Performance Issues of Routing Protocols in MANET
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ABSTRACT

A mobile ad-hoc network is an assortment of wireless mobile hosts, which establishes a momentary network without any assist of centralized administrator. The characteristics of an ad-hoc network can be explored on the base of routing protocols. The dynamic topology is the vital characteristic in which nodes frequently change their position. In the ad-hoc networks, there are mobile nodes such as personal digital assistance (PDA), smart phone and laptops; they have limited operational resources like battery power and bandwidth. Thus the control traffic is to be minimized, which is the main responsibility of routing protocols by selecting the shortest path and controlling the traffic. In this study work we focus on performance issues of routing protocols Optimized Link State Routing (OLSR), Ad Hoc On-Demand Distance Vector (AODV), Dynamic Source Routing (DSR), and Temporally Ordered Routing Algorithm (TORA) in mobility and standalone ad-hoc networks. For this purpose we first study and explain these protocols and then we use the Optimized Network Engineering Tool (OPNET) modeler tool and analyze the performance metrics delay, throughput and network load.

Keywords: MANET, Performance Evaluation, Routing Protocols, Ad-hoc Network, Routing Challenges, Performance Metrics and Mobility
ACKNOWLEDGEMENTS

In the name of ALLAH, who is most merciful and compassionate, and in our Holy Prophet (PBUH), whose love is the soul of our life in this world and Hereafter.

I am thankful to my parents, my wife, my sons Zain Ali, Muhammad Shamraiz and my daughter and my brothers who sacrificed in my absence and have always prayed for me with heart and soul that become a guiding force to complete my studies successfully.

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Tahir & Kifayat
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<th>Description</th>
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<tbody>
<tr>
<td>MANET</td>
<td>Mobile Ad Hoc Network</td>
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<tr>
<td>PDA</td>
<td>Personal Digital Assistance</td>
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<td>DSR</td>
<td>Dynamic Source Routing</td>
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<tr>
<td>AODV</td>
<td>Ad Hoc on-Demand Distance Vector</td>
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<td>TORA</td>
<td>Temporally Ordered Routing Algorithm</td>
</tr>
<tr>
<td>ABR</td>
<td>Associatively-Based Routing</td>
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<tr>
<td>SSBR</td>
<td>Signal Stability Adaptive Routing</td>
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<tr>
<td>ARA</td>
<td>the Ant-Colony-Based Routing Algorithm</td>
</tr>
<tr>
<td>ROAM</td>
<td>Routing On-Demand Acyclic Multipath</td>
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<tr>
<td>DSDV</td>
<td>Destination-Sequenced Distance-Vector</td>
</tr>
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<td>OLSR</td>
<td>Optimized Link State Routing</td>
</tr>
<tr>
<td>CGSR</td>
<td>Cluster-Head Switch Routing</td>
</tr>
<tr>
<td>WRP</td>
<td>Wireless Routing Protocol</td>
</tr>
<tr>
<td>STAR</td>
<td>Source Tree Adaptive Routing</td>
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<td>ZRP</td>
<td>Zone Routing Protocols</td>
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<td>FSR</td>
<td>Fisheye Stat Routing</td>
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<td>LANMAR</td>
<td>Landmark Ad Hoc Routing</td>
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<td>RDMAR</td>
<td>Relative Distance Micro-discovery Ad Hoc Routing</td>
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<tr>
<td>SLURP</td>
<td>Scalable Location update-Based Routing Protocols</td>
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<tr>
<td>A4LP</td>
<td>A4 LP Routing Protocols</td>
</tr>
<tr>
<td>LAR</td>
<td>Location-Aided Routing</td>
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<td>DREAM</td>
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<td>GPRS</td>
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<td>Location Aided Knowledge Extraction Routing for Mobile Ad Hoc Networks</td>
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<td>NTBR</td>
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<td>IP</td>
<td>Internet Protocol</td>
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<td>Access Point</td>
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<td>Peer to Peer</td>
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<td>WiMAX</td>
<td>Word-Wide Interpretability for Microwave access</td>
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<td>RFC</td>
<td>Request for Comments</td>
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<td>PDR</td>
<td>Packet Delivery Ratio</td>
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<td>SANET</td>
<td>Static Ad-hoc Networks</td>
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<td>IETF</td>
<td>Internet Engineering Task Force</td>
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<td>UMTS</td>
<td>Universal Mobile Telecommunication System</td>
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<td>MPLS</td>
<td>Multiprotocol Label Switching</td>
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<td>IPV6</td>
<td>Internet Protocol Version 6</td>
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<td>Topology Control</td>
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<td>OPNET</td>
<td>Optimized Network Engineering Tool</td>
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<td>WLAN</td>
<td>Wireless Local Area Network</td>
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<td>R&amp;D</td>
<td>Research and Development</td>
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<td>FTP</td>
<td>File Transfer Protocols</td>
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<td>DSN</td>
<td>Destination Sequence Number</td>
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<td>UDP</td>
<td>User Datagram Protocols</td>
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<td>RREQ</td>
<td>Route Request</td>
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<tr>
<td>RERRs</td>
<td>Route Errors</td>
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<tr>
<td>RREPs</td>
<td>Route Replies</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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</tr>
<tr>
<td>TTL</td>
<td>Time-To- Live</td>
</tr>
<tr>
<td>DAG</td>
<td>Directed Acyclic Graph</td>
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<tr>
<td>QoS</td>
<td>Quality of Service</td>
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Chapter 1 Introduction
1 Introduction

A form of wireless network where each node communicates with other node using multi-hop links without stationary infrastructure is called Ad-hoc network. According to [1], an Ad hoc network is crew of wireless mobile nodes that creates a network without any assist of centralized administrator. It uses multi-hop point-to-point (P2P) routing as an alternative of stationary network communication to offer network connectivity [2]. In such circumstances, due to partial range of mobile host in wireless transmission, each node needs to join up other node in order to communicate with each other and to reach to the destination if located far away. This communication involves the mechanism of finding paths from one end node to other through which data can be transferred.

Routing in ad-hoc networks has been a challenging task ever since the wireless networks came into existence. The major reason for this is the nature of ad-hoc networks where network topologies cannot be static [3]. The non-static nature of Ad-hoc networks raises various performance challenges for routing protocols.

The conceptual framework of routing involves decision as to what appropriate optimal routing paths should be taken for transferring the data (packets) through an internetwork. The first concept, i.e. determining an optimal path, is a very complex activity while the later one, i.e. forwarding data through selected path, is a straight forward activity [4]. In order to exchange information between different nodes, routing needs to be done by using different routing protocols. Therefore efficient routing protocols are key components of successful, reliable and proficient communications. Efficient routing protocol means that an optimal route selection is done by the protocol in different scenarios to improve the overall network performance [5].

In order to evaluate the performance of protocols in terms of effectiveness, different performance metrics can be used. In this study, our focus is on delay, network load and throughput for the selected protocols.

Though extensive research [6], [7], [8], [9] has been done on the performance assessment of ad-hoc routing protocols, there is still need for more results regarding comparison of different protocols. In this study, we first identify different performance challenges for routing protocols then we will evaluate the selected routing protocols with respect to selected performance metrics in different network scenarios.

1.1 Aims and Objectives

The aim of this thesis is to assess the relative performance of routing protocols for the considered mobile ad-hoc network and to identify their performance challenges. The outcome for this study is in the form of quantitative results of efficiency of the routing protocols with reference to performance metrics. These results can be used as baseline for selecting routing protocols in a variety of situations.

The objectives are:

- To conduct a detailed literature survey to review the current state of art of routing protocols used in Ad-hoc networks.
- To explore different classifications of routing protocols in Ad-hoc networks and their mobility features. Furthermore, to identify the performance challenges for routing protocols in such networks.
• To study the mobility features in Ad-hoc networks. For this purpose, network scenarios having mobile nodes are designed. The performance of routing protocols in mobile nodes network is evaluated to identify the impact on node mobility.

• To evaluate the routing protocols with reference to their performances in fixed nodes network. In this evaluation, static network nodes are selected while designing network scenario. The performance statistics of each routing protocols for set of performance metrics are collected.

• Comparison regarding performance of different routing protocols for a set of performance metrics in fixed nodes networks. A table is maintained showing the results of this comparison. This helps to identify which routing protocol performs best in static nodes network.

• To design different network scenarios using OPNET simulator for implementation of different routing protocols. These scenarios will mainly be different based on network nodes i.e., mobile and static nodes. Secondly, the number of communicating nodes, application classes and selection of routing protocol differentiate these scenarios from each other.

• Comparison regarding performance of different routing protocols for the same set of performance metrics in mobile nodes network. For this purpose tabulated results are shown. This comparison helps to see which routing protocol performs best in mobile nodes network.

• Comparison of overall results of different routing protocols in both mobile and fixed nodes network for the same set of performance metrics.

• In order to evaluate the performance of routing protocols, a cross comparison is performed based on collected statistic, which will be shown in a table. The collected statistics present the protocol performance with respect to nodes type, i.e., static or mobile. This helps to assess the best routing protocols for different network scenarios.

1.2 Research Question

The focus is on the following:

1. What are the performance challenges for routing protocols in MANET, which will address the performance challenges of routing protocols?

2. How to assess the performance of routing protocols in MANET, which further shows how the performance of routing protocols can be evaluated?

3. How to select the most appropriate routing protocols in MANET with respect to performances, which addresses the overall performance of routing protocols?

4. What are the most appropriate routing protocols in the presence of mobility?

1.3 Thesis Scope

Routing protocols have two classes, one is reactive (DSR, AODV and TORA) and the other is proactive (OLSR). The combination of reactive and proactive protocols is referred to as hybrid class. As in the ad-hoc networks both classes of routing protocols are used that’s why it is called hybrid. In this project we evaluate the performance of routing protocols when these are implemented in a network. In order to understand the effect on network we briefly mention and explain the design of these protocols.

1.4 Thesis Outline

The thesis document is divided into seven chapters. Chapter 1 is introduction of the topic. It describes the MANET, research question and the problem statement. Chapter 2 describes the background of mobile ad-hoc network and the related works. In chapter 3 there is theoretical concepts of ad-hoc routing protocols that are considered in this the thesis. Chapter 4 describes the performance metrics, network load, throughput and end-to-end delay of considered protocols.
Chapter 5 describes the analysis and results of routing protocols. Chapter 6 is about conclusions and future work.
Chapter 2 Background and Related Work
2.1 Background

MANET has a dynamic nature, which makes it ideal for different applications. This kind of network is more suitable in emergencies such as natural disasters due to quick deployment and minimal configuration. MANET is becoming more popular in the advance technology deployment devices such as mobile phones, MP3 players, and Wi-Fi capable laptops etc.

A panoptic research has been conducted on the performance of routing protocols by using NS2 network simulator [32]. Different simulation environment and methods provide different results for the routing protocols of Mobile Ad-hoc Networks. However, there is still need to view in a broader way the effects of routing protocols that are not considered in the specific environment [10].

In this project we evaluate the performance of Ad-hoc routing protocols Ad-hoc On Demand Distance Vector (AODV), Dynamic Source Routing (DSR), Optimized Link state Algorithm (OLSR) and Temporally-Ordered Routing Algorithm (TORA) used in MANETs. For doing this we use OPNET [33]. In this performance evaluation, we use the http traffic to observe the effects of Ad-hoc routing protocols used in MANET. The simulation to evaluate the performance of above mentioned protocols provides a link of theoretical concepts as well as the expected performance of routing protocols in mobile ad-hoc networks.

2.2 Related Work

In [11] NS2 is used for the performance comparison of AODV, TORA, DSR, and DSDV. They concluded that generally, AODV outperforms TORA and DSR. The performance of simple link state protocols DSR and AODV has been studied in [12]. The conclusion of this comparison is that the DSR and AODV perform better when the network load is normal and if the traffic load is heavy the link state outperforms reactive protocol OLSR. In order to study the simulation affects on the performance another author has analyzed the DSDV and DSR [13].

The GloMoSim Simulator is used for the performance evaluation of DSR and On-demand protocol AODV [14]. The conclusion is that AODV outperforms DSR when the source sends data to different destinations and AODV suffers degradation in the average packet delivery rate when the sources send the data to a common destination. They point out the problems that may occur when common gateways are used and provided solutions to minimize this effect. In our project we use different simulation environment to analyze the similar situation of MANET when nodes send data to a common destination.

2.3 Wireless Network Types

The system that receives and transmits data over the air is referred to as wireless network. It has two main types, one is infrastructure network and the other is infrastructure-less or ad-hoc network.

2.3.1 Infrastructure Networks

A network with a fixed physical layout is called an infrastructure network. A central device is responsible for connecting all communicating devices through wireless or wired link. This central device is referred to as Access Point (AP), which is responsible for the management of network operations such as network security implementation, IP configuration. If a device is using wireless technique for connecting to AP, it can connect to any AP, which is in its wireless range depending on the security authorization from AP.
In the WiFi or cellular networks, which are infrastructure-based wireless networks, the wireless link has one-hop or multiple –hop up to the base station and the remaining routing is done with wired infrastructure. The bandwidth, topology, switching and routing resources of infrastructure networks are provisioned to ensure best result to the expected traffic [16].

2.3.2 Ad-hoc Network

A network is installed without fixed physical layouts, which are generally deployed in emergencies, or battlefield communication on temporary basis. When there is not an infrastructure network available or it is cost effective and devices need to connect for communication, multiple nodes are connected wirelessly. In these devices one or more devices act like nodes as well as routers [16].

Such a network is very easy to deploy and flexible, because devices are not bound to any agreement to stay connected. It can be categorized in following two types

- Static Ad-hoc Networks (SANET)
- Mobile Ad-hoc Networks (MANET)

2.4 Static Ad-hoc Network

The wireless network in which nodes are fixed and there is low host mobility or the mobility is disabled. The host communicates with each other by established by predefined links [29].

2.5 Mobile Ad-hoc Networks

The MANET is collection of mobile clients and servers connected by wireless links. In this type of networks there is no fixed and centralized infrastructure. The nodes can freely move without care of topology [7].

As the MANET has limited bandwidth and mobile nodes, it needs to consider the issues of limited bandwidth, unreliable communication, topology change and energy efficiency of nodes while designing the MANET. The mobile nodes act as both hosts and routers as it can route and accept the traffic from neighbor nodes [17]. The challenges of self-configuration are announced when the network grows and also there are frequent re-associations and connection tearing.

In order to cope with the MANET dynamic nature, ad-hoc routing protocols like AODV, TORA, DSR, OLSR, ZRP and WRP are developed [15]. The traffic routing in the network and the battery power utilization of participating node are used to determine the effectiveness of routing protocol. The detailed study of the above mentioned protocols is conducted in the next chapter.

2.6 MANET Application

The self configuration and flexibility of MANET makes it suitable for a wide-range of applications. They can be implemented where there is no landline infrastructure and during the natural disasters like earthquake, in the area of flood, air plane or train crash area. They can also be used to extend the communication services as on airports hotspots. In the conferences communication the MANET is commonly used. Low cost of deployment and self-configuration makes it ideal nominee for such applications [15]. Some applications of ad-hoc network are Emergency Services in disaster recovery, Conferencing, Embedded Computing Applications, Sensor Dust, Home Networking, Personal Area Networks and Bluetooth, Automotive/PC Interaction [16].
During the natural disaster, Wireless Interoperability for Microwave Access (WIMAX), a radio link is established in one area and MANET is established for the coverage extension to the affected areas. In this condition the nodes that are away from the base station depend on the intermediate nodes during the communication. The figure below shows the deployment of MANET on the radio link WIMAX.

![Figure 2.1: A Scenario of MANET Application](image)

In the figure above there is a natural disaster hit area, where a radio link WIMAX, mobile nodes and a WLAN router forms a MANET in order to cover the whole area for communication. The WLAN router transforms between the WIMAX protocols, communication backbone and the ad-hoc protocols.
Chapter 3 Routing Protocols in MANET
3 Routing Protocols in MANETs

In this chapter, we describe the key concepts of ad hoc routing protocols. We describe two classes of routing protocols, first the proactive routing protocols in which we study the OLSR, we then explain the reactive ad-hoc routing protocols in which we study the AODV, DSR and TORA.

The function of ad hoc routing protocol is to control the node decisions when routing packets between devices in MANET. When a node joins or tries to join the network it does not know about the network topology. By announcing its presence or by listening from the neighbor nodes it discover the topology. In a network route discovery process depends on the routing protocol implementation.

For wireless ad hoc networks, several routing protocols have been designed and all these protocols are classified under two major fields of protocols called reactive or proactive. An ad hoc routing protocol with combination of these two is called a hybrid protocol [18].

![Image of Routing Protocols Categories]

**Figure 3.1: Ad-hoc Routing Protocols’ Categories [16]**

3.1 Types of Routing

There are two basic types of routing

1-Dynamic Routing

2- Static Routing

**Dynamic Routing:** The routing is done by the router. Taking decisions based on predefined scenario is called dynamic routing. In this routing the routing of traffic depends on the routing table. At run time the remote resource’s location is decided. In this type of routing when the topology changes the router can exchange the information. The routers also know about the network and the topology information is added in the routing table of routers [19].
This routing is flexible; it has the ability to reduce the traffic overload. Different paths are used to forward the data packets from source to destination.

**Static Routing:** This kind of routing is done by administrators, who do it manually in order to send the packets of data in the desired destination. This setting cannot be changed. At design time the location of remote resources is defined. The routes of the network are configured manually and there are no routing tables build or used. The routers are bound to do which the administrator has informed it.

### 3.2 Proactive Routing Protocols

The purpose of proactive routing protocol is to maintain and build routing information for all nodes and it works independently of the router [20]. This is achieved by periodically transmitting the control messages. These protocols continuously broadcast control messages even if there is no data flow, due to this reason these protocols are not bandwidth efficient. The proactive routing protocols have its advantages and disadvantages. One of the main advantages is that nodes can easily establish a session and can get routing information. When there is link failure its restructure process is slow, the nodes handles too much data for the route maintenance, which is the drawback of proactive routing protocols.

#### 3.2.1 Optimized Link State Routing

OSR is proactive routing protocol for wireless ad-hoc networks that is used in mobile ad-hoc networks. WIMAX Mesh (Backhaul) also uses this protocol. OLSR has got the name because of its proactive nature. In order to discover their neighbors, the nodes get information of topology being used in the network by topology control (TC) and hello packets. Packets are not broadcasted by all nodes. Packets are only routed by multipoint relay (MPR) nodes. Source to destination routes are established well before their use.

There is a routing table kept by each node. These routing tables create higher routing overhead for OLSR compared to other reactive routing protocols. With the increase in number of routes the overhead not increases because new routes are not establishes when needed. It only decreases the delay for route discovery.

![Figure 3.2: HELLO Message in MANET using OLSR](image)

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In OLSR, at predetermined interval Hello messages are periodically sent to the neighbor nodes in order to determine the link status. For instance, if node A and B are neighbors, Hello message is sent to node B by node A and if the message is successfully received by a node B then the link is called asymmetric. This is also true for node B if it sends a Hello message to node A. For two way communication the link is called symmetric as shown in figure 3.2. The information of neighboring nodes is contained by Hello messages. A node is built in network with a routing table, which contains the information of multiple hope neighbors. After the symmetric connections are established, a minimal number of MPR nodes are selected to broadcast TC messages at a predetermined interval [20]. The information of selected MPR nodes is contained by TC message. Routing calculations are also handled by TC messages.

3.3 Reactive Routing Protocols

These protocols are bandwidth efficient. The routes are built on demand, which is accomplished by sending requests for routes in the network. The disadvantage of reactive routing protocols is that it offers high latency while finding the routes [21]. In our thesis we have considered DSR, AODV, and TORA.

3.3.1 Ad hoc On-demand Distance Vector (AODV)

In ad-hoc network AODV is a loop free protocol. It has the characteristic of self-starting in the mobile node environment. Route Maintenance and Route Discovery are its important mechanisms [6]. If a link gets failed, a notification is sent to the affected nodes and therefore, this invalidates the routes via failed link. It requires less memory overhead and establishes unicast routes between source and destination therefore the network utilization is minimal. AODV has low overhead and its on-demand nature does not burden the network. Routing traffic is minimal because routes are built on network demand. There is no need to keep information of those routes that are not being used by the network. When two nodes want to make a connection, the multi hop routes are built between mobile nodes by AODV. AODV uses destination sequence number (DSN) in order to avoid from counting to infinity. This feature distinguishes it from other algorithms. Sequence number based optimal routes are also selected by AODV [22].

There are three messages defined by AODV: Route Requests (RREQ), Route Errors (RERRs) and Route Replies (RREPs) [23]. With the help of UDP packets, AODV messages are used to find out and then maintain the routes from source to destination across the network. IP address is used as a source address by a node when it requests for a route. The numbers of hops for a particular routing message has to propagate in ad-hoc network are determined by time-to-live (TTL), which is found from the information contained in IP header.

Whenever a source wants to communicate with destination there is the need for new route from source to destination, for this purpose the source node broadcasts RREQ message. When this broadcasted message reaches at the next hop node, intermediate node or at the destination a route is determined. The broadcasted message contains the destination IP address, next hop, destination sequence number, lifetime and routing flag. In the response of RREQ the source receives the message RREP [21]. If there is any link failure, a message RERR is generated that contains the information of nodes that cannot access due to this failure and IP addresses of those nodes that are using it.

As AODV is table-driven routing protocol the information of routing is stored in the form of tables. These tables contains the information of DSN, destination IP address, hop count, stare, flag, next hop, list of precursors, lifetime and network interface.
3.3.2 Dynamic Source Routing

The DSR, simple and efficient routing protocol is designed for multi-hop wireless ad-hoc networks. Using DSR, there is no need for administration or existing network infrastructure and the network is completely self-configuration and self-organizing. It is not table driven like AODV but it has on-demand characteristics and based on source routing [23]. The source routing is a technique in which the source of the packet determines the complete sequence of nodes through which to forward the data packets. The source routing has the advantage that there is no need to maintain the routing information by the intermediate hops [34]. Due to routing decision of source it is different from link-state routing and table driven routing [23].

The DSR protocol has route discovery and route maintenance mechanisms that work together in the ad-hoc network [7].

**Route Discovery** is the mechanism in which source node wish to send a packet to destination, it first check the route cache that the route information already exist or not. If it has the route information which is not expired, it will utilize this route to send data packet, otherwise it will initiate the route discovery by broadcasting a route request. This route request packet consist of a unique “request id”, address of source and destination node [34].

The route discovery process and sequence in an ad hoc wireless network using DSR is illustrated in Fig 3.2. If node A wants to communicate with node F, the RREQ packets with unique ids are broadcasted to all its neighboring nodes.

![Route Discovery Process of DSR](image)

**Figure 3.3: Route Discovery Process of DSR**

**Route Maintenance** mechanism is used to detect the network topology when originating or forwarding a packet to destination. During the transmission each node is responsible to detect, if its next hop has broken. For example the below situation shows that the node A has originated a data
packet for node H by using source routing through nodes A to D, D to G, G to F and node F to node H:

![Diagram showing source routing from A to H through D, G, and F]

In this case the node A is responsible for link A to D, node D is responsible for the link D to G, node G is responsible for the link G to F and F is responsible for the link F to H [35]. When the link break is detected by a node it returns a route error packet to the originator node. When the originator receives the erroneous packet, it deletes the hop from the route cache where in the error has occurred [34].

### 3.3.3 Temporally-Ordered Routing Algorithm (TORA)

Temporally-Ordered Routing Algorithm is based on algorithm “link reversal” and is a distributed protocol. TORA guarantees the loop-free routes, and provide the multiple routes for the packets to alleviate the congestion. It is “source initiated” protocol that creates different routes from source to destination. Every node maintains the information about his adjacent nodes. There are three basic functions of TORA: route creation, route maintenance and route erasure. Three control packets are used to complete these functions: query (QRY) for route creation, update (UPD) for creating and maintaining of routes and clear (CLR) for route erasure. The “height” metric is used to establish the directed acyclic graph (DAG) at destination during the creation and maintenance of route. Each node is an ordered quintuple $H_i=(\tau_i, \text{Oid}_i, r_i, \delta_i, i)$ with upstream or downstream “lexographic” distance measured against the neighboring nodes with $H_i$. Where $\tau_i$ is the calculated time of link failure, $\text{Oid}_i$ is the object id of the node, which is referenced as a new point of level, $r_i$ is the reflection bit indicated in the given parameters, $\delta_i$ reflects the rate of change of propagation and $i$ is the address of node itself. In TORA every node maintains a vector table stored in its memory that save the impression of its height as well as the status of interrelated links to all connection backed up by the network. For bandwidth, the node has to broadcast its availability to other nodes in order to update and manage topology variations [34]. This routing algorithm is used to increase the scalability in MANET. This algorithm does not use the shortest path but it uses the optimized route [24].

The node that wants to communicate with the destination send query message to the destination, which contains the node id of destination. When this query message reaches at the destination the update message is sent to the sender. This update message contains the destination field [24]. The process is shown below.
In fig 3.3, the source node is represented by A and the destination node is labeled by H. A query message is broadcasted across the network by the source node A. This message is responded by only one-hop neighbors. When query message is received, the node updates the sender. Here in this fig, the distance of the node D and G from the destination is one hop. Therefore, these nodes send updates as shown in figure 3.4.
The main disadvantage of this network is that it depends on the activated nodes which are selected while initiating the setup at the beginning [25]. The other disadvantage is that the response to demand for traffic is dependent on the number of nodes (or rate of change of traffic) in the networks. In a network where the traffic volume has steep positive gradient, this protocol would not work efficiently.
Chapter 4 Performance Evaluation of Routing Protocols
4.1 Performance Metrics

In the evaluation of routing protocols different performance metrics are used. They show different characteristics of the whole network performance. In this performance comparison we evaluate the Network Load, throughput and End-to-End delay of selected protocols in order to study the effects on the whole network.

4.1.1 Network Load

It is the total load measured in bits/sec, which all higher layers put forward on the WLAN layers in network. It represents the effectiveness of routing protocols when the packets are being received. When there is rush of traffic on the network and it is not easy to manage this is referred as network load. For the best performance it is the quality of network to handle all the traffic in smooth manners so that the deadlock may not occur.

4.1.2 Throughput

Throughput is the ratio of total amounts of data that reaches the receiver from the source to the time taken by the receiver to receive the last packet [27]. It is represented in packets per second or bits per second. In the MANET unreliable communication, limited energy, limited bandwidth and frequent topology change affect throughput [15]. A network requires high throughput and can be represented mathematically by the following equation.

\[
\text{Throughput} = \frac{\text{Number of delivered packets} \times \text{Packet Size} \times \text{Bandwidth}}{\text{Total simulation period}} \quad \text{...... (4.1)}
\]

4.1.3 End-to-End Delay

The average time taken by the packets to pass through the network is called end-to-end delay. This is the time when a sender generates the packet and it is received by the application layer of destination, it is represented in seconds. This is the whole time that includes all delay of network such as transmission time, buffer queues, MAC control exchanges and delay produced by routing activities.

Different applications require different packet delay levels. Low average delay is required in the network of delay sensitive applications like voice. MANET has the characteristics of packet transmissions due to weak signal strengths of nodes, connection make and break, and the node mobility. These are several reasons that increase the delay in the network. Therefore the end-to-end delay is the measure of how a routing protocol accepts the various constraints of network and show the reliability.

End-to-end delay can be represented mathematically by the following equation.

\[
D_{\text{end-end}} = N \left[ D_{\text{trans}} + D_{\text{prop}} + D_{\text{proc}} \right] \quad \text{.................. (4.2)}
\]

Where

\[
D_{\text{trans}} = \text{Transmission delay}
\]
\[ D_{prop} = \text{Propagation Delay} \]
\[ D_{proc} = \text{Processing Delay} \]
\[ D_{end-to-end} = \text{End-to- End Delay} \]

Hence the end-to-end delay can also be defined as combination of the N times transmission, propagation and processing delay.

4.2 Performance Challenges of Routing Protocols

There are different performance challenges of routing protocols in the MANET as explained below [29].

![Figure 4.1: Challenges of Routing Protocols](image)

4.2.1 Security

Mobile ad-hoc networks experience a radio environment that is not dedicated, therefore is not secure posing a security threat to the network stability. As the traffic is relayed through different nodes therefore traditional security measures such as cryptography, interleaver is inefficient to ensure the security. A more robust, generalized security measures for node-to-node / end-to-end security solution needs to be investigated.

4.2.2 Quality of Service (QoS)

Performance characteristics such as jitter, delay, bandwidth, packet loss probability measure the quality of service to be attained. The quality of the link remains varying during the connectivity time of ad-hoc networks, thereby the quality parameters are more difficult to be maintained. Moreover the behavior of the above parameters on different routing protocols is not same. Quality of Service in mobile ad-hoc networks requires integration of vertical-layer or cross-layer. Therefore the means to
detect and troubleshoot the artifacts of above mentioned parameters need to be optimized in order to ensure the quality of service to end users.

4.2.3 Scalability

The scalability challenge appears when the performance of routing protocol in ad-hoc network is tested by increasing the network size, open challenge of ad-hoc networks is defined as whether the wider ad-hoc network is capable to give the service that is acceptable. The dynamic environment of wireless ad-hoc network poses big challenge to cater the huge amount of broadcast traffic in change of topology.

4.2.4 Saving Energy

Due to the mobile nature and environmental variations saving the energy of the network has been a desired feature. As the infrastructure in ad-hoc network is not fixed, thereby increasing the overhead data that results in more consumption of transmitted power. The requirement of user that is near the transmitter is different from the requirement of that user who is away from transmitter. Adding diversity increases consumption of power, therefore energy management by optimizing the power consumption is an important performance challenge.

4.3 Simulation Environment

The simulation for this study is done by using OPNET modeler 16.0. OPNET is a network and application management simulation tool offered by OPNET technologies Inc. Packet levels simulation is operated through OPNET. OPNET technologies provides solutions to help the academic research through its R&D in the areas, evaluation and design of MANET, power management schemes in sensor networks, analysis the optical network designs, enhancement and evaluation of wireless technologies, UMTS, WiFi, WIMAX and enhancement in the MPLS, IPV6 the core network technologies. There are also other tools like NS2, GloMoSim. The following table shows comparison of these tools.

<table>
<thead>
<tr>
<th>Simulation Tool</th>
<th>License</th>
<th>Open Source</th>
<th>Programming Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPNET</td>
<td>Required</td>
<td>No</td>
<td>C</td>
</tr>
<tr>
<td>NS2</td>
<td>Not Required</td>
<td>Yes</td>
<td>TCL, C++</td>
</tr>
<tr>
<td>GloMoSim</td>
<td>Limited</td>
<td>Yes</td>
<td>Parsec</td>
</tr>
</tbody>
</table>

We use OPNET in our study. OPNET is network level and event level simulation tool. Four main steps involves in its use are modeling, statistics, run simulation, view and analysis of results.
4.3.1 Model Design

The first step while creating the network is to generate blank scenario by using startup wizard. Project editor workspace opens by this in order to design the network. The design is completed either
manually or automatically. There are two cases involves for designing. In the first case the objects are dragged from the object palette on the project editor workspace. In the second case the topologies are generated using rapid configuration automatically. In case the predefined scenarios match the user requirements, it can be imported. However, designing of wireless networks cannot be done by importing scenarios [28]. When the network has been designed the nodes should be configured either by the pre-defined parameters or manually.

4.3.2 Simulation Settings

We use the OPNET modeler 16.0 in order to simulate the routing protocols involves in our study. The figure 4.3 shows the setup of one simulation environment of 50 nodes, which are moving with the speed of 10 m/s and the pause time of 300 sec. The details of simulation parameters are given in table 4.2.

<table>
<thead>
<tr>
<th>S.NO</th>
<th>PARAMETERS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No of Nodes</td>
<td>30(Initial Phase)50(Second Phase)</td>
</tr>
<tr>
<td>2</td>
<td>Routing Protocols</td>
<td>DSR, AODV, OLSR, TORA</td>
</tr>
<tr>
<td>3</td>
<td>Performance Metrics</td>
<td>Network Load, Delay, Throughput</td>
</tr>
<tr>
<td>4</td>
<td>Simulation Area</td>
<td>1Km*1Km</td>
</tr>
<tr>
<td>5</td>
<td>Traffic Type</td>
<td>http</td>
</tr>
<tr>
<td>6</td>
<td>Packet Size</td>
<td>512 Bytes</td>
</tr>
<tr>
<td>7</td>
<td>Mobility Rate</td>
<td>10 m / second</td>
</tr>
<tr>
<td>8</td>
<td>Pause Time</td>
<td>300 seconds</td>
</tr>
</tbody>
</table>

In initial phase we use 30 nodes in our scenario and simulate using mobility of the nodes for the performance metrics network load, delay and throughput of routing protocols AODV, DSR, TORA, and OLSR. In the next scenario we create the static nodes by disabling the mobility of nodes.

In the second phase we use 50 nodes in our scenario and simulate using mobility of nodes for the performance metrics network load, delay and throughput of AODV, DSR, TORA and OLSR the routing protocols. In the next scenario we create the static nodes network by disabling the mobility of nodes.
Figure 4.3: Simulation Setup
Chapter 5 Results and Analysis
5 Results and Analysis

The derivation of results and analysis are the best way to validate simulation, which we intend to discuss at breath in this chapter. The graphs shown in this chapter would mainly entail our at length analysis from network load. The in-depth analysis progress to throughput and take us into the details of performance checks by studying into the throughput and last but not the least the delay in the network vis-à-vis routing protocols. The parameters used to optimize all the important details of mobile ad-hoc network have been discussed in previous chapter. In this chapter the focus is laid on the figures, explaining the parameters discussed in previous chapters.

5.1 Network Load

In figure 5.1-5.2, the graphs represents the network load in bits per second, wherein the horizontal line shows the time in seconds and the vertical line indicates the network load in bits per second. In the scenario of 30 mobile nodes, DSR has less network load. Therefore it will perform well as compared to the other routing protocols AODV, OLSR and TORA. DSR has less network load, as it has the characteristics of on-demand routing, and also there is no need to update the routing tables, that’s why it has the less delay and it performs better than AODV, OLSR and TORA. Also there is source routing in DSR, which means that the source of the packet determines the complete sequence of nodes through which to forward the data packets. DSR choose only one route for the packet delivery. OLSR has higher network load than DSR and AODV because there is need to maintain the routing table at each node. TORA has higher network load from AODV, DSR and OLSR because it send routing information to all adjacent nodes. It causes the extra load on the network. The routing procedure in TORA is also complicated. In the 30 static nodes scenario, DSR has the best rated performance as compared to the other routing protocols.
Figure 5.1: Network Load in 30 Mobile Nodes

Figure 5.2: Network Load in 30 Static Nodes
Figure 5.3-5.4 entails 50 mobile and static nodes scenario. In this scenario DSR has less network load as compared to the AODV, OLSR and TORA in the presence of high number of sources. Its performance is good as compared to the other protocols. In the scenario of 50 static nodes, the DSR performs well as compared to the other routing protocols.

![Network Load in 50 Mobile Nodes](image)

**Figure 5.3: Network Load in 50 Mobile Nodes**
All the above results potentiate DSR as more stable and very efficient routing protocols that may work under any condition whether the network is mobile or standalone.

5.2 End-to-End Delay

Figure 5.5-5.6 entails 30 mobile and static nodes scenario. The horizontal line shows the time in seconds and the vertical line shows delay in second. In this scenario OLSR has less delay of 0.001seconds which shows that it performs well as compared to the AODV, DSR and TORA. The reason is that OLSR is proactive routing protocol, which means that there are routing tables with each node, and the packets are not broadcasted by all nodes. Its performance is good as compared to the other protocols. In the scenario of 30 static nodes, the OLSR performs well as compared to the other routing protocols.

DSR shows higher delay than AODV and OLSR due to the reason that when a RREQ is sent, the destination replies to all RREQ it receives, which make it slower to determine the least congested route. In AODV every destination replies to only first RREQ. In 30 nodes scenario the TORA has less delay as compared to the scenario of 50 nodes, because TORA has the characteristic of worst delay due to the loss of distance information. The route construction in TORA may not occur quickly. This leads towards the lengthy potential delay while waiting the new routes to be determined. It is also observed that as the number of nodes increases AODV and DSR shows the less delay and performs better due to the reason that the route discovery process is very fast.
Figure 5.5: Delay for 30 Mobile Nodes

Figure 5.6: Delay for 30 static nodes
Figure 5.7-5.8 entails the 50 mobile and static nodes scenario. In this scenario OLSR has less delay as compared to the AODV, DSR and TORA if there is large number of nodes. Its performance is good as compared to the other protocols. In the scenario of 50 mobile static nodes also the OLS performs well as compared to the other routing protocols.

Figure 5.7: Delay for 50 Mobile Nodes
The above results show that in case of end-to-end delay, OLSR has best performance ability in both mobile and static networks.

5.3 Throughput

The throughput for the network is shown in figure 5.9-5.12, which refers to the throughput as the ratio of total amounts of data that reaches the receiver from the source to the time taken by the receiver to receive the last packet. The X-Axis represents the time in second and Y-Axis indicates the throughput in bits per second. When the number of sources increase the throughput will also increase and hence the performance will be high. In case of 30 mobile nodes scenario, OLSR has high throughput of 650000 bits per seconds. In this case OLSR outperforms the AODV, DSR and TORA. OLSR inherits the link state legacy that is routes are immediately available when there is requirement. OLSR is highly reliable in terms of large-scale environment and high-speed. TORA is worst in reliability and has low throughput because of extra overhead for establishment and upgrading of path. The reason for high throughput of OLSR in comparison with other protocols is that, for OLSR routing path are easily available due to the characteristic of proactive routing protocols. In the 30 static nodes scenario also OLSR has high throughput that’s why it comparatively performs better to the other routing protocols.

Figure 5.8: Delay for 50 Static Nodes
Figure 5.9: Throughput for 30 Mobile Nodes

Figure 5.10: Throughput for 30 Static Nodes
The following two figures are the result of 50 mobile and static nodes scenarios. In this scenario, OLSR has high throughput as compared to the AODV, DSR and TORA. Its performance is good as compared to the other routing protocols. In the scenario of 50 static nodes, the OLSR performs well as compared to the other routing protocols.

Figure 5.11: Throughput for 50 mobile nodes

Figure 5.12: Throughput for 50 static nodes
The routing protocol which has higher throughput will give best performance. The above results show that OLSR has a higher throughput than the other routing protocols. Hence in case of throughput OLSR performs better comparatively to AODV, DSR, and TORA.

The following table is showing the comparison of mobile and static ad-hoc networks routing protocols.

Table 5.1: Comparisons between AODV, DSR, OLSR and TORA for Static and Mobility based Ad-hoc Networks.

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Scenario</th>
<th>Parameters</th>
<th>AODV</th>
<th>DSR</th>
<th>OLSR</th>
<th>TORA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Delay (sec)</td>
<td>0.002 sec</td>
<td>0.003 sec</td>
<td>0.001 sec</td>
<td>0.027 sec</td>
</tr>
<tr>
<td>30</td>
<td>Static</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Throughput (bit/sec)</td>
<td>220000 bits/sec</td>
<td>35000 bits/sec</td>
<td>670000 bits/sec</td>
<td>180000 bits/sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Network Load (bit/sec)</td>
<td>40000 bits/sec</td>
<td>30000 bits/sec</td>
<td>43000 bits/sec</td>
<td>90000 bits/sec</td>
</tr>
<tr>
<td></td>
<td>Mobility based</td>
<td>Delay (sec)</td>
<td>0.003 sec</td>
<td>0.004 sec</td>
<td>0.001 sec</td>
<td>0.025 sec</td>
</tr>
<tr>
<td>50</td>
<td>Static</td>
<td></td>
<td>0.002 sec</td>
<td>0.003 sec</td>
<td>0.001 sec</td>
<td>4.0 sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Throughput (bit/sec)</td>
<td>200000 bits/sec</td>
<td>50000 bits/sec</td>
<td>650000 bits/sec</td>
<td>150000 bits/sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Network Load (bit/sec)</td>
<td>35000 bits/sec</td>
<td>25000 bits/sec</td>
<td>45000 bits/sec</td>
<td>80000 bits/sec</td>
</tr>
<tr>
<td></td>
<td>Mobility based</td>
<td>Delay (sec)</td>
<td>0.003 sec</td>
<td>0.004 sec</td>
<td>0.001 sec</td>
<td>4.0 sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>80000 bits/sec</td>
<td>50000 bits/sec</td>
<td>130000 bits/sec</td>
<td>190000 bits/sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Throughput (bit/sec)</td>
<td>100000 bits/sec</td>
<td>bits/sec</td>
<td>26,50,000 bits/sec</td>
<td>350000 bits/sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Network Load (bit/sec)</td>
<td>50000 bits/sec</td>
<td>250000 bits/sec</td>
<td>200000 bits/sec</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mobility based</td>
<td>Delay (sec)</td>
<td>0.003 sec</td>
<td>0.004 sec</td>
<td>0.001 sec</td>
<td>4.0 sec</td>
</tr>
</tbody>
</table>

We use the different scenarios in order to explore the routing protocols. From the above table, in case of 30 static nodes, AODV has the delay of 0.002 sec, throughput of 220000 bits/sec and network load of 40000 bits/sec. DSR has the delay of 0.003, throughput of 350000 bits/sec and network load of 30000 bits/sec. OLSR has the delay of 0.001sec, throughput of 670000 bits/sec and network load of 43000 bits/sec. and TORA has the delay of 0.020 sec, throughput of 180000 bits/sec and network load of 90000 bits/sec.

From above results it is also concluded that in case of 30 static and mobile nodes DSR performs better because it has less network load. Similarly in case of 50 static and mobile nodes DSR outperforms the AODV, OLSR and TORA, which means that when the network size increase it does not affect the performance of DSR. In case of end-to-end delay, when using the 30 static or mobile nodes the OLSR has less delay, which means that it performs better. If the network size is increased from 30 nodes to 50 nodes OLSR has less delay as compared to AODV, DSR and TORA.
In case of 30 mobile nodes AODV has the throughput 200000 bits/sec, DSR has throughput of 50000 bits/sec, OLSR has the throughput of 650000 bits/sec and TORA has the throughput of 150000 bits/sec, which shows that OLSR has higher throughput. In case of 30 static nodes OLSR also outperforms AODV, DSR and TORA. Similarly in case of 50 static and mobile nodes OLSR too performs better as compared to other routing protocols AODV, DSR and TORA.
Chapter 6 Conclusion and Future Work
6.1 Conclusion

This thesis report has two parts of study, the analytical study and simulation study. From analytical study, it is concluded that routing protocols plays very important role in the telecommunication and seamless communication. Different protocols has different qualities, the selection of a suitable protocol definitely increase the performance of network. Mobile ad-hoc network has the privilege to use two categories of routing protocols, one of which is proactive routing protocols and the other is re-active routing protocols. The assortment of these two categories is called hybrid routing protocols. The best choice among these protocols is the torchbearer to best optimum solution and effective performance.

We evaluate the performance issues of routing protocols AODV, DSR, OLSR and TORA in static and mobile based ad-hoc network environment in our simulation study. We have analyzed the major performance in the key areas of end-to-end-delay, network load and throughput which duly affect the QoS.

The overall performance of DSR in terms of network load is best as compared to AODV, OLSR, and TORA. When the network size is increased it does not affect the performance of DSR in both mobile and static ad-hoc networks which means that DSR outperforms AODV, OLSR and TORA. DSR is a source routing and has the characteristics of on-demand routing. The end-to-end delay of OLSR has less as compared to AODV, DSR and TORA when the traffic load is high, which means that its performance is best in both static and mobility ad-hoc network. The increase in network size does not affect the performance of OLSR in both mobile and static ad-hoc networks. The reason is that OLSR is proactive routing protocol, which means that there are routing tables with each node, and the packets are not broadcasted by all nodes. In the case of throughput OLSR attains high rate in both static and mobile ad-hoc networks. When the network size is increase is does not affect the performance of OLSR, which means that OLSR outperform the AODV, DSR and TORA. OLSR is reliable in terms of large-scale environment and high-speed. The reason for high throughput of OLSR in comparison with other protocols is that, for OLSR routing path are easily available due to the characteristic of proactive routing protocols.

6.2 Future Work

As future work in addition to end-to-end delay we intend to study the delay jitter parameter, and investigate its impact on congestion control when the network is highly loaded. Efficiency of mobile ad-hoc networks in terms of delay jitter would result in decreased power consumption; therefore network life would be prolonged.
REFERENCES
[27] Uyen Trang Nguyen and Xing Xiong, “Rate-adaptive Multicast in Mobile Ad hoc Networks,” IEEE International Conference on Ad hoc and Mobile Computing, Networking and Communications, WiMob, Montreal, Canada, 2005
[28] OPNET Modeler 14.5 Documentation
[33] N. Adam, M. Y. Ismail, J. Abdullah, “Effect of Node Density of Performances of Three MANET Routing Protocols”, Department of Science Physics, Department of Communication Eng., Faculty of Science and Technology, Faculty of Electrical and Electronic Eng., University of Malaysia Terengganu, University of Tun Hussein Onn Malaysia 2010, P 321-325.
[34] Q. Liang, “Pro-Active Route Maintenance in DSR”, School of Computer Science Carleton University, Ottawa, Canda, August, 2001.
[Accessed September 27, 2010].