants, Pocket PCs, Cellular Phones, Internet Mobile Phones, Palmtops or any other mobile wireless devices. All of these have the capability and need to exchange information over a wireless medium in a network. Mobile ad hoc wireless devices are typically lightweight and battery operated.

A mobile ad hoc network (MANET) is an adaptive, self-configurable, self-organizing, infrastructure-less multi-hop wireless network with unpredictable dynamic topologies [2]. By adaptive, self-configurable and self-organizing, means an ad hoc network can be formed, merged together or partitioned into separated networks on the fly depending on the networking needs. *i.e.* a formed network can be deformed on the fly without the need for any system administration. By infrastructure-less, means an ad hoc network can be promptly deployed without relying on any existing infrastructure such as base stations for wireless cellular networks. By multi-hop wireless, means, in an ad hoc network the routes between end users may consists of multi-hop wireless links.

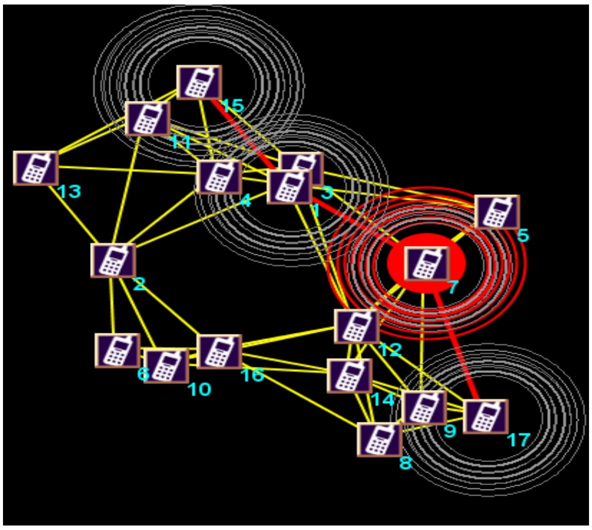

Figure 1. Communication scenario in MANET.

In addition, each node in a mobile ad hoc network is capable of moving independently and forwarding packets to other nodes.

The important characteristics of ad hoc wireless networks [2] are: dynamic topologies, low bandwidth, limited battery power, decentralized control, weak physical protection, etc. *Dynamic Topologies*: The nodes in ad hoc wireless networks are free to move independently in any direction. The network topology changes randomly at unpredictable times and primarily consists of bidirectional links. *Low Bandwidth*: These networks have lower capacity and shorter transmission range than fixed infrastructure networks. The throughput of wireless communication is lesser than wired communication because of the effect of the multiple access, fading, noise, and interference conditions. *Limited Battery Power*: The nodes or hosts operate on small batteries and other exhaustible means of energy. So, energy conservation is the most important design optimization criteria. *Decentralized Control*: Due to unreliable links, the working of ad hoc wireless network depends upon cooperation of participating nodes. Thus, implementation of any protocol that involves a centralized authority or administrator becomes difficult. *Weak Physical Protection*: Nodes in ad hoc wireless networks are usually compact, soft, and hand-held in nature. Today, portable devices like mobile phones or personal digital assistants (PDAs) are getting smaller and smaller. They could get damaged or lost or stolen easily and misused by an adversary.

The domain of applications for ad hoc wireless networks is diverse, ranging from small, static networks that are constrained by power sources, to large-scale, mobile, highly dynamic networks [2,4]. Such networks are frequently viewed as a key communications technology enabler for network-centric warfare and military tactical operations-for fast establishment of military communications and troop deployments in hostile and/or unknown environments, disaster relief operations-for communication in environments where the existing infrastructure is destroyed, search and rescue operations and emergency situations-for communication in areas with no wireless infrastructure support, law enforcement-for secure and fast communication during law enforcement operations, commercial use-for enabling communications in exhibitions, conferences & large gatherings, intelligent transportation systems and fault-tolerant mobile sensor grids. Most of these applications demand a secure and reliable communication.

2. Routing in Mobile Ad Hoc Networks

Mobile hoc network (MANET) is built on the fly where a number of mobile nodes work in cooperation without the engagement of any centralized access point or any fixed infrastructure. The nodes in the network are free to move independently in any direction. Node mobility causes route changes. The nodes themselves are responsible for dynamically discovering other nodes to communicate. When a node wants to communicate with a node outside its transmission range, a multi-hop routing strategy is used which involves some intermediate nodes. The network's wireless topology changes frequently and randomly at unpredictable times. Every node in ad hoc wireless network acts as a router that discovers and maintains routes in the network. Hence, the primary challenge is to establish a correct and efficient route between a pair of nodes and to ensure the correct and timely delivery of packets. Route construction should be done with a minimum of overhead and bandwidth consumption. Various protocols-proactive, reactive and hybrid-have been proposed and widely evaluated for efficient routing of packets in the literature [3].

Routing protocols [5] often are very vulnerable to node misbehavior. A node dropping all the packets is considered as malicious node or selfish nodes. A malicious node misbehaves because it intends to damage network functioning. A selfish node does so because it wants to save battery life for its own communication by simply not participating in the routing protocol or by not executing the packet forwarding. A malicious node could falsely advertise very attractive routes and thereby convince other nodes to route their messages via that malicious node.

3. Routing Protocols in Mobile Ad Hoc Networks

The main objective of ad hoc routing protocols is how to deliver data packets among nodes efficiently without predetermined topology or centralized control. Expected properties of MANET routing protocols are [6]: a routing protocol for MANET should be distributed in manner in order to increase its reliability, the routing protocol should assume routes as unidirectional links, the routing protocol should be power-efficient, the routing protocol should consider its security, and a routing protocol should be aware of Quality of Service (QoS). Based on the method of delivery of data packets from the source to destination, classification of the MANET routing protocols could be done as unicast, multicast or geocast routing protocols [6].

Unicast Routing Protocols: The routing protocols that consider sending information packets to a single destination from a single source.

Multicast Routing Protocols: Multicast is the delivery of information to a group of destinations simultaneously. Multicast routing protocols for MANET use both multicast and unicast for data transmission. Multicast routing protocols for MANET can be classified again into two categories: tree-based and mesh-based multicast routing protocols. *Mesh-based routing protocols* use several routes to reach a destination while the *tree-based protocols* maintain only one path. Tree-based protocols ensure less end-to-end delay in comparison with the mesh-based protocols.

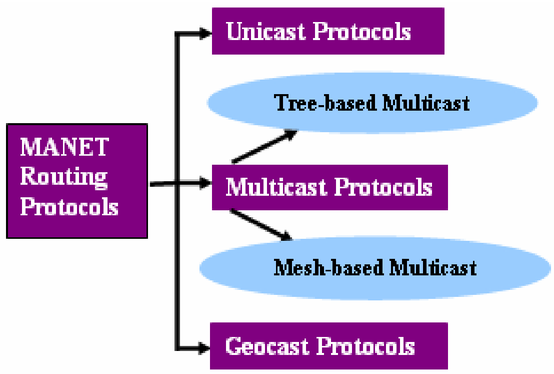

Figure 2. Classification of routing protocols.

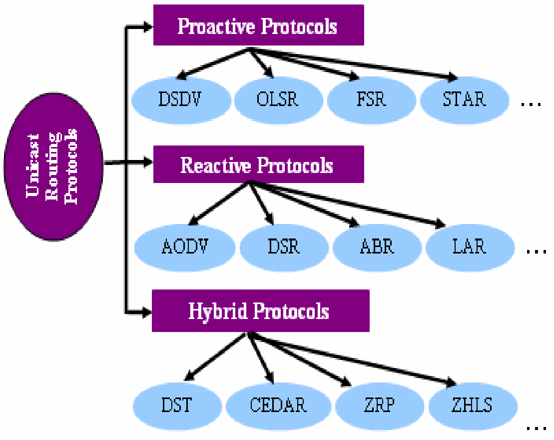

Figure 3. Classification of unicast routing protocols.

Geocast Routing Protocols: The routing protocols aim to send messages to some or all of the wireless nodes within a particular geographic region. Often the nodes know their exact physical positions in a network, and these protocols use that information for transmitting packets from the source to the destination(s).

Ad hoc wireless network unicast routing protocols can be further classified into three major categories based on the routing information update mechanism: proactive or table driven, reactive or on-demand, and hybrid routing protocols.

3.1. Proactive Routing Protocols

In *proactive routing protocols*, also known as table-driven routing protocols, each node maintains one or more tables that contain consistent and up-to-date routing information to every other node in the network. The routing information is usually kept in a number of different tables. Proactive protocols continuously learn the global topology of the network by exchanging topological information among the network nodes. When the network topology changes, the nodes propagate update messages and the topology change information is distributed across the network. If the network topology changes too frequently, the cost of maintaining the network might be very high. Each node continuously evaluates routes to all reachable nodes. The overhead to maintain up-to-date network topology information is high.

Some of these protocols are: Destination Sequenced Distance Vector routing protocol (*DSDV*), Optimized Link State Routing protocol (*OLSR*), Fisheye State Routing protocol (*FSR*), Source Tree Adaptive Routing protocol (*STAR*), Wireless Routing Protocol (*WRP*), Global State Routing (*GSR*), Cluster-head Gateway Switch Routing protocol (*CGSR*), Hierarchical State Routing protocol (*HSR*).

3.1.1. Destination Sequenced Distance Vector Routing Protocol (DSDV)

The Destination Sequenced Distance Vector (DSDV) [9] is a proactive unicast routing protocol that solves the major problem associated with distance vector routing of wired networks, *i.e.* count-to-infinity, by using destination sequence numbers. It uses the classical Bellman-Ford routing algorithm with some improvements on routing performance that guarantees loop free routes. Each node maintains a routing table that stores all possible available routes for each destination, the hop counts as routing metrics to reach the destination and the unique sequence numbers to keep up-to-date information about its neighbors. A sequence number created by the destination is used to distinguish stale routes from new one and avoids formation of route loops. The route with higher sequence number is newer. If two routes have the same sequence number then the route with the best metric (*i.e.* shortest route) is used.

Every node periodically exchange routing table updates to its immediate neighbors. The route updates can be either time-driven or event-driven. Two types of route update packets: full dump and incremental packets are used. The *full dump* packet carries all the available routing information, *i.e.*, the entire routing table to the neighbors and the *incremental* packet carries only the information changed since the last full dump. For updating the routing information in a node, the update packet with the highest sequence number is used. The incremental update messages are sent more frequently than the full dump packets. The protocol will not scale in large network since a large portion of the network bandwidth is used in the updating procedures.

3.1.2. Optimized Link State Routing Protocol (OLSR)

The Optimized Link State Routing (OLSR) [11] is a proactive unicast optimized version of a pure link state routing protocol that employs an efficient link state packet forwarding mechanism called multipoint relaying. This protocol performs hop-by-hop routing; that is, each node in the network uses its most recent information to route a packet. The routing optimization is done mainly in two ways. *Firstly*, OLSR reduces the size of the control packets for a particular node during each route update by declaring only a subset of links with the node's neighbors who are its multipoint relay selectors, instead of all links in the network. Any node which is not in the set can read and process each packet but do not retransmit. *Secondly*, it minimizes flooding of the control traffic by using only the selected nodes, called multipoint relays to disseminate information in the network. To select the multipoint relaying, each node periodically broadcasts a list of its one hop neighbors using hello messages. From the list of nodes in the hello messages, each node selects a subset of one hop neighbors, which covers all of its two hop neighbors. It provides optimal routes to every destination in terms of number of hops, which are immediately available when needed. As only multipoint relays of a node can retransmit its broadcast messages, this protocol significantly reduces the number of retransmissions in a flooding or broadcast procedure.

Therefore, the protocol works based on the mechanisms of: neighbors-sensing based on periodic exchange of *hello* messages, efficient flooding of control traffic using the concept of multipoint relays, and computation of an optimal route using the shortest-path algorithm. This protocol does not notify the source immediately after detecting a broken link and source node comes to know that route is broken when the intermediate node broadcasts its next packet. The proposed protocol is best suitable for large and dense ad hoc networks.

3.1.3. Fisheye State Routing Protocol (FSR)

The Fisheye State Routing (FSR) [12] is a proactive unicast routing protocol based on link state routing algorithm with effectively reduced overhead to maintain network topology information. The novelty of FSR is that it uses a special structure of the network called the "fisheye". FSR maintains the accurate distance and path quality information about the immediate neighboring nodes and progressively reduces detail as the distance increases. In link state routing algorithm, used for wired networks, link state updates are generated and flooded through the network whenever a node detects a topology change. However, in FSR nodes exchange link state information periodically only with the neighboring nodes to maintain up-to-date full topology information of the network. To reduce the size of link state update messages, FSR uses different update periods for different entries in the routing table. Link state updates corresponding to the nodes within a smaller scope are propagated with higher frequency.

The FSR protocol is an improvement of Global State Routing (GSR). The large size of update messages in GSR wastes a considerable amount of network bandwidth. In FSR, each update message does not contain information about all nodes. Instead, it reduces the size of the update messages by exchanging information about closer nodes more frequently than it does about farther nodes, which lie outside the fisheye scope. The scope is defined in terms of the nodes that can be reached in a certain number of hops. So, each node gets accurate information about neighbors and accuracy of information decreases as the distance from node increases.

The advantage of FSR is that even though a node does not have accurate information about a destination, as the packet moves closer to the destination, more correct information about the route to the destination becomes available. FSR exhibits a better scalability concerning the network size compared to others as the overhead is controlled in this scheme.

3.1.4. Source Tree Adaptive Routing Protocol (STAR)

The Source Tree Adaptive Routing [13] protocol is based on the link state algorithm. Each node maintains a source routing tree, which is a set of links containing the preferred paths to every destinations and broadcasts its source-tree information to its neighbors and builds a partial graph of the topology. When a node has data packets to send to a destination for which no path exists in its source-tree, it originates an update message to all its neighbors indicating the absence of a path .This update message triggers another update message from a neighbor which has a path. After getting this, the node updates its source-tree and then finds path to all nodes in the network. In addition to path breaks, the intermediate nodes are responsible for handling the routing loops.

STAR will scale well in large networks since it has significantly reduced the amount of routing overhead disseminated into the network by using a least overhead routing approach (LORA) to exchange routing information. However, this protocol may have significant memory and processing overheads in large and highly mobile networks, because each node is required to maintain a partial topology graph of the network (it is determined from the source tree reported by its neighbors), which changes frequently as the neighbors keep reporting different source trees.

3.2. Reactive Routing Protocols

In *reactive routing protocols*, also known as on-demand routing protocols, a node creates a route in an on-demand fashion, *i.e.* it computes a route only when needed. When a source wants to send packets to a destination, it invokes the route discovery mechanisms to find the path to the destination. Route discovery usually occurs by flooding a route request packet throughout the network. Route reply is sent back if the destination itself or node with route to the destination is reached. The discovery procedure terminates either when a route has been found or no route available after examination for all route permutations. Reactive routing does not maintain global topological information and, therefore, substantially reduces energy consumption. Some of these protocols are: Ad hoc On-Demand Distance Vector routing protocol (*AODV*), Dynamic Source Routing protocol (*DSR*), Associativity Based Routing protocol (*ABR*), Location Aided Routing protocol (*LAR*), Light-weight Mobile Routing protocol (*LMR*), Temporally Ordered Routing Algorithm (*TORA*), Ant-colony-based Routing Algorithm (*ARA*), Cluster-based Routing Protocol (*CBRP*).

3.2.1. Ad Hoc On-Demand Distance Vector Routing Protocol (AODV)

The Ad hoc On-Demand Distance Vector (AODV) [14] routing protocol is a reactive unicast routing protocol. The protocol constructs efficient route on demand with minimal control overhead and minimal route acquisition latency. AODV is essentially a combination of both DSR and DSDV algorithms and it borrows the basic on demand mechanism of route discovery and route maintenance from DSR, plus the use of hop-by-hop routing sequence numbers from DSDV. The destination sequence number can be used to ensure loop-free and to identify which route with the greatest sequence number is newer one.

AODV has bidirectional route from source to destination. To find a path from source to destination, the source broadcasts a route request packet. The neighbors in turn broadcast the packet to their neighbors till it reaches an intermediate node that has recent route information about the destination or till it reaches the destination. A node discards a route request packet that it has already seen. The route request packet uses sequence numbers to ensure that the routes are loop free. When a node forwards a route request packet to its neighbors, it also records in its tables the node from which the first copy of the request came. This information is used to construct the reverse path for the route reply packet. AODV uses only symmetric links because the route reply packet follows the reverse path of route request packet. As the route reply packet traverses back to the source, the nodes along the path enter the forward route into their tables. For route maintenance, when a source node moves, it can reinitiate route discovery to the destination. If one of the intermediate nodes moves, then the moved nodes neighbor realizes the link failure and sends a link failure notification to its upstream neighbors and so on till it reaches the source upon which the source can reinitiate route discovery if needed.

The difference between DSR and AODV is that in DSR, each packet carries full routing information, whereas in AODV, the packets carry the destination address. This means that AODV has potentially less routing overheads than DSR. The other difference is that the route replies in DSR carry the address of every node along the route, whereas in AODV, the route replies only carry the destination IP address and the sequence number.

The advantage of AODV is that it is adaptable to highly dynamic networks. However, node may experience large delays during route construction, and link failure may initiate another route discovery, which introduces extra delays and consumes more bandwidth as the size of the network increases.

3.2.2. Location Aided Routing Protocol (LAR)

The Location Aided Routing (LAR) [15] protocol is a reactive unicast routing scheme. In this, a source node estimates the current location range of the destination based on information of the last reported location and the mobility pattern of the destination. In this, an expected zone is defined as a region that is expected to hold the current location of the destination node. During route discovery procedure, the route request flooding is limited to a request zone, which contains the expected zone and location of the sender node. LAR decreases overhead of the route discovery by using the location information. It limits the search to a smaller request zone, causing significant reduction of the number of routing messages.

This protocol assumes that each node knows its location through a GPS. Two different LAR schemes were proposed in [15], the first scheme calculates a request zone which defines a boundary where the route request packets can travel to reach the required destination. The second scheme stores the coordinates of the destination in the route request packets. These packets can only travel in the direction where the relative distance to the destination becomes smaller as they travel from one hop to another. Both methods limit the control overhead transmitted through the network and hence conserve bandwidth. They will also determine the shortest path to the destination, since the route request packets travel away from the source and towards the destination.

The disadvantage of LAR protocol is that each node is required to carry a GPS. Another disadvantage is, especially for the first method, that protocols may behave similar to flooding protocols (e.g., DSR and AODV) in highly mobile networks.

3.3. Hybrid Routing Protocols

In *hybrid routing protocols*, some of the characteristics of proactive protocols and some of the characteristics of reactive protocols are combined into one to get better solution for mobile ad hoc networks. These protocols exploit the hierarchical network architecture and allow the nodes with close proximity to work together to form some sort of backbone, thus increasing scalability and reducing route discovery. Nodes within a particular geographical region are said to be within the routing zone of the given node. For routing within this zone, a table-driven approach is used. For nodes that are located beyond this zone, an on demand approach is used.

Some of the hybrid routing protocols are: Distributed Spanning Tree based Routing Protocol (DST), Core-Extraction Distributed Ad Hoc Routing protocol (CEDAR), Zone Routing Protocol (ZRP), Zone-based Hierarchical Link State Routing Protocol (ZHLS), Distributed Dynamic Routing protocol (DDR), Scalable Location Update Routing Protocol (SLURP), Hybrid Ad hoc Routing Protocol (HARP).

3.3.1. Zone Routing Protocol (ZRP)

The Zone Routing Protocol (ZRP) [16] is a hybrid routing protocol, where the network is divided into routing zones according to the distances between nodes and the routing zone defines a range (in hops) that each node is required to maintain network connectivity proactively. In this, proactive routing approach-Intra Zone Routing Protocol (IARP) is used inside routing zones and reactive routing approach-Inter Zone Routing Protocol (IERP) is used between routing zones. Therefore, for nodes within the routing zone, routes are immediately available. For nodes that lie outside the routing zone, routes are determined on-demand (*i.e.* reactively), and it can use any on-demand routing protocol to determine a route to the required destination. Route creation is done using a query-reply mechanism. During the forwarding of the query packet, a node identifies whether it is coming from its neighbor or not. If yes, then it marks all of its known neighboring nodes in its same zone as covered. A covered node is a node which belongs to the routing zone of a node that has received a route query. The query is thus relayed till it reaches the destination. The destination in turn sends back a reply message via the reverse path and creates the route.

ZRP is suitable for the networks with large span and diverse mobility patterns. The advantage of this protocol is that it has significantly reduced the amount of communication overhead when compared to pure proactive protocols. It also has reduced the delays associated with pure reactive protocols such as DSR, by allowing routes to be discovered faster. This is because, to determine a route to a node outside the routing zone, the routing only has to travel to a node which lies on the boundaries (edge of the routing zone) of the required destination. Since the boundary node would proactively maintain routes to the destination (*i.e.* the boundary nodes can complete the route from the source to the destination by sending a reply back to the source with the required routing address).

The disadvantage of ZRP is that for large values of routing zone, the protocol can behave like a pure proactive protocol, while for small values it behaves like a reactive protocol.

4. Overall Comparison of All Unicast Routing Protocols

Advantages and disadvantages of proactive, reactive and hybrid approaches are shown in **Table 1** and overall comparison of all unicast routing protocols are shown in **Table 2**.

Table 1. Advantages and disadvantages of proactive, reactive and hybrid routing protocols.

	Advantages	Disadvantages
Proactive	-Up-to-date routing information -Quick establishment of routes -Small delay -A route to every other node in the network is always available	-Slow convergence -Tendency of creating loops -Large amount of resources are needed -Routing information is not fully used
Reactive	-Reduction of routing load -Saving of resources -Loop-free	-Not always up-to-date routes -Large delay -Control traffic and overhead cost
Hybrid	-Scalability -Limited search cost -Up-to-date routing information within zones	-Arbitrary proactive scheme within zones -Inter-zone routing latencies -More resources for large size zones

Table 2. Overall comparison of all unicast routing categories [20].

Routing Property	Proactive	Reactive	Hybrid
Routing Structure	Both flat and hierarchical	Mostly flat, except CBRP	Mostly hierarchical
Route Availability	Always available, if the nodes are reachable	Determined when needed	Depends on the location of the destination
Traffic Control Volume	Usually high	Low	Mostly lower than proactive and reactive
Mobility Handling Effects	Usually updates occur based on mobility at fixed intervals	ABR introduced LBQ, AODV uses local route discovery	Usually more than one path may be available
Storage Requirements	High	Usually lower than Proactive protocols	Usually depends on the size of each cluster
Delay Level	Small routes are predetermined	Higher than proactive	For local destinations small, since Inter-zone may be as large as reactive protocols
Scalability Level to Perform Efficient Routing	Usually up to 100 nodes	Source routing protocols up to few 100 nodes Point-to-point may scale higher	Designed for up to 1000 or more nodes

5. Performance Evaluation and Analysis

5.1. Simulation Model

The simulations were performed using the network simulator *QualNet* 4.0 which is a discrete event simulator developed by Scalable Networks. It is extremely scalable accommodating high fidelity models of networks. QualNet makes good use of computational resources and models large-scale networks with heavy traffic and mobility in reasonable simulation times.

The study has been done to compare the efficiency of the various categories of routing protocols: DSDV, AODV, FSR, LAR, OLSR, STAR, and ZRP. The overall goal of our simulation study is to analyze the behavior and performance of the protocols under a range of various scenarios. Simulations have been run using a mobile ad hoc networks composed of 10, 15, 25, 50 and 75 nodes moving over a rectangular 1500 m × 1500 m space and operating over 30 seconds of simulation time. All nodes move according to the random way point mobility model. The traffic sources in our simulation are constant bit rate (CBR) traffic. Each traffic source originates 512 bytes data packets. The simulation parameters are shown in **Table 3**.

Table 3. Simulation parameters.

Parameter	Value
Number of nodes	10, 15, 25, 50, 75
Number of traffic sources	3
Simulation Time	30 Seconds
Traffic Type	CBR
Packet Size	512 bytes
Topology Size	1500m × 1500m
Mobility Pattern	Random way point

5.2. Simulation Metrics

The metrics that are used to evaluate the performance of the routing protocols are: throughput, average end-to-end delay, average jitter, total packets received, packet delivery ratio and routing overhead.

Throughput is the average rate of successful message/ packets delivery over a communication channel. *i.e.* Throughput is the measure of how fast we can actually send the packets through network. The throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second or data packets per time slot.

Average end-to-end delay is the delay experienced by a packet from the time it was sent by a source till the time it was received successfully at the destination. *i.e.*, the *end-to-end delay* is the time a data packet is received by the destination minus the time the data packet is generated by the source. Average end-to-end delay includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, and propagation and transfer times of data packets.

Average jitter measures the packet delay variation. It is calculated as the average of the difference of the inter arrival time between subsequently received packets.

Total packets received is the number of packets received by the TCP sink at the final destination and the number of packets generated by the traffic sources.

Packet delivery ratio is the ratio of the number of data packets successfully delivered to the destinations to those generated by the constant bit rate (CBR) sources. *Routing overhead* is the number of control packets produced per mobile node. Control packets include route requests, replies and error messages. The routing load specifies the load over communications links for traffic flow.

5.3. Simulation Scenarios

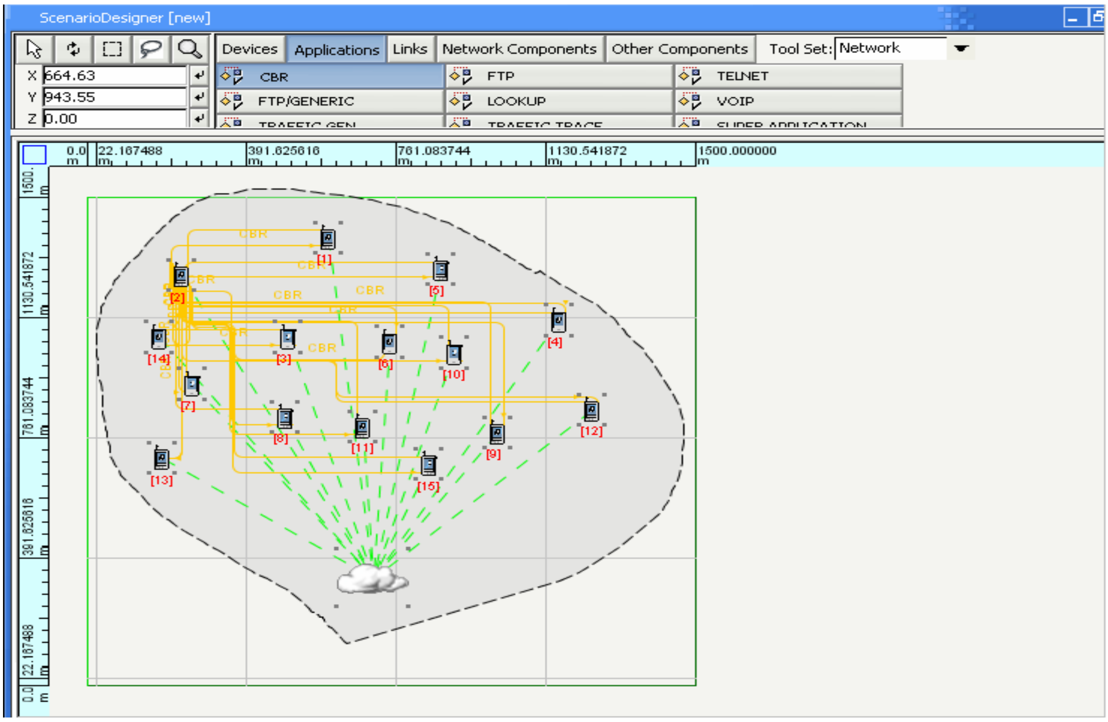

Figure 4. Designer window scenario for 15 nodes.

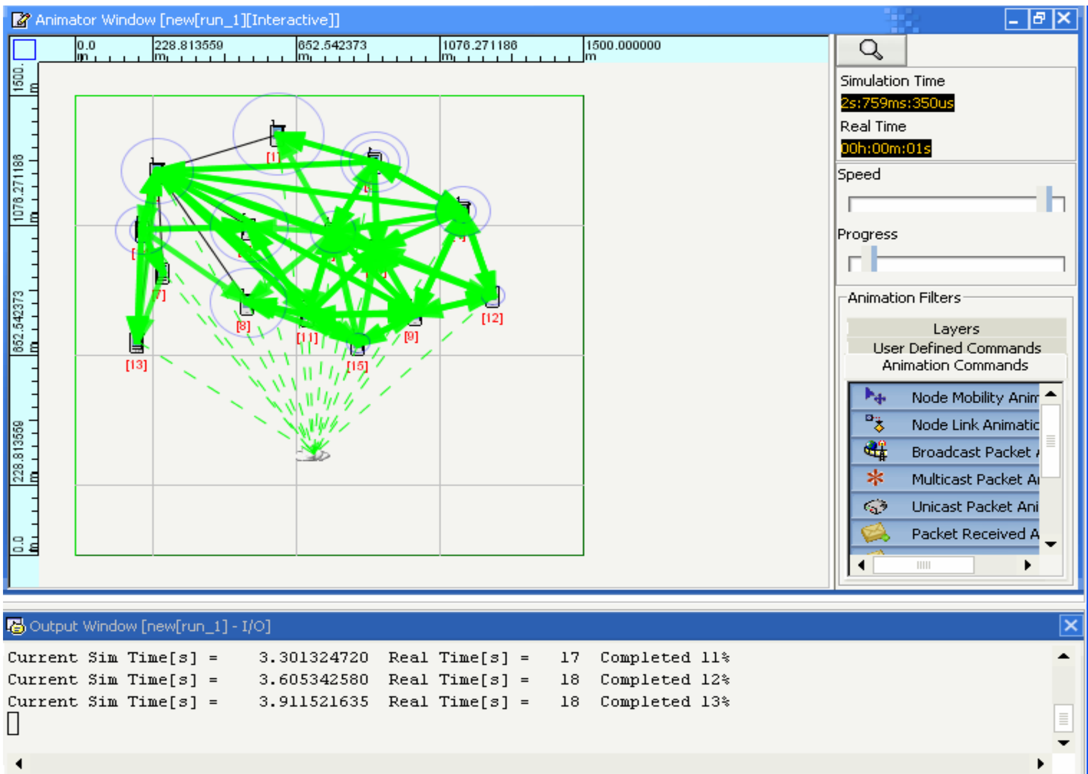

Figure 5. Animator window scenario for 15 nodes.

Table 4. Metric values for 15 nodes.

Protocols/ Parameters	DSDV	AODV	FSR	LAR	OLSR	STAR	ZRP
Throughput(10^4)	5.85	5.85	4.0	6.1	5.7	3.65	4.85
End-To-End Delay	-	-	1.17	3.25	0.08	0.4	1.56
Average Jitter	-	-	3.48	2.5	0.5	0.4	4.68
Total Packets Received (10^2)	3.35	3.35	1.9	3.22	2.97	1.83	2.56

Table 5. Metric values for 25 nodes.

Protocols/ Parameters	DSDV	AODV	FSR	LAR	OLSR	STAR	ZRP
Throughput(10^5)	0.99	1.01	0.63	0.98	0.94	0.51	0.48
End-To-End Delay	-	-	2.8	11.6	0.1	0.6	3.8
Average Jitter	0.1	-	1.2	11.7	0.6	0.6	3.5
Total Packets Received (10^2)	5.6	5.7	2.8	5.4	4.8	2.7	2.4

Table 6. Metric values for 50 nodes.

Protocols/ Parameters	DSDV	AODV	FSR	LAR	OLSR	STAR	ZRP
Throughput(10^5)	2	0.07	1.24	1.17	0.98	1.96	0.75
End-To-End Delay	-	-	7.5	46	0.75	31	40.8
Average Jitter	-	-	20.75	21.3	0.5	36.75	32.5
Total Packets Received(10^3)	1.16	1.16	0.53	1.13	0.08	0.61	0.41

Table 7. Metric values for 75 nodes.

Protocols/ Parameters	DSDV	AODV	FSR	LAR	OLSR	STAR	ZRP
Throughput(10^5)	3.14	3.14	1.87	1.76	3.04	1.28	0.38
End-To-End Delay	-	-	13	78	1	67	42
Average Jitter	-	-	16	96	5	50	25
Total Packets Received (10^3)	1.76	1.76	0.78	0.84	1.54	0.8	0.25

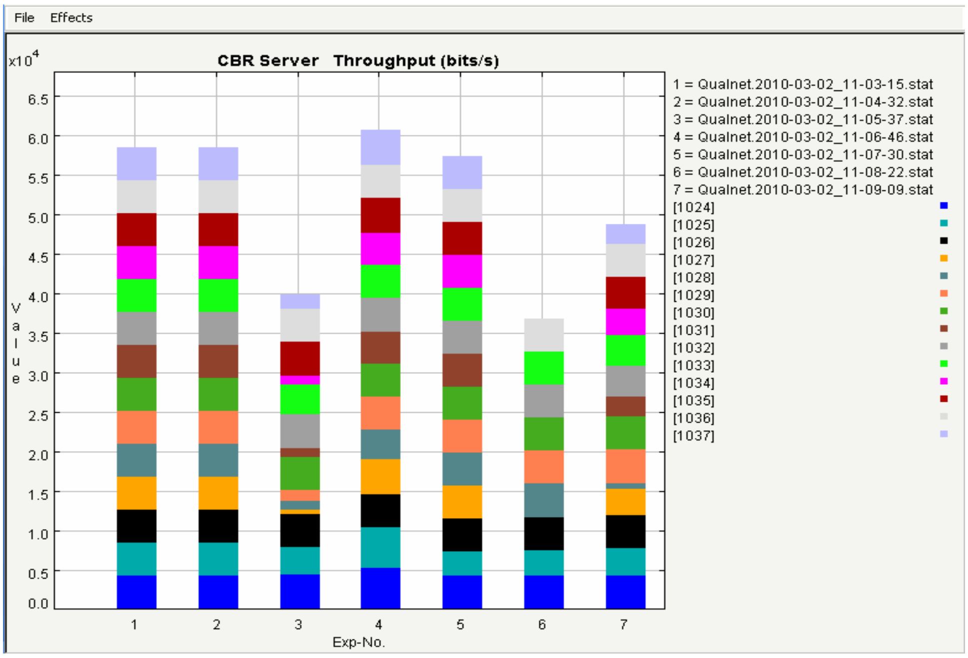

Figure 6. Multi experimental comparison chart (15 nodes) for the metric: throughput.

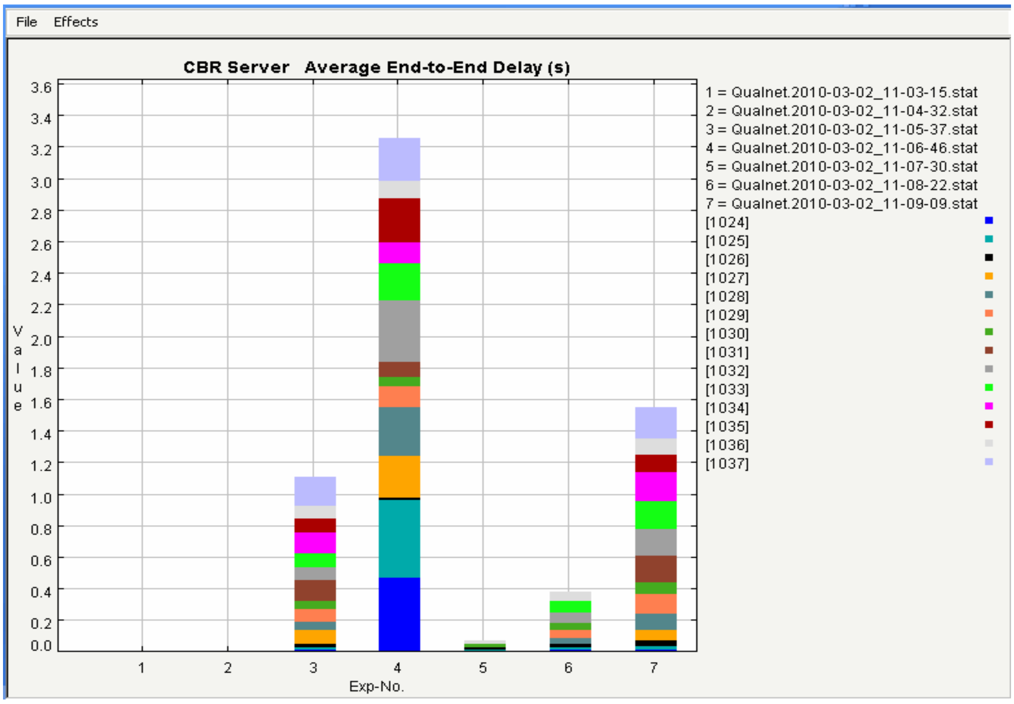

Figure 7. Multi experimental comparison chart (15 nodes) for the metric: Average end-to-end delay.

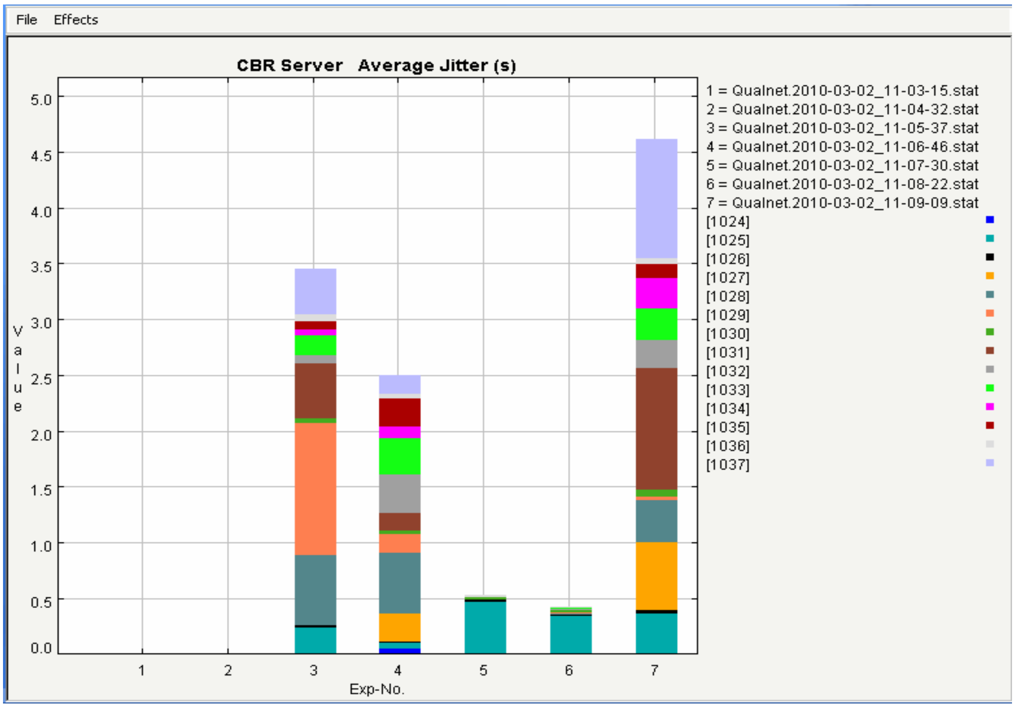

Figure 8. Multi experimental comparison chart (15 nodes) for the metric: Average jitter.

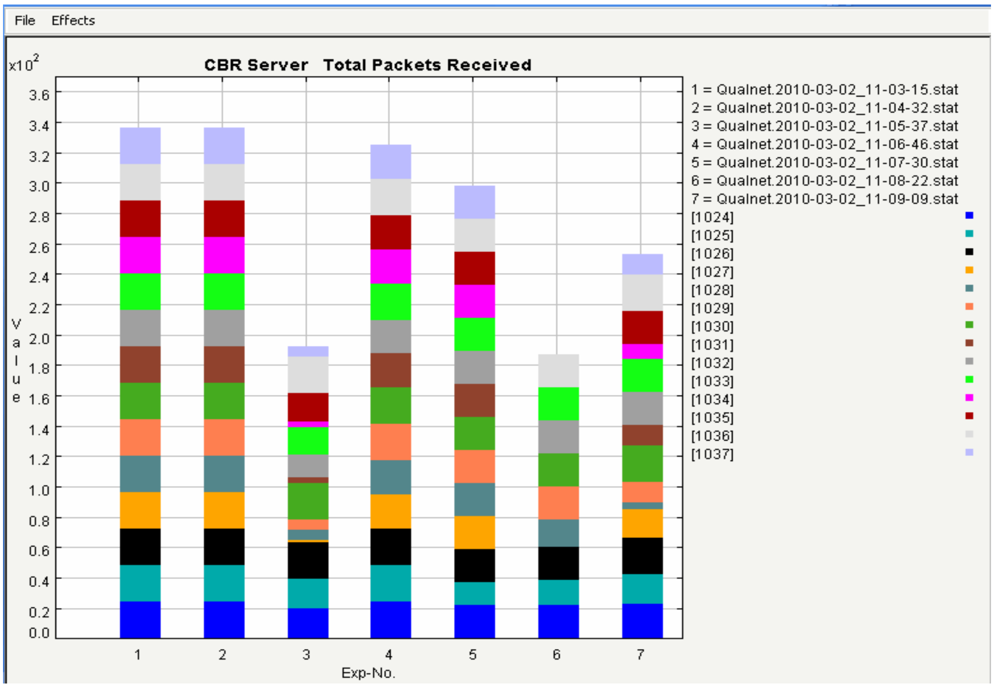

Figure 9. Multi experimental comparison chart (15 nodes) for the metric: Total packets received.

5.4. Simulation Results and Analysis

The simulation study has been done using the network simulator *QualNet* 4.0 for performance comparison of the protocols: DSDV, AODV, FSR, LAR, OLSR, STAR and ZRP. The all seven routing protocols result in improvements of the performance metrics that include throughput, jitter, end-to-end delay and total packets received.

It was observed from the simulation that DSDV and AODV gives nearly same and maximum throughput in small sized networks. Throughput of FSR, LAR, OLSR, and STAR is increasing as the network size is increasing, but OLSR performs well in large sized networks. Throughput of ZRP is well and it is nearer for small and large networks, but for large sized networks it is decreasing. For end-to-end delay and average jitter, the performance of DSDV and AODV is better than FSR, LAR, OLSR, STAR and ZRP in case of small sized networks. In medium and large sized networks, the end-to-end delay and average jitter of AODV and DSDV protocols are same.

The improvements shown in LAR are gradually increasing than others. Hence, it can be concluded that LAR is the best among the studied routing protocols.

6. Conclusions

In this article, the classifications of routing protocols for ad hoc wireless networks were discussed. In proactive protocols, each node maintains network connectivity and up-to-date routing information to all the nodes in the network. In reactive protocols, a node finds the route to a destination when it desires to send packets to the destination. In hybrid routing protocols, some of the characteristics of proactive and some of the characteristics of reactive are combined, by maintaining intra-zone information proactively and inter-zone information reactively, into one to get better solution for mobile ad hoc networks.

Generally speaking, reactive protocols require fewer amounts of memory, processing power, and energy than that of the proactive protocols. The mobility and traffic pattern of the network must play the key role for choosing an appropriate routing strategy for a particular network. It is quite natural that one particular solution cannot be applied for all sorts of situations and, even if applied, might not be optimal in all cases. Often it is more appropriate to apply a hybrid protocol rather than a strictly proactive or reactive protocol as hybrid protocols often possess the advantages of both types of protocols.

DSDV and GSR uses destination sequence numbers to keep routes up-to-date and loop-free. HSR and ZHLS are hierarchical routing protocols. FSR reduces the size of tables to be exchanged by maintaining less accurate information about nodes farther away. CGSR and CBRP are cluster-based routing protocol where nodes are grouped into clusters. AODV is an on-demand version of DSDV routing protocol. ABR uses the degree of associativity to select routes and a localized broadcast query is initiated when a link goes down. WRP maintains the best-path information to a destination, avoids routing loops during route discovery process, and converges quickly after a link failure. In LAR, the route request packets propagate in the request zone only. DSR is a source routing protocol where the route is in each packet. DSR had higher routing overhead as compared to AODV. ZHLS and SLURP are highly adaptable to changing topology, since only the node ID and zone ID of the destination is required for routing to occur. They do not use a cluster-head to coordinate data transmission, which means that a single point of failure and performance bottlenecks can be avoided. The ZRP routing protocol is designed to increase the scalability of mobile ad hoc networks. The advantage of this protocol is that it maintains strong network connectivity (proactively) within the routing zones while determining remote route (outside the routing zone) quicker than flooding.

The simulation study has been done using the network simulator *QualNet* 4.0 for performance comparison of the protocols: DSDV, AODV, FSR, LAR, OLSR, STAR and ZRP. The improvements shown in LAR are gradually increasing than others. Hence, it can be concluded that LAR is the best among the studied routing protocols.

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