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Research Article

Simulation-based Evaluation of Mobile *Ad Hoc* Network Routing Protocols: *Ad hoc* On-Demand Distance Vector, Fisheye State Routing, and Zone Routing Protocol

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ABSTRACT

Mobile *ad hoc* network (MANET) is an infrastructure-less and decentralized network without any physical connections. Nodes are mobile, free to move, and independent of each other which makes routing a difficult task. Hence, a dynamic routing protocol is needed to make MANET reliable and function properly. Several routing protocols have been proposed with different working mechanisms and performance levels. Therefore, the performance study of those protocols is needed. This paper evaluates the performance of MANET routing protocols using simulation based experiments to observe the behavior of the network as the density of the nodes increases. The paper evaluates the performance of proactive (fisheye state routing), reactive (*ad hoc* on-demand distance vector), and hybrid (zone routing protocol) routing protocols in terms of the packet delivery fraction, average throughput, and average end-to-end delay. The simulations of protocols to analyze their performance in different conditions were performed using the network simulator 2 (NS 2).

Keywords: Mobile *ad hoc* network, routing protocols, wireless networks

INTRODUCTION

Today, mobile wireless networking is one of the most innovative topics in computer technologies.[1,2] There are two types of the wireless network. The first type is called an infrastructure network. In an infrastructure network, there exists a device called a base station and all mobile devices within the area will communicate with the base station. The base station, in turn, is connected to the wired network. The second type of wireless network is called the *ad hoc* network.[3] Mobile *ad hoc* network (MANET) is a set of nodes, which are able to link on a wireless medium forming an arbitrary and dynamic network. The *ad hoc* network which is also called infrastructure-less network is deployed in places where there is no availability of network infrastructure. The *ad hoc* network typically consists of nodes that are portable devices operating in a dynamically changing topology. The base station in such a network is not available. All the mobile devices connect and communicate with each other dynamically without the assistance of fixed devices. The wireless links are the means by which the mobile nodes get connected with each other in an arbitrary manner. In such network, all nodes play an important role in route discovery and maintenance, and at the same time, each mobile node acts as a router where it has the ability to forward data packets as necessary from the source to the destination. In wireless *ad hoc* network, the mobile nodes are free to leave and join the network at any time without any kind of restriction on their behavior. This is results in a rapid change in the network's interconnections and topology.[4]

MANET has many features, and due to its flexibility, it has become suitable to be used in emergency rescue operations, military operations, and surveillance tasks. However, at the same time, it is not easy to handle the operation in the *ad hoc* networks because of the irregular change in the network's structure. Given this dynamically changing environment, links can become unreliable which creates further challenges for those *ad hoc* networks. This warrant the need for efficient routing protocol specially designed to handle the dynamic topology of MANET. The main issue of routing protocols in MANET is how to send data packets from one node to another when there is no direct link exists between the source and destination nodes. This resulted in many routing protocols being developed for MANET; these protocols are implemented with some basic objectives. Some of these protocols are suitable for limited network's nodes, and some of them deal with high power consumption or low bandwidth or high error rate.[5]

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The rest of the paper is organized as follows: Section 2 describes the studied routing protocols, and Section 3 gives the details of the simulation environment and the implementation of the routing protocols and the simulation setup used in this research. The simulation results are presented in Section 4 and finally, in Section 5, we conclude the paper and describe our future scope.

THE ROUTING PROTOCOLS IN MANET

Routing is a process to choose or to find a path from the source to the destination within the network.[6] The network routing is being used in numerous types of networks, such as electronic data, internet, and telephone networks. In the *ad hoc* networks, the concept of routing refers to the technique of choosing the correct path to deliver packets from the source to the destination. Throughout the process of routing, there will be at least one intermediate node within the network is encountered. The two main activities that have to be mentioned about routing are how to determine the optimal path for routing and how to transfer the data packets throughout the network. Moreover, MANET routing protocols have to preserve the processing and communication time spent to the lowest possible, and these protocols have to adapt and get used to the unpredictable sudden changes in the network topology. Routing protocols in MANET can generally be categorized into three approaches, namely, (a) table-driven routing protocols (proactive), (b) on-demand routing protocols (reactive), and (c) hybrid routing protocols.[7] This is shown in Figure 2.

Table 1 presents a categorization of MANET routing protocols studied in this research. In the following sub-sections, the three different routing approaches will be discussed.

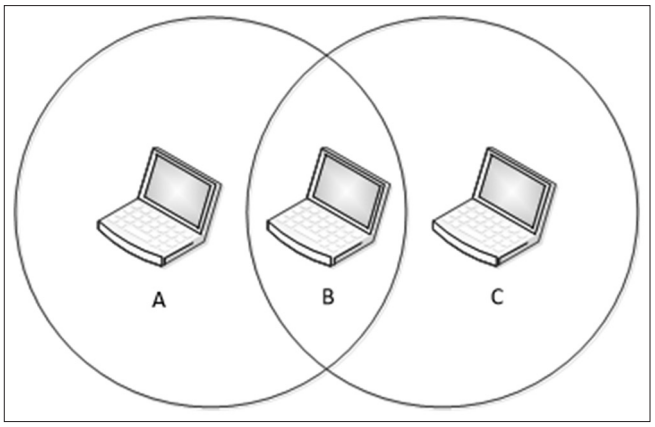

Figure 1: Example of mobile *ad hoc* network

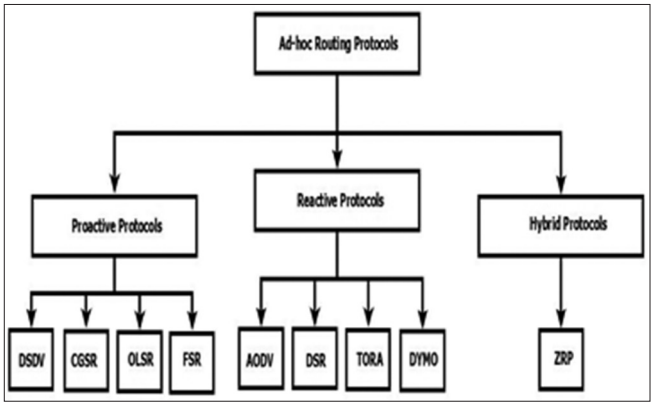

Figure 2: Mobile *ad hoc* network protocols

Table 1: Categorization of MANET routing protocols

Selected MANET routing protocols		
Table-Driven routing protocols (proactive)	**On-demand routing protocols (reactive)**	**Hybrid Routing protocols**
Fisheye state routing	*Ad hoc* on-demand distance vector	Zone routing protocol

MANET: Mobile *ad hoc* network

Proactive Routing Protocols

In the proactive routing protocols, each node maintains routing information for every other node in the network. The routing information is often sheltered in a number of different routing tables.[7] The tables must be updated as the network topology is changing dynamically. The routing protocol adapts to the sudden changes in topology by broadcasting network updates whenever changes occur. Fisheye state routing (FSR), destination sequence distance vector, and optimized link state routing are examples of proactive routing protocols.[8]

FSR

The FSR protocol[9] is one of the table-driven routing protocols based on link state routing algorithm and uses a hierarchical routing scheme. The mobile nodes refresh the information about the destinations by repeatedly update their routing tables. The main aim of the fisheye approach is to decrease the volume of the information required to represent data using the fisheye technique. The link state packets in the FSR are not flooded. Instead, there will be a link state table maintained by the mobile nodes based on the updated information received from neighboring nodes, and this table is exchanged periodically only with their local neighbors without any flooding.[8,9] The fisheye routing is able to see objects when they are close to its focal point in a better way rather than seeing these objects when they are far which means each node keeps precise data about near neighborhood nodes and not so precise data (less detail) about the nodes which are not near or distant. The scope of fisheye is described as a group of nodes which might be reached within a specified number of hops. The FSR has the ability to minimize the bandwidth used to transmit link state update packets between surrounding nodes, and it attempts to decrease the size of the message belongs to topology information because of the exclusion of topology information about far nodes.[9] Figure 3 below illustrates how the fisheye technique is applied to a MANET. In Figure 3, three scopes of fisheye routing are defined with regard to node number 11 which is the focal point. A group of nodes for each scope is defined which can be reached using a particular number of hops. The FSR has the ability to minimize the bandwidth used to transmit link state update packets between surrounding nodes, and it attempts to decrease the size of the message belongs to topology information because of the exclusion of topology information about far nodes.

Reactive Routing Protocols

The on-demand or reactive routing approach is the second and most prominent category of routing protocols in MANET. These routing protocols choose routes to other nodes only when they are needed. When a node in the network wants to communicate with another node, a route discovery process is launched. The route discovery process helps the communicating nodes to collect routing information to find the best possible path between the source and destination inside the network. The *ad hoc* on-demand distance vector (AODV), dynamic source routing, and the temporally ordered routing algorithm are the examples of reactive routing protocols.[8]

AODV

AODV is a reactive protocol.[10] It uses the hop-by-hop methodology for routing the data. Nodes in AODV maintain a route which includes only the next hop routing information for the destination nodes. In AODV, only the active network routes are maintained. When there is a route needed in the network, AODV will execute a route discovery process to find the route to the desired destination. As soon as a route is generated in the network, it is maintained as long as it is still needed using a route maintenance process. The routing information in AODV routing protocol is preserved in routing tables at the mobile nodes. One characteristic of AODV is that it aids nodes in the network by responding quickly to any change in topology and to link failure, and this protocol works in loop-free manner.

There are three different types of messages used in AODV which are the route request (RREQ), route reply (RREP), and route error (RERR).[11] Using those main routing messages, AODV organizes its work as an on-demand routing protocol in *ad hoc* networks. In case a mobile node in the *ad hoc* network demands to communicate with another node, it first searches through its existing routing information for a valid route to the other node. If one route is present there the node uses that existing route for communicating with the destination node. Otherwise, the node broadcasts a RREQ message to its neighbor's nodes throughout the network to discover a route to the destination. This RREQ message contains information such as the IP address of the source and destination nodes, current sequence number, broadcast ID, and latest sequence number for the destination known to the source node. Then, the intermediate nodes start forwarding the RREQ. When the nodes which are either a destination node or one of the intermediate nodes receive the request, it establishes a RREP which includes information that the source node needs with the valid route. If in case any problem happens in the network or link failure is discovered, the protocol will initiate a RERR message. This message will be sent throughout the network with a list of all unreachable destinations.[12] Figure 4 represents a RREQ broadcast in AODV routing protocol.

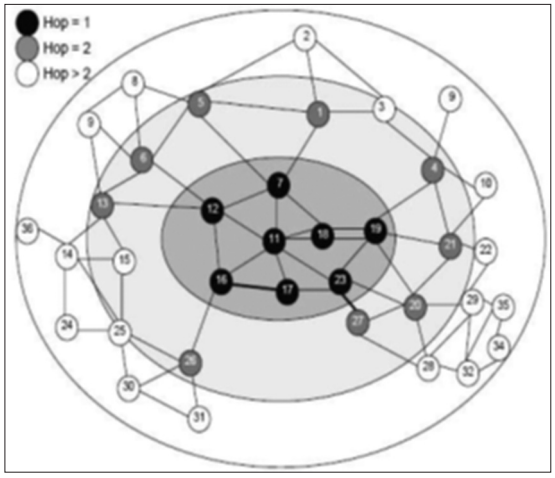

Figure 3: Fisheye scope

Hybrid Routing Protocols

The hybrid approach in MANET is very popular and over time has gained a wide-spread acceptance and applied in various *ad hoc* networks.[13] In the hybrid approach, the route starts with a simple proactive mode but later uses the reactive flooding to support the request from the mobile nodes in the network. Hybrid routing tries to offer a way to minimize the inefficiencies of MANET routing. However, the performance evaluation and the implementation in practical conditions of the hybrid routing are still an on-going process. The network in the hybrid routing approach is initially divided into different zones to reduce overhead. The proactive approach is applied when routing to another node in the same zone or when nodes communicate with their neighbors while the use of reactive routing approach is mainly for the purpose of routing to far distance nodes which are located outside the zone area. The hybrid protocols are designed to conform and adapt to any random arbitrary *ad hoc* network. The most popular protocol that falls under this category is the zone routing protocol (ZRP).[14,15]

ZRP

ZRP is a proactive or reactive protocol (hybrid routing) that divides the network into zones.[15] ZRP tries to address the problems of the proactive and reactive routing by exploiting the preferable properties and eliminate the weaknesses of both approaches. ZRP takes advantage of proactive detection within a node's local neighborhood and applying a reactive protocol for the contact between these neighborhoods. The proactive one that controls and monitors the local zones which are used within routing zones is called intra-ZRP (IARP), and the reactive one that controls and monitors the global zones which are used between the routing zones is called inter-ZRP (IERP). In the case when the source and destination happen to be in the same zone, the data packets can be transferred directly. This happens because the establishment of a path to a

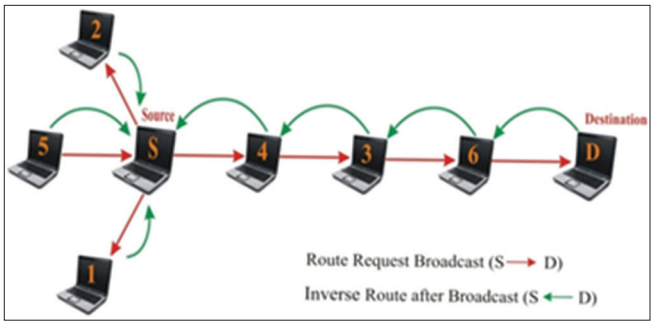

Figure 4: Route request broadcast

target node inside the local zone can be done using the stored routing table of the source by IARP. Nearly, all of the current proactive systems can be applied as IARP in ZRP. The process of determining and finding a route occurs reactively for routes which may be located out of the range of a specific local zone. This happens when the source node initiates a request message to the border nodes of the zone. The message carries the source node's address, the destination node's address, and a special sequence number. The borders investigate their local zone for the target to check its availability. If the destination is not available or not found, the node tags to the request packet the current address that it possesses and sends that packet to its borders again as this target is not a member of the current local zone. If it happens that the target node is available and found, it sends back a RREP on the reverse direction to the source as this target is a member of the current local zone. The origin node benefits from the path kept in the reply packet to transfer data packets to the target.

SIMULATION SETUP

Mobility Model

The mobility model must attempt to mimic the actions and movements of real mobile nodes. For this research study, the selected mobility model is the Random Waypoint Mobility Model which is one of the most widely used mobility models among the research community.[16] This mobility model can highly represent the actions and movements of real mobile nodes in real conditions.

Simulation Parameters

In the simulation, various parameters have been defined to analyze the comparative performance of Proactive FSR, reactive AODV, and Hybrid ZRP routing protocols. The configured simulations parameters are shown in Table 2.

NS-2 Simulator

The network simulator (NS2) is a discrete-event driven simulation software developed as part of the VINT project at the University of California in Berkeley and targeted for network simulation.[17] The NS2 simulation project is mainly funded and supported by DARPA in cooperation with XEROX Palo Alto Research Center and Lawrence Berkeley National Laboratory. Among networking community, the performance of NS2 as a simulator is greatly trusted and it is an effective standard in simulations.

Performance Metrics

To study the routing protocols (AODV, FSR, and ZRP), we selected three performance metrics for evaluation which are, packet delivery fraction, average end-to-end delay, and average throughput.

Packet delivery fraction

The packet delivery fraction is known as the ratio of successfully delivered data packets to destination nodes over the total number of data packets produced for those destinations. The packet loss ratio is defined as the packet delivery fraction.

Table 2: Simulations parameters

Simulation parameters	
Parameters	**Values**
Platform	Linux (Ubuntu) 10.04
Simulation tool	Network Simulator 2
Routing protocols	FSR, AODV, Zone routing protocol
Pause time	10 s
Experiment Duration	200 s
Number of nodes	20, 40, 60
Traffic model	Constant bit rate
Packet size	512 bytes
Packet rate	2 packets/s
Area	500 m×500 m
Maximum speed	20 m/s
Mobility model	Random waypoint
MAC layer protocol	IEEE 802.11b
Antenna type	Antenna/Omni antenna

Average end-to-end delay

The average delay in transmission of a data packet between two nodes from a source to destination in the network is known as the average end-to-end delay. This indicates the time that a data packet utilizes to move from the source node to the application layer of the destination node.

Average throughput

The throughput of the network denotes the average rate of successful message delivery over a communication channel. It is the average number of packets successfully obtained their destinations per unit time. The throughput is usually measured in bits per second (bit/s or bps).

SIMULATION RESULTS

This research consists of three main experiments that have been conducted for the aim of an effective evaluation study regarding three different protocols of MANET networks under different environmental conditions by the varying the number of nodes. The results after simulation are viewed in figures.

Packet Delivery Fraction

Figure 5 shows the comparison between the simulated routing protocols (FSR, AODV, and ZRP) on the basis of packet delivery fraction as an evaluation metric.

From the results in Figure 5, it can simply be noticed that almost all routing protocols performed relatively well in small MNAET, Less number of nodes (20 Nodes). This due to the fact that only a few hops need to be taken by the packets to reach the destination node.

It can also be observed that as the MANET size grows more and the scenario become more stressful, all routing protocols experience lower performance. However, the reactive routing protocol (AODV) has performed better and

delivered more packets than the proactive (FSR) and hybrid (ZRP) counterparts. It can be noticed that the performance of the AODV routing protocol decreases only slightly with an increase in MANET size. This is due to the behavior of reactive protocols which always try to guarantee that the packets will be delivered to the destination even if that may cause some delays. Therefore, it is the most appropriate consideration for a network if data delivery is of the highest consideration.

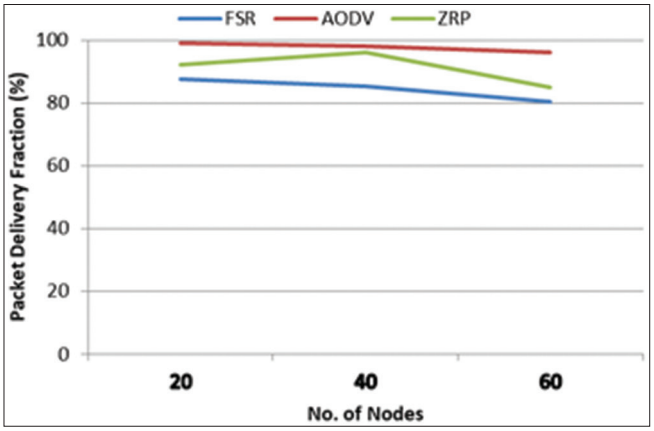

Figure 5: Packet delivery fraction versus number of nodes

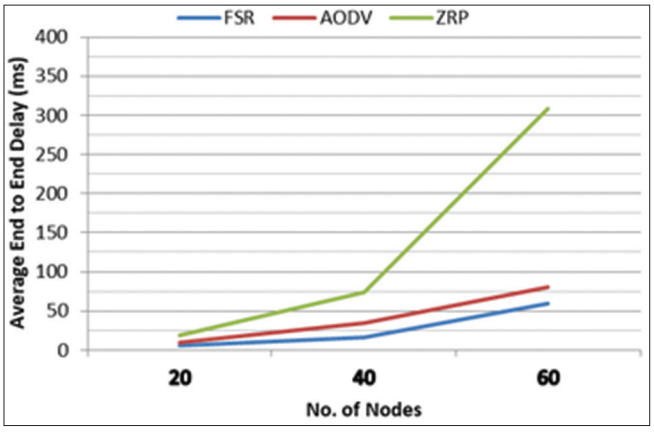

Figure 6: Average end to end delay versus number of nodes

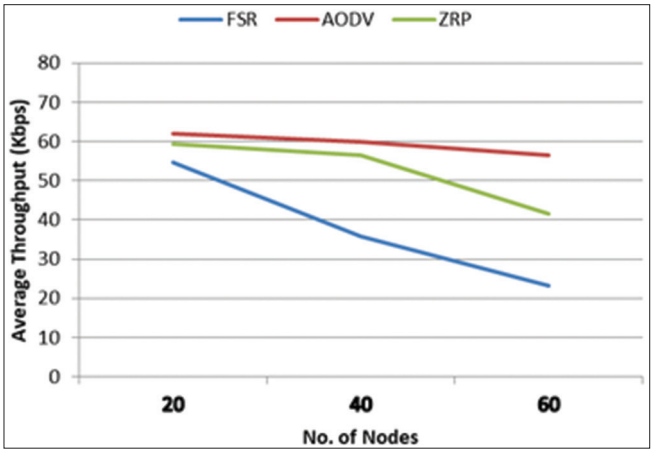

Figure 7: Average throughput versus number of nodes

Average End-to-End Delay

Figure 6 shows the simulation results of the average end-to-end delay in milliseconds. The simulation results indicate that all routing protocols experience higher delay values as the number of wireless nodes or network size grows. This is due to the fact that when MANET size grows; there will be more broken routes. As those routes break, nodes have to discover new routes which make it possible to have longer end-to-end delays.

According to simulation results, the proactive FSR routing protocol has performed well having the lowest end-to-end delay compared to other protocols in this simulation scenario. The reason behind that could be due to the proactive nature of the FSR where the routes for all the destinations are preserved in routing tables and there is no need to initiate the RREQ procedure more frequently. Therefore, it has less network delay. The performance of the reactive routing protocol (AODV) is almost uniform in this simulation scenario. The results also indicate that the ZRP routing protocol did not perform well. It has higher values of average end-to-end delay, especially with a higher number of nodes.

Average Throughput

Figure 7 illustrates the average throughput results of the comparison between the three simulated routing protocols (FSR, AODV, and ZRP).

In this scenario, a significant difference in throughput can be observed. This is because of the increase in the number of mobile nodes which results in higher load in the network. The on-demand reactive AODV routing protocol has achieved a higher throughput compared to other protocols. The throughput of AODV seems to be more stable and consistent as the number of nodes increases. Among the three routing protocols, FSR has the worst performance. The performance of FSR degrades with a higher number of nodes and it can be noticed that FSR is nowhere near the other protocols in terms of consistency. Overall, it can be claimed that the best performance achieved is by AODV closely followed by ZRP routing protocol.

CONCLUSION

MANET is an infrastructure-less network with a dynamic nature. Nodes are mobile and independent of each which triggers the need for a reliable routing protocol to make the network function properly. Several routing protocols have been developed by a researcher, yet choosing a reliable protocol could be a challenging task. This research, study the performance of proactive routing mechanism in MANET and compare it with the reactive and hybrid counterparts, to evaluate the strengths and weaknesses of each of these mechanisms. This study indicates that the routing protocols play a prominent role in developing better communication between nodes in the network. It observed generally that increasing number of nodes results in decline in performance for all routing protocols. According to our simulation results, the reactive routing protocol (AODV) has demonstrated the first best performance and outperformed FSR and ZRP in terms of packet delivery fraction and average throughput,

while the hybrid routing protocol ZRP has presented an overall average performance except it has suffered from delays, especially under a high number of nodes scenario. FSR has shown the lowest end-to-end delay as a proactive routing protocol. Thus, in cases where the delay is a major concern in the *ad hoc* network, this table-driven protocol could be a good compromise. However, FSR performance in terms of packet delivery fraction and throughput was poor. For future works, other aspects of routing protocols in MANET such as privacy and security will be considered.

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