OPNET Based Performance study and comparison of MANET Routing Protocols with variable FTP Traffic Load Patterns

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DECLARATION

This thesis is my original work and has not been presented in any other University for a degree or otherwise.

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This thesis has been submitted for examination with our approval as the University supervisors.

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DEDICATION

This thesis is dedicated to my parents, my brothers and sisters for their endless love, support and encouragement.

ABSTRACT

In a Mobile Ad hoc Network (MANET) there is no wired infrastructure by which the routing functionalities are performed. The mobile nodes work as routers in that the routing and message delivery is performed by the nodes. The absence of fixed centralized infrastructure and unpredictably varying topology in MANETs make routing and the design of routing protocols complex and challenging issues. A lot of prominent researches have been done on the area and different routing protocols were developed such as AODV, DSR, OLSR, TORA and others mainly for the efficient delivery of message from source to destination. A good understanding of their performance characteristics helps to find out and deploy appropriate protocol for a given network scenario and do further optimizations. Several researches have been conducted on the performance analysis and comparison of different protocols with the help of different tools and different performance characteristics. In most of these previous works, the analysis were not performed based on a broad range of control variables on which the protocols are mainly optimized such as traffic loads, network size and mobility scaling. There are no adequate and comprehensive researches on the effect of each control variables on the protocols. Most of the researches were done based on constant bit rate (CBR) on NS-2 simulator. Therefore, there is still a need for further studies on the performances of MANET protocols with different simulation platforms and different network scenarios by considering the control parameters along which the protocols are mainly optimized. In this research the performance analysis and comparison of three popular protocols (AODV, DSR and OLSR) have been conducted using OPNET Modeler under different network scenarios by scaling the FTP traffic loads, Network size and mobility speed of nodes against the performance measurement metrics of end-to-end delay and throughput. The effect of FTP traffic load scaling, network size and mobility variations on each of the protocols considered were analyzed in terms of average end to end delay and throughput.

Simulation results show that the throughput performance increases and the delay performance decreases when traffic load and network size increase in all the protocols. Mobility has no significant effect on the performance of the protocols. OLSR and AODV have overall better performances in terms of end-to-end delay and throughput respectively in almost all the scenarios considered. Reactive protocols have inconsistent and larger delay performance.

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ABBREVATIONS

AODV	Ad-hoc On-Demand Distance Vector routing protocol
BSC	Base Station Controller
BTS	Base Station Transceiver
CBR	Constant Bit Rate
CGSR	Cluster-head Gateway Switch Routing protocol
CPU	Central Processing Unit
DSDV	Destination Sequence Distance Vector
FTP	File Transfer Protocol
DSR	Dynamic Source Routing Protocol
GRP	Graphical Routing Protocol
HTTP	Hyper Text Transfer Protocol
I-DSDV	Improved Destination Sequence Distance Vector
MANETs	Mobile Ad hoc Networks
MRL	Message Retransmission List
NS-2	Network Simulator version 2
OLSR	Optimized Link State Routing
OPNET	Optimized Network Engineering Tool
OSPFv3	Open Shortest Path First version 3
QoS	Quality of Service
RREP	Route REPLY
RREQ	Route REQUEST
RTT	Round Trip Time
TCP	Transmission Control Protocol
TORA	Temporally Ordered Routing Algorithm

UMTS	Universal Mobile Telecommunications System
VoIP	Voice over Internet Protocol
Wi-Fi	Wireless Fidelity
Wi-Max	Worldwide Interoperability for Microwave Access
WRP	Wireless Routing Protocol

CHAPTER ONE

INTRODUCTION

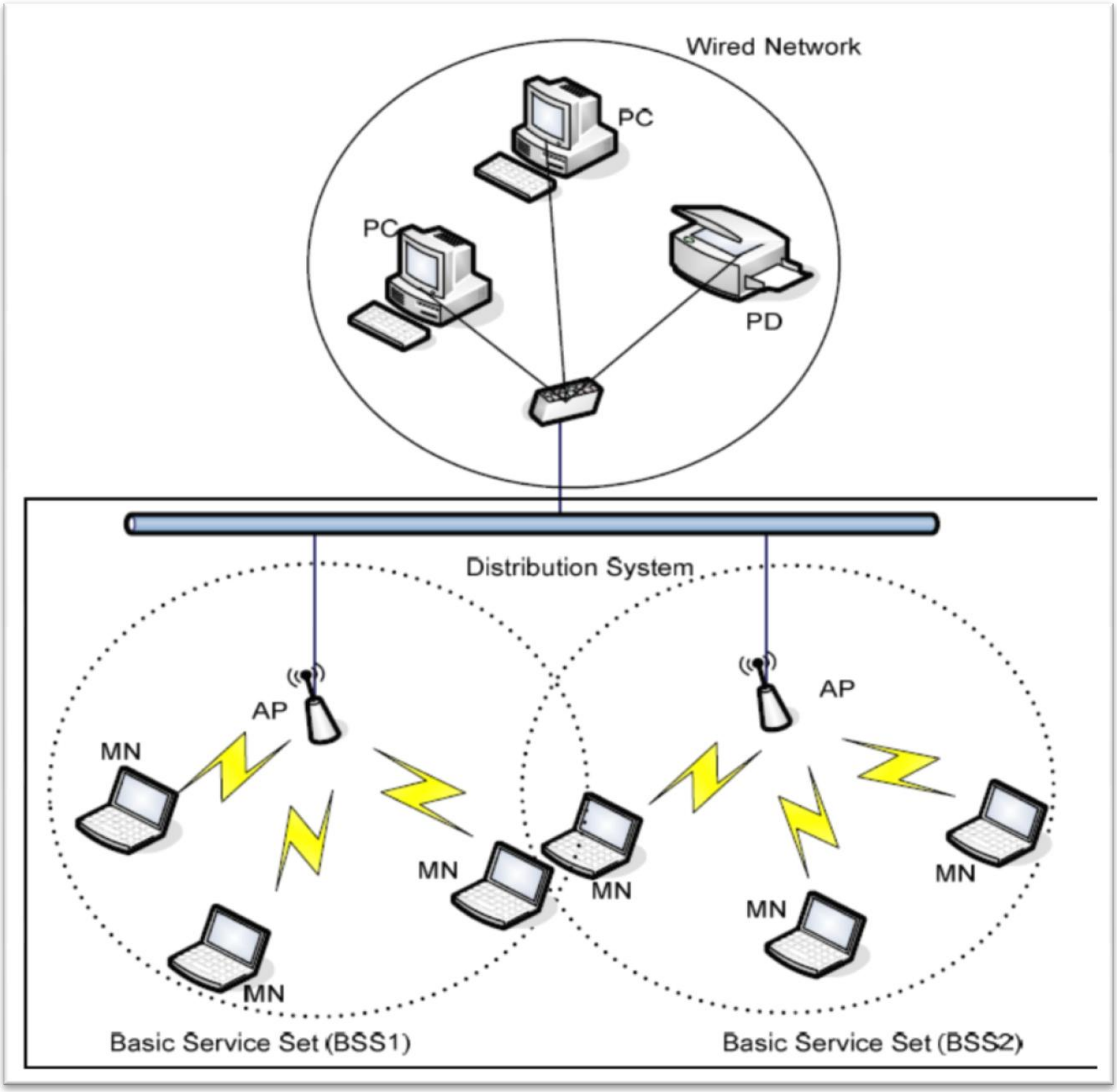
1.1 BACKGROUND

The proliferation of mobile computing and communication devices such as smart cell phones, laptops, personal digital assistants (PDAs), and other sophisticated handheld digital devices is driving a revolutionary change in our information society [7]. We are moving from the Personal Computer age (i.e., a one computing device per person) to the Ubiquitous Computing age in which users utilize, at the same time, several electronic platforms through which they can access all the required information whenever and wherever needed. The nature of ubiquitous devices makes wireless networks the easiest solution for their interconnection and, as a result, the wireless arena has been experiencing exponential growth in the past two decades. Not only are mobile devices getting smaller, cheaper, more convenient, and more powerful, but they also run more critical applications and network services, commonly driving the rapid and explosive growth of mobile computing equipment market [7]. Depending on the underlying configurations, wireless networks for WLANs are divided in to two major categories by the IEEE 802.11 standard [30] as: Infrastructure based and Infrastructure-less. The infrastructure based wireless network as seen in figure 1.1 is a wireless network that has a central fixed coordinating systems (Access Points) connected with existing wired LANs. In contrast, the infrastructure-less (ad hoc) networks do not have centralized fixed coordinating systems and need only mobile communicating devices to cooperate in a peer-to-peer fashion to form an Independent Basic Service Set (IBSS) [30] in order to communicate with each other.

Next generation of wireless communication systems are being engineered to service independent mobile users where each user involved in the network will communicate with the others without any dependency in a centralized coordinating system [1]. These autonomous mobile users (nodes) are connected through wireless links to build a live and on-the-fly network called a Mobile Ad-hoc Network. The nodes involved in this system should collaborate among themselves and can function as both hosts and routers. They work together only based on cooperation and mutual agreement, without knowing about the network topology around them [1]. Wireless Mobile Ad Hoc Networks (MANETs for short) [12] are characterized by their mobility, self-configuration without a centralized administration, ease of deployment and ability of nodes to communicate with each other even in out-of-range conditions with intermediate nodes performing the routing functions [6,7,8,9,10,11,17].

MANETs are also flexible enough to get connected to cellular as well as wired networks. The features that delineate them from traditional networks are the absence of need for an infrastructure and centralized administration, the mobility of the nodes, and the ability to configure on the fly as the situation demands. The network is decentralized where all network activity, including delivering messages and discovering the topology must be executed by the nodes themselves. Therefore routing functionality, the act of moving information from source to a destination, will have to be incorporated into the mobile nodes [5]. The nodes can function both as hosts and as routers. When they act as a host, nodes function as a source and destination in the network and when they act as a router, nodes act as intermediate bridges between the source and the destination giving store-and-forward services to all the neighboring nodes in the network [5].

Hence routing is one of the most important and yet very challenging issue in mobile ad hoc networks.



Extended service Set (ESS1)

Figure1.1: An Infrastructure-based wireless LAN consisting of wireless access points (APs) and mobile nodes (MN), personal computers (PCs) and a network printer (PD) [30]

1.1.1 Mobile Ad hoc Networks

The recent advances and the convergence of micro electro-mechanical systems technology, microprocessor hardware and nano technology, integrated circuit technologies, wireless communications, distributed signal processing, Ad-hoc networking routing protocols and embedded systems have made the concept of Wireless Networks [9]. Ad-hoc networks are a new paradigm of wireless communication for mobile hosts. Fixed base station is no more a requirement of the wireless network as a base station in mobile switching network. Each user communicates directly via wireless links between them and transfer messages to next user spaced at far distance. Node mobility causes frequent changes in topology [17].

Mobile ad-hoc networks hold the promise of the future, with the ability to establish networks at anytime, anywhere [2]. These networks do not rely on inessential hardware which makes them an ideal candidate for rescue and emergency operations. As these networks are devoid of any single traffic concentration point, each node in the network plays the role of a router on the run [2]. This technology is rapidly experiencing the real world implementation and one of the leading researchers' areas although it has its challenges of device heterogeneity, mobility, random traffic profiles and power conservation. As it is shown in the diagram below, different mobile (unfixed) nodes are connected through a wireless link.

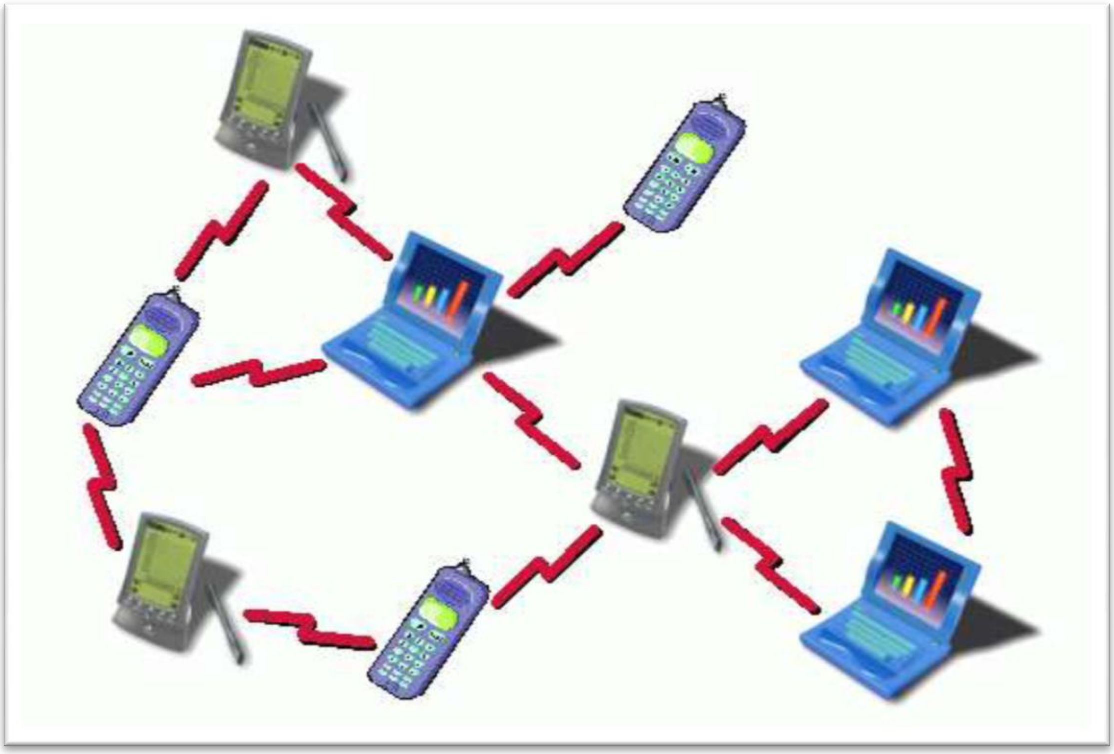


Figure 1.2: An example of a MANET [12]

1.1.2 Characteristics of Mobile Ad hoc Networks (MANETs)

MANETs have different unique characteristics in addition to the inherited characteristics from the legacy (traditional wired) network. These characteristics are derived from the distributed function of their medium access mechanisms and the inherent nature of their wireless communication medium [30]. Some of the characteristics are discussed in this section as follows.

Wireless Channel: The communication channel of mobile ad hoc networks is wireless and is vulnerable to different transmission impediments such as fading, interference, path loss and blockage [30].

Mobility: The nodes in MANETs are usually in a random motion and therefore the topology can be dynamically changing. Communication sessions in MANETs, therefore, suffer from frequent path breakage and link failures due to the highly dynamic topology [30].

Bandwidth: Unlike their wired counter parts such as fiber optics which has abundant bandwidth, the available radio frequency channel bandwidth for MANETs is considerably low. The available bandwidth is also shared by all the nodes within the same transmission range. Therefore, the available bandwidth per channel depends on the number of nodes involved and the traffic flow generated by each node and added in to the network [30].

Limited Resources: Mobile ad hoc network nodes are subjected to different constraints such as low computational capability, limited energy and storage (memory) size. Most of the nodes involved in the mobile ad hoc network usually work on batteries and have limited memory space and processing capability.

1.1.3 Applications of Mobile Ad hoc Networks (MANETs)

The applications of MANETs range from simple civil and commercial applications to a very critical military operations and high risk emergency services [30, 31]. Some of the application domains of MANETs are discussed below.

Civil and commercial applications: MANETs, in this application scenario, can be used in short range vehicular wireless communications in urban environments to control and monitor the vehicle’s mechanical components and ensure road safeties through peer-to-peer interactions and coordination [30]. MANETs can also be used in personal area networks where a group of people with different network devices can temporarily set up a network to exchange some data, files and other network resources.

Military Operations: Another wide range application of MANETs is in military operations where very complicated and mission critical operations are performed. In the future, battlefield operations are believed to be performed through autonomous agents such as unmanned ground, air and sea born vehicles for surveillances, intelligence, enemy antiaircraft suppression and other tactical operations [30]. These agents will, therefore, organize themselves and act as mobile nodes in order to accomplish the mission. Figure 1.3 shows an example of the applications of MANET.

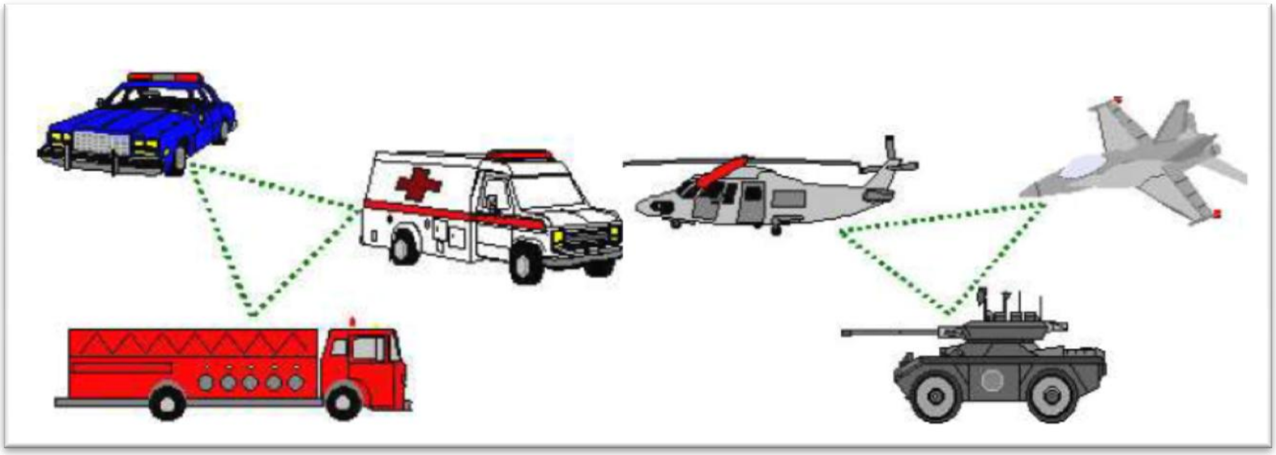


Figure 1.3: Application of mobile ad hoc networks (MANETs) [35]

Emergency Services: Another important application area of MANETs is in emergency search and rescue operations by immediately deploying and help in rapid activities coordination in situations where the existing infrastructure based networks are destroyed by natural or man-made disasters such as earth quack and fire or simply when there are not any infrastructure based networks [30].

Due to their additional unique characteristics (that is the dynamic topology caused by the node mobility and self-organizing nature), Mobile ad hoc networks need new requirements on the routing protocols. Different mobile ad hoc network routing protocols have been, therefore, developed by network designers and researchers primarily to enhance the performance of mobile ad hoc network with regard to proper and efficient route establishment between a source and destination for reliable message delivery. A clear understanding of the performance characteristics of these different protocols will help an efficient optimization and appropriate deployment of mobile ad hoc networks.

1.2 STATEMENT OF THE PROBLEM

Classical IP based routing protocols are not appropriate for ad hoc mobile networks because of the mobile and dynamic nature of the network links. Routing protocols for such environments must, therefore, be able to keep up with the high degree of node mobility that often changes the network topology dynamically and unpredictably. Therefore, different types of mobile ad hoc network routing protocols with different performance characteristics and efficiencies have been developed. Studying the performance characteristics against some performance metrics and identifying their weaknesses and strengths is crucial in order to find out the suitable routing protocol to make an efficient routing for a given particular network operation scenario and make further optimizations.

Although different researches have been done on the performance analysis and comparison of different routing protocols in MANET, there are no adequate and comprehensive researches done on the performance analysis and comparison of the popular MANET routing protocols (AODV, DSR and OLSR) based on a broad range of control variables on which the protocols are mainly optimized such as varying FTP traffic loads, network size scaling and mobility on the literature. Therefore, there is still a need to widen the spectrum on the performance analysis of the protocols. Thus, in this research the performances of AODV, DSR and OLSR have been investigated in simulated networks to compare the impact of their technology designs on end-to-end behaviors such as end-to-end delay and throughput under different network scenarios using an OPNET modeler.

1.3 RESEARCH QUESTIONS

The main research questions that have been addressed in this research thesis are listed as follows:

1. How do the AODV, DSR and OLSR MANET routing protocols perform their routing functionalities?
2. How protocols performances will be affected by the FTP traffic load variations, mobility speed of nodes and the size of the network?
3. Does any protocol perform better or worse than the other with respect to delay and throughput? What factors influence the end-to-end performance characteristics of routing protocols?

1.4 OBJECTIVES

1.4.1 Main Objective

The main objective of this research thesis is to study, analyze and compare the performances of AODV, DSR and OLSR MANET routing protocols using OPNET Modeler with FTP traffic under different network situations.

1.4.2 Specific Objectives

The specific objectives of this research thesis are:

1. To study the working functionalities of AODV, DSR and OLSR MANET routing protocols
2. To analyze the impacts of FTP traffic load, network size and mobility speed variations on the performances of the protocols in terms of delay and throughput.
3. To analyze and identify the scenarios where one protocol is better or worse than the other through simulations.

1.5 JUSTIFICATION

Due to their nature (that is the dynamic topology caused by the node mobility), Mobile ad hoc networks need new requirements on the routing protocol. Different mobile ad hoc network routing protocols have been, therefore, developed by network designers and researchers primarily to enhance the performance of mobile ad hoc networks with regard to proper and efficient route establishment between a source and destination for reliable message delivery. A clear understanding of the performance characteristics of these different protocols will help an efficient optimization and appropriate deployment of mobile ad hoc networks. Therefore, it is important to analyze routing protocols using a standardized benchmark of testing and comparing their overall performances. Therefore, in this research the performances of three protocols have been analyzed and compared in different network scenarios using OPNET Modeler.

1.6 SCOPE OF THE RESEARCH

Although there are different MANET routing protocols, the scope of this research is limited to performances analysis and comparison of three popular protocols under varying FTP traffic load, Network size and mobility speed. That is, the focus of the research is to study, analyze and compare the performances of Ad hoc On-demand Distance Vector (AODV), Dynamic source routing protocol (DSR) and Optimized Link State Routing (OLSR) MANET routing protocols by scaling the FTP traffic load levels, network size and mobility speeds. The rationale these three protocols are chosen in this research is first, they are the most popular protocols among the other protocols and second, AODV and DSR represent well known reactive routing protocols whereas OLSR is the most popular protocol from the Proactive routing protocols so that it will also help to investigate the performance differences of reactive and proactive protocols. End to end delay and throughput are used as performance metrics.

1.7 LIMITATION

In this research, the performance analysis and comparisons of only three protocols were considered and the scalability analysis was made based on three FTP traffic loads, three network sizes and two mobility speeds because of the limited time and resources available. And also only average end-to-end delay and throughput were considered as performance measurement metrics.

Being a commercial software and expensive, we were not able to find the OPNET Modeler in time and it has somehow contributed to the time limitation constraint.

1.8 THESIS OUTLINE

This research thesis consists of five chapters. In chapter 1, the general introduction of the topic in question and the background, the problem statement, the objectives and research questions of the study are presented. Chapter 2 presents the literature review in which the general overview of the concepts of the MANET routing protocols and previous related works are presented. Chapter 3 presents the methodology used in this research. The performance parameters and simulation environments are briefly discussed. In chapter 4, the results and analysis of the research output are presented. Chapter 5 presents the conclusions drawn from the overall research and puts recommendations and a direction for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Since mobile ad-hoc networks are networks composed of independent mobile nodes mainly characterized by the absence of any fixed infrastructure or centralized coordination, which makes the nodes in the network act as a potential router with a dynamically and rapidly changing topology, the classical routing algorithms fail to perform properly, as their technology designs are not robust enough to accommodate such a changing environment [15]. Consequently, different researches have been conducted and various protocols that would be able to accommodate for such networks have been developed. In this chapter an overview of the existing MANET routing protocols, working functionalities of selected routing protocols and previous related works are presented.

2.2 GENERAL OVERVIEW OF MANET ROUTING PROTOCOLS

Routing is a process by which information or a message is delivered to a destination communication node from a communication source node through the best path whereas routing protocols are set of rules or algorithms which govern the routing process. Most routing protocols in mobile ad hoc networks are derived either from distance vector or link state algorithms. In distance vector routing, each router maintains a table containing the distance from itself to all possible destinations. Each router periodically transmits this table information to all routers in its neighbor, and updates its own table by using the values received from its neighbors [9]. A router can decide the next hop as the shortest path from itself to the specified destination based on the comparison of the distances obtained from its neighbors for each destination [9]. When each router has a packet to send to some destination, they simply forward the packet to their decided next hop router [9]. The algorithm accelerates the convergence to the correct path when the routing table is frequently updated. Nevertheless, the overhead in CPU time and network bandwidth for flooding routing updates also increases. And also when the mobility of each node increases, the time latency at which the system converges to the correct path may increase [9].

In link state routing, on the other hand, every node constructs a map of the overall topology of the network so as to show the connections of each node to every other nodes. Each node tracks the connection type (characteristics) and status of each link and independently calculates a link metric or link cost based on which a path is chosen to route the messages from source to destination. Each node in the network periodically broadcasts the link cost of its outgoing links to the remaining nodes in the network through flooding to keep a consistent view of the costs in the topology. Upon receiving this information, each node updates its topological view of the network and uses the shortest path algorithm to select the next hope for each destination. The Ad-hoc routing protocols are broadly classified into three main groups based on their routing approaches [5, 13]:

1. Proactive or (Table-driven)
2. Reactive or (On-demand driven)
3. Hybrid (Proactive and Reactive)

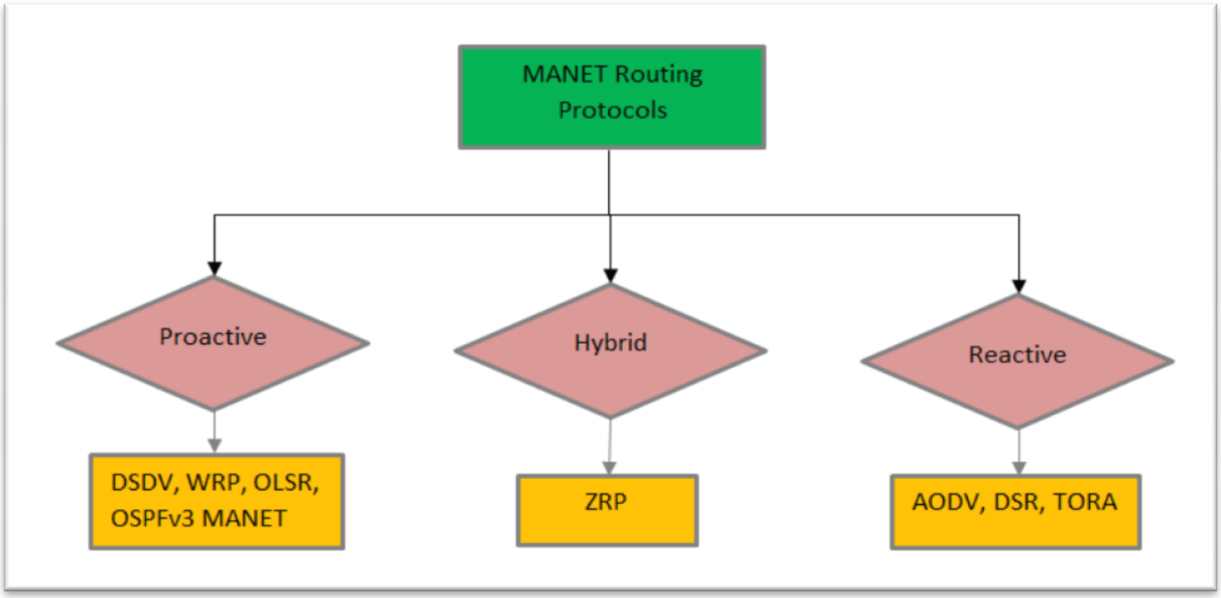


Figure 2.1: Classification of MANET routing protocols

2.2.1 Proactive Protocols

These protocols try to maintain latest routing information in a table to every node through periodic dissemination of topology updates. That is, the nodes in mobile ad hoc networks should keep track of routes to all possible destinations so that when a packet is needed to be forwarded, the route is already available in the routing table and can be used immediately [23]. Proactive protocols have the advantage of low latency that a node experiences minimal delay whenever a route is needed as a route is immediately selected from routing table [22]. However, proactive protocols require nodes to periodically transmit routing table update packets regardless of the network traffic [9, 18]. When the number of nodes in the network grows the size of the routing tables and the bandwidth required to update them also grows [18]. This overhead is considered as the main drawback of Proactive protocols. Some popular examples of proactive protocols are briefly explained below.

2.2.1.1 Destination Sequence Distance Vector (DSDV)

Destination Sequence Distance Vector (DSDV) [18] which maintains consistent network view via periodic routing updates is one of the oldest distance vector routing protocols for MANET. In DSDV routing information is stored inside routing tables maintained by each node. New route broadcasts contain the address of the destination, the sequence number of the destination, the number of hops to reach destination and a new sequence number unique to broadcast [18]. A route with a recent sequence number is considered as a fresh route. If sequence numbers are found to be the same, then the route with better metric will be selected. The main weakness of DSDV is that it requires nodes to periodically transmit routing table update packets regardless of the network traffic [18]. When the number of nodes in the network grows the size of the routing tables and the bandwidth required to update them also grows [18].

2.2.1.2 Cluster-head Gateway Switch Routing protocol (CGSR)

Cluster-head Gateway Switch Routing protocol (CGSR) is another proactive protocol, in which nodes are organized into clusters and the coordination among members are maintained by assigning a cluster-head [18]. Having a frequent cluster head changes can adversely affect routing protocol performance since nodes are busy with cluster head selection rather than packet relaying [18]. Cluster head table also pose additional requirement to the memory.

2.2.1.3 Wireless Routing Protocols (WRP)

Wireless Routing Protocol (WRP) [18] is a table based distance vector routing protocol in which each node will use four routing tables (i.e. routing table, link-cost table, distance table and message retransmission list (MRL) table) to maintain accurate information. Nodes in WRP maintain four tables thus require sufficiently higher memory than some other table driven protocols [18]. When the number of nodes in the network is more, then this can lead the memory requirements and it creates temporary loops [14-18].

2.2.1.4 Optimized Link State Routing (OLSR)

Optimized Link State Routing (OLSR) [23] is a link state proactive IP routing protocol optimized to work for MANETs that discovers and distributes link state information of the entire topology of the network to the other nodes in the network using hello and topology control (TC) messages. Each node in the network computes next hop destinations using this over all topology information for all the network nodes using the shortest path (hop) forwarding. The key feature of OLSR is that it basically uses a Multi-Point Relaying (MPR) to optimize flooding. OLSR protocol at each participating node discovers 2-hop neighbor information using hello messages and performs election of a set of MPRs in a distributed manner. Each Node selects MPRs independently such that there is a path to each of its 2-hop neighbors via a node selected as an MPR. Each node periodically declare and broadcast list of only the MPR selectors in the TC messages instead of the whole list of neighbors in the link-state message which minimizes the size of link-state messages. Only the mobile nodes which are selected as MPRs will generate and forward link-state messages, therefore limiting the number of nodes that emit link-state messages. It will be discussed in more detail later in this chapter.

2.2.1.5 Open Shortest Path First version 3 MANET (OSPFv3 MANET)

Another example of proactive protocol is OSPFv3 (Open Shortest Path First version 3) MANET protocol [27]. OSPFv3 was first implemented for infrastructure based and wired networks.

Enhancements on OSPFv3 for Mobile Ad Hoc Networks (MANETs) help optimize the performance and scalability of OSPFv3 in highly dynamic, wireless mobile environments [27]. According to Kaur. H and Amandeep. V (2012) [27], enhancements on OSPFv3 MANET improve routing efficiency and reduce overhead traffic in mobile ad hoc environments, so that network clusters can scale to support more users.

2.2.2 Reactive (On-demand) Protocols

These routing protocols find path by exchanging the routing information (by flooding the network with Route Request packets) only when a node requires a path to communicate with the destination. Unlike proactive protocols, there is no periodic dissemination of routing table update messages. This prevents the nodes from updating every possible route in the network, and instead allows them to focus either on routes that are in the process of being set up or that are being used at that time [14, 17]. Examples of on-demand or reactive routing protocols are briefly discussed as follows.

2.2.2.1 Dynamic Source Routing Protocol (DSR)

Dynamic Source Routing Protocol (DSR) [18] is a link state source routed reactive protocol in which a node in the network maintains route caches containing the source routes that it has learnt. That is, the entire path from the source to the destination is provided by the source in a packet header. The routing metric method is the shortest path or next path available. In DSR a route has to be discovered before the actual data packet is transmitted. This initial search latency may degrade the performance of real-time and interactive applications. Moreover, the quality of path is not known prior to call setup [18].

2.2.2.2 Ad-hoc On-Demand Distance Vector routing protocol (AODV)

Ad-hoc On-Demand Distance Vector routing protocol (AODV) [18] builds routes using a route request and route reply query cycle. For destination that source nodes have no prior information, they broadcast a route request (RREQ) packet. Nodes receiving RREQ update their information and set-up backward pointers to the source node [18]. When the source node receives the RREP it begins to forward data packets to the destination [18]. AODV is an on demand approach but still use periodic broadcast of "hello message" to track neighboring nodes [18]. This periodic propagation causes network overhead in AODV. The routing metric method is the freshest and shortest path. In AODV a route has to be discovered before the actual data packet is transmitted. This may cause initial search latency and degrade the performance of real-time and interactive applications [18].

These protocols, in general, have the advantages of no big overhead for global routing table maintenance as in proactive protocols and quick reaction for network restructure and node failure [1, 9, 14, 17, 18]. Even though reactive protocols have become the main stream for MANET routing, they still have the disadvantages of high latency time in route finding and network clogging due to excessive flooding.

2.2.3 Hybrid routing protocols

The third category of MANET routing protocols is the Hybrid protocols. These types of protocols combine the advantages of proactive and reactive routing protocols. Zone Routing protocol that uses proactive approach to nodes within the zone and reactive approach to nodes outside the zone is an example of hybrid routing protocol. The disadvantage of the hybrid technique depends on the number of active nodes involved in the network. Potential inefficiency may occur when flooding of the RREQ packets goes through the entire network [18].

2.2.3.1 Zone Routing Protocol (ZRP)

Zone Routing protocol, which was first introduced by Haas in 1997 [23], is the first hybrid protocol with the characteristics of both proactive and reactive routing protocols. Routing mechanism in this protocol is made by two sub protocols called Intra-zone Routing Protocol (IARP) and Inter-Zone Routing protocol (IERP). The former is a proactive protocol and is used inside routing zones where as the later is a reactive routing protocol that is used between routing zones [23]. Within the local zone a path to a destination can be established from the proactively cached routing table of the source by the Intra Zone Routing Protocol (IARP). Thus, if the source and destination nodes are within the zone, packet delivery will be made immediately using the existing proactive protocols as IARP. But if the destination nodes are outside the node, the route discovery process will be done in a reactive manner. In the next sub section, the working functionalities of the protocols targeted in this research are discussed.

2.3 ROUTING PRINCIPLES OF AODV, DSR AND OLSR ROUTING PROTOCOLS

2.3.1 Dynamic Source Routing (DSR) Protocol

The Dynamic Source Routing (DSR) protocol, as its name indicates, is a source routed reactive protocol, in which a node in the network maintains route caches containing the source routes that it has learnt. That is, the entire path from the source to the destination is provided by the source in a packet header. The address of each node between the source and destination are required to be accumulated during the route discovery process to determine source routes. The accumulated route information is cached by each node involved in processing the route discovery packets and then the packets are routed through the learned paths [23]. The addresses of each device that the packet will traverse are contained in the routed packets so as to accomplish the source routing. This may cause an overhead for long addresses or paths. DSR also provides another option by which packets can be forwarded on a hop-by-hop basis by defining a flow id. The routing philosophy of Dynamic Source Routing protocol has the following phases: Route Discovery, Route maintenance and Route Reply. However, the first two are the major phases as route reply is generated if the message or packet has reached the destination node [23].

Route Discovery**:** When a source node intends to send a packet to a destination, it first checks its route cache to determine whether it already has a route to the destination node. If it gets an unexpired route to the destination node, then the source node uses this route to forward the packet to the destination. But if there is no such a route in the rout cache, then it initiates the route discovery process by broadcasting a route request packet [23]. The addresses of the source and the destination, and a distinctive identification number are contained in the route request packet header [23]. Each intermediate node checks whether it knows of a route to the destination [33]. If it does not, it appends its address to the route record of the packet and forwards the packet to its neighbors [33]. An intermediate node processes the route request packet only if it has not already seen the packet and its address is not present in the route record of the packet in order to limit the number of route requests propagated. When either the destination or an intermediate node with current information about the destination receives the route request packet, a route reply will be generated [33].

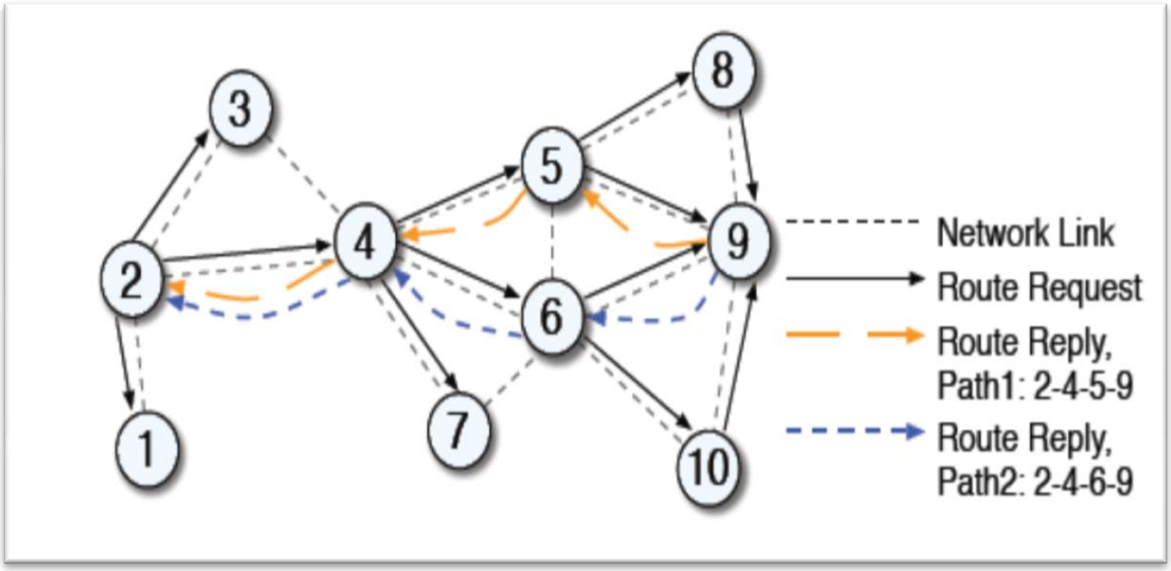


Figure 2.2: Building Route Record during Route Discovery and Route Reply [34]

A node that receives a route request checks whether the destination address of the request matches with its own address or not. If it matches, it is the destination and sends a route reply back to the source through the route by which the request reached this node from the source. But if it doesn't match, it is an intermediate node. If the node has never seen this route request before and has a route to the destination in its cache table, it creates an intermediate-node route reply packet with the route from its cache, and sends it back to the source. If it does not have a route to the destination, it appends its own address to the route record, increments hop count by one, and rebroadcast the request. The process goes on until the destination receives the request. Up on receiving the route reply, the source appends this route to its cache table and sends pending data packets. The route record formation when the route request propagates through the network and route reply generation by destination node, are depicted as shown in the figures 2.2 and 2.3 respectively.

***Route Maintenance*:** If any link of a source route is detected (detected by the MAC layer of the transmitting node) to be broken, the Dynamic Source Routing protocol uses two types of packets called Route Error packet and Acknowledgements to maintain the error. A node generates a Route Error packet if it encounters a fatal transmission problem at its data link layer. The route error is unicasted back to the source using the part of the route traversed so far, erasing all entries of the link in error from the route caches along the way. The correct operations of the links are verified by acknowledgement packets.

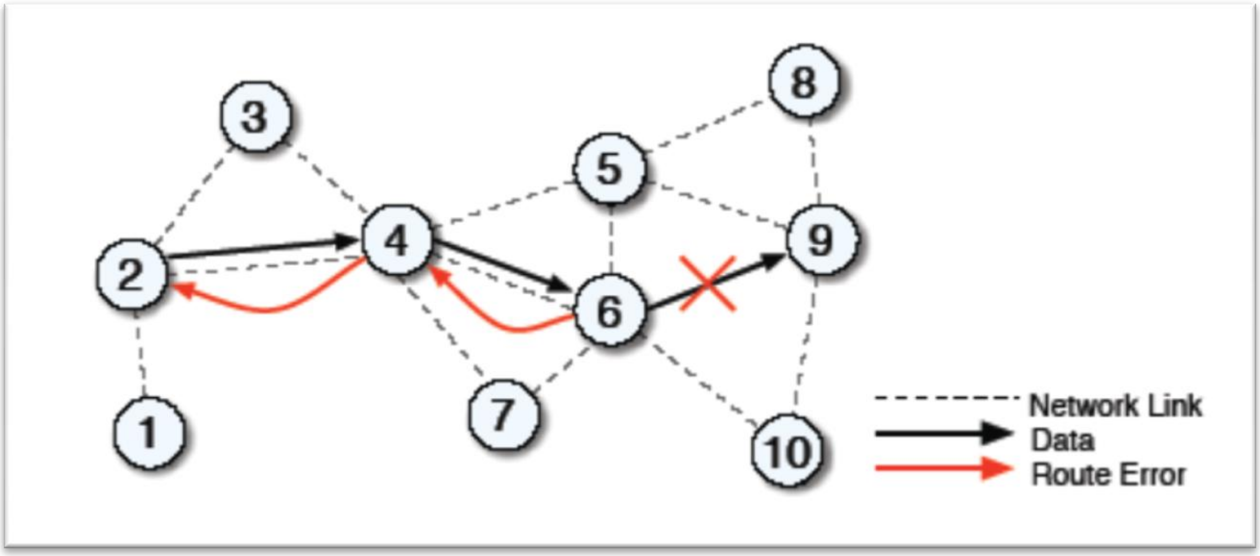


Figure 2.3: Route error maintenance in DSR [34]

Advantages of DSR

In DSR, since the route is determined when required (on demand basis), it has the advantage of no flooding of the network by routing updates. Another advantage of DSR is that the information cached by the intermediate nodes support to reduce routing overhead.

Disadvantages of DSR

It has also some disadvantages in failed route reconstruction. When an error occurs, the maintenance is not done by the local node where the failure occurs. And also, there is a larger set up delay relative to proactive protocols. DSR also performs better in low-mobility or static network situations.

2.3.2 Ad hoc On Demand Vector (AODV) routing protocol

Ad hoc On-Demand Distance Vector (AODV) Routing protocol is a reactive routing for ad hoc network that is capable of both unicast and multicast routing. AODV, as its name indicates, is a distance vector routing protocol that constructs routes when there is a demand. It basically consists of combined characteristics of Destination Sequence Distance Vector (DSDV) and Dynamic Source Routing (DSR). It takes the basic on-demand mechanisms of route discovery and route maintenance from DSR and the sequence numbers, hop-by-hop based routing, and periodic beacons from DSDV. Unlike the DSDV's routing algorithm which maintains a complete list of routes, AODV create route on on-demand basis thereby minimize the number of required broadcasts. The routing philosophy of AODV has the following phases:

Route discovery: when a node intends to send a message to a destination and does not already have a route, it broadcast a route request (RREQ) packet to the nodes in its radio range to initiate a route discovery process to find the destination. The neighboring nodes again further broadcasts the RREQ to their neighbors, and so on until the destination or an intermediate node with a "fresh enough" route to the destination is found. AODV checks if all routes are loop-free and contain the most recent information using destination sequence numbers. All nodes maintain their own sequence number and broadcast ID. For every RREQ a node initiates, the broadcast ID increase by one and, along with the IP address, distinctively identifies the RREQ. In addition to the node's sequence number and broad cast ID, the RREQ also includes the most recent sequence number it has for the destination. If intermediate nodes have route to the destination with a sequence number greater or equal than to that contained on the RREQ, they replay to the RREQ. When RREQ is broadcasted, intermediate nodes record the address of the neighbor from which the first copy of the broadcast packet is received, in their route table to establish a reverse path. If other additional same RREQ are received later, they are discarded. If a RREQ reached the destination or an intermediate node with fresh enough route, the node unicasts a route reply (RREP) packet back to the neighbor node which the RREQ was received from.

As shown in figure 2.4 below, the route reply is routed back along the reverse path, nodes along this path form forward route entries in their route tables from which the RREP came. These indicate the active forward route. There is a route time associated with each route entry to specify the lifetime with in which the route entry will be used before it is deleted. The route reply (RREP) is sent back along the path created by RREQ. This indicates that AODV supports only the use of symmetric links. The source node that needs to send a message can now send its message along the path with least number of hopes.

Route Maintenance: Since the nodes involved in the MANET network freely move, there are frequent link breakages. When a node along a route moves, its upstream neighbor notices the move and propagates an RREP with infinite metric as a link failure notification message to all active upstream neighbors to notify them the breakage of that part of the route. These nodes will also do the same procedure and so on until the destination node is reached. Up on receiving the link failure notification, the source node may re-initiate a route discovery process for that destination if there is still a need for a route. Another aspect of AODV is a periodic local broadcast of hello messages by a node to notify other nodes in its neighborhood. Although they may not be always required, hello messages can be used to maintain local connectivity.

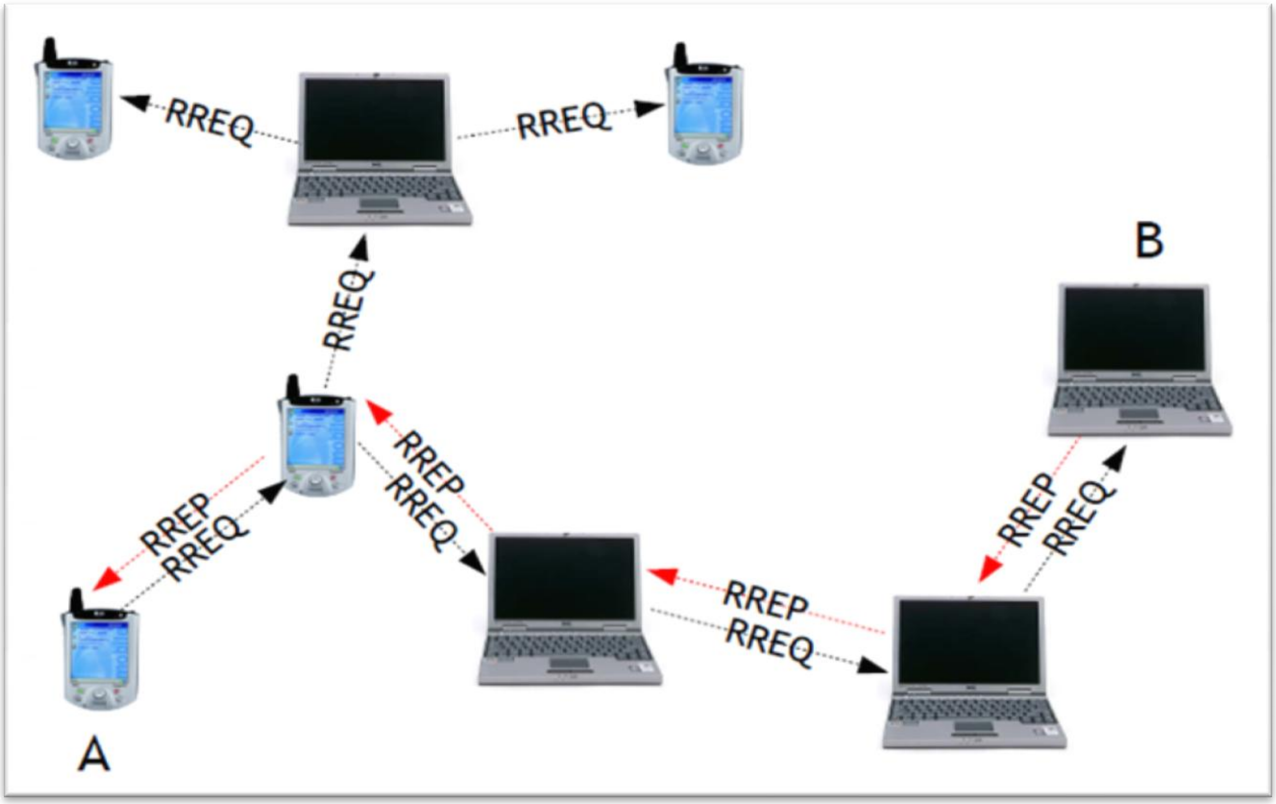


Figure 2.4: Route discovery process in AODV

Source: https://www.google.com/Mobile+Ad-Hoc+Network+Andreas Tonnesen+andreto@olsr.org

Advantages of AODV

The main advantage of AODV is has no large overhead as it is an on-demand basis routing protocol and does not create extra traffic for communication along the existing links. The latest routes to the destination are also found using the destination sequence number. Since AODV is a distance vector routing protocol, it is simple and does not require large storage (memory) and processing (calculations) capacity.

Disadvantage of AODV

AODV requires more connection establishment or time, and the initial route establishment communication is heavier than other schemes. There can also be inconsistent routes when the intermediate nodes have a higher but not the latest destination sequence number and source sequence number is very old, thus stale entries. And also, as reactive routing protocol, the route discovery process can cause a larger delay.

2.3.1 Optimized Link-State Routing (OLSR) Protocol

Optimized Link State Routing (OLSR) [23] is a link state proactive IP routing protocol optimized to work for MANETs that discovers and distributes link state information of the entire topology of the network to the other nodes in the network using hello and topology control (TC) messages. Each node in the network computes next hop destinations using this over all topology information for all the network nodes using the shortest path (hop) forwarding. Unlike classical link-state routing schemes in which all nodes need to flood network with link-state information, OLSR provides a mechanism to optimize link-state messaging.

As OLSR is a proactive protocol that has a periodic nature, it can create a large routing overhead. In order to reduce this overhead, the OLSR basically uses a neighbor/ link sensing, a Multi-Point Relaying (MPR) which is used to optimize flooding and a Link-state messaging and route calculations. OLSR protocol at each participating node discovers 2-hop neighbor information using hello messages and performs election of a set of MPRs in a distributed manner. Each Node selects MPRs independently such that there is a path to each of its 2-hop neighbors via a node selected as an MPR. Each node periodically declare and broadcast list of only the MPR selectors in the TC messages instead of the whole list of neighbors in the link-state message which minimizes the size of link-state messages. Since OLSR is a table driven or reactive protocol, all mobile nodes need to maintain and update their routing tables that contain the routes to all reachable nodes. Only the mobile nodes which are selected as MPRs will generate and forward link-state messages, therefore limiting the number of nodes that emit link-state messages. What makes the use of MPR functionalities in OLSR unique from other link-state routing protocols is that the TC messages are not forwarded on a shared path; only subset of nodes source link-state information and all links of a node are not advertised but only those that represent the MPR elections[23].

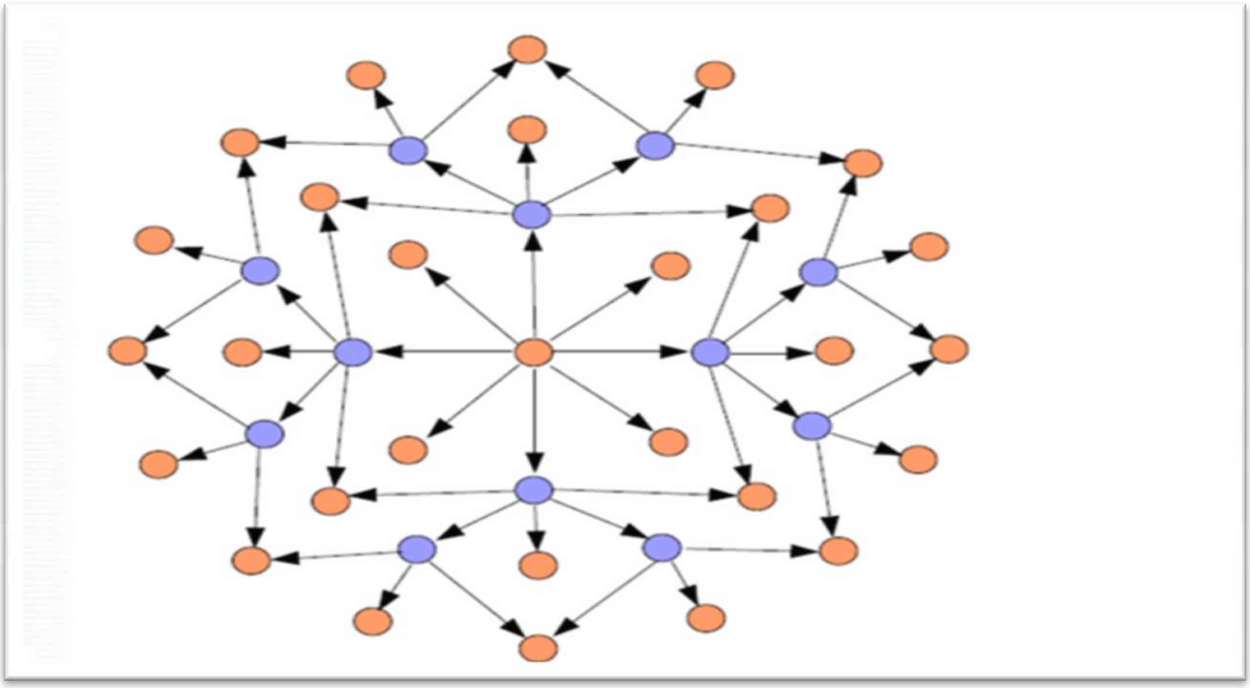


Figure 2.5: Multipoint Relaying (MPR) flooding on OLSR

Source: https://www.google.com/Mobile+Ad-Hoc+Network+Andreas Tonnesen+andreto@olsr.org

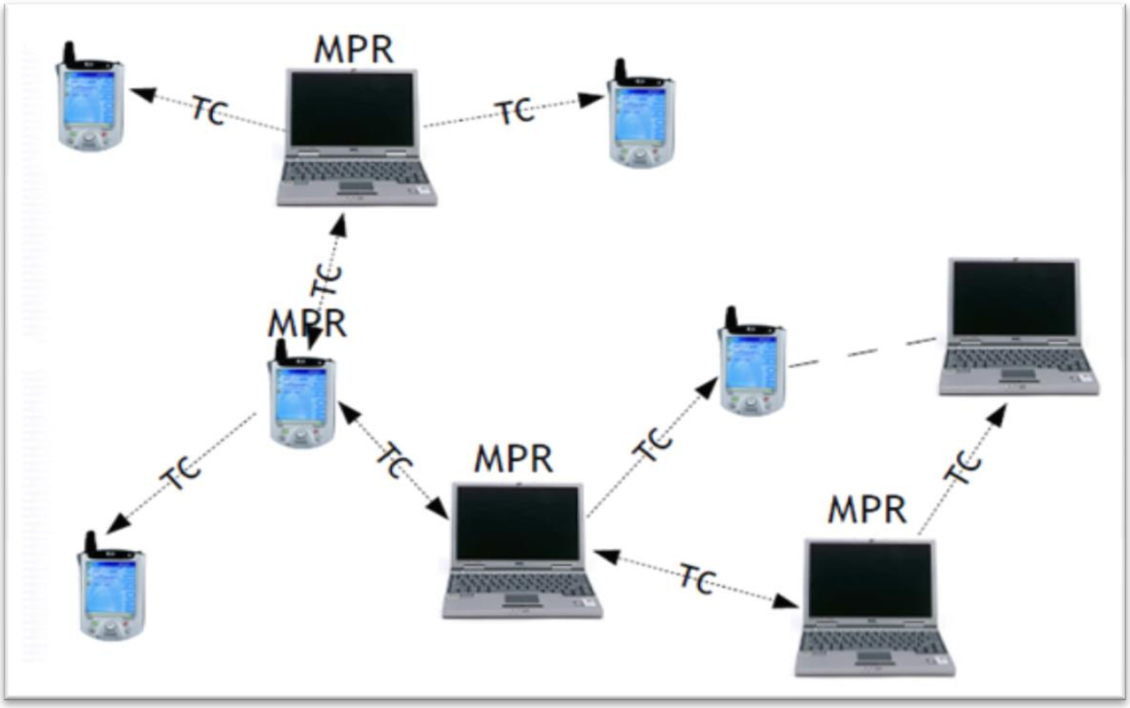


Figure 2.6: Link-state: TC messages and MPRs

Source: https://www.google.com/Mobile+Ad-Hoc+Network+Andreas Tonnesen+andreto@olsr.org

OLSR Messages

OLSR has three different messages which have different roles. They are 'Hello Messages', Topology Control (TC) messages and Host and Network Association (HNA) messages. OLSR uses the 'hello' messages to discover the one-hop neighbors and two-hop neighbors so that the sender can select the MPR, the TC messages to distribute neighbor information to the entire network and the Network Association (HNA) messages to distribute network route advertisements.

Advantages of OLSR

As OLSR is a proactive (table-driven) routing protocol, there are predefined routes to all the destinations. Therefore network nodes can use the available routes to send their messages or packets to the destination without any route discovery process. This helps to avoid the delay associated with the route discovery. Another advantage of OLSR is that increasing the number of route being used does not increase the routing overhead.

Disadvantage of OLSR

The disadvantages of OLSR is that it has a larger routing overhead due to the periodic broadcasting of routing table updates in order to build the global view of the network topology. Another disadvantage of OLSR is that it requires a reasonably large amount of bandwidth and CPU power to compute optimal paths in the network because of its link-state nature.

2.4 PREVIOUS RELATED WORKS

The absence of the need for a centralized administration infrastructure such as base stations and base station controllers (BTS & BSC) contributes positively to the ease of an ad hoc network to be used in situations where implementing centralized infrastructures are economically infeasible and physically impossible such as battle fields and disaster areas. Due to the infrastructure-less, unstable wireless links, limited bandwidth, highly dynamic and unpredictable topology and battery dependable nature of mobile ad hoc networks, their routing scheme presents a challenging research. Since MANETs are generally deployed in disaster management and critical situations, there is a substantial amount of real-time content in their operation [12]. Time plays a crucial role in the communication activities, whether it is a protocol transfer session or a normal routing operation. In view of these facts, efficient protocol deployment assumes the highest level of importance in practical implementations of MANETs [12].

In MANETs, the efficiency of a routing protocol is directly related to numerous factors such as node mobility and dynamically varying topology, power consumption issues, the communication capabilities of the nodes, bandwidth constraints and network traffic loads, network size and scalability, security and a host of other interrelated parameters, all of which have to be well analyzed and evaluated to choose and deploy the efficient routing protocol for a given network scenario [12].

Although it is possible to make general evaluations and comparisons of the performances of the proactive, reactive and hybrid routing protocols, it is always good to take the protocols individually and make experimental analysis under different network scenarios and compare their performances against different performance metrics. This is because the performances of the protocols vary under different network scenarios such as network size variation, mobility speed of nodes, traffic load and others. Therefore, different researches have been done on the performance study and comparison of different protocols in different network scenarios with different performance metrics. This section discusses the previous related works.

Ramesh. V et al, (2010) [16] did performance analysis and comparison of DSDV and AODV with the help of simulations using NS-2 under different pause times, number of nodes and mobility speeds. Packet delivery ratio and average delay were used as performance measurement metrics. A UDP based traffic type, constant bit rate (CBR), was employed. Both protocols were found to have greater performance in packet delivery ratio under little mobility. AODV performs best in terms of packet delivery ratio in all the scenarios. It was also indicated in the simulation results that AODV suffers from a longer end to end delay relative to DSDV while DSDV has a very low packet delivery ratio as compared to that of AODV's in high mobility scenarios. The authors asserted that for communications under UDP based traffic type, AODV is an ideal choice.

Manoj. K et al, (2012) made effective analysis of data traffic received, control traffic received and sent, retransmission attempts, throughput, and traffic received parameters in ad hoc networks for AODV, DSR and TORA using OPNET simulator with 30 fixed number of nodes and three different mobility speeds [19]. According to this study, TORA was found to perform better in terms of control traffic sent, control traffic received, and data traffic sent [19]. However, AODV was found to perform better in terms of throughput and data traffic received.

Jassim. S. I, (2013) studied the performance analysis of AODV, GRP and OSPFv3 with performance metric of delay, throughput and network load under different network scenarios by varying the network size [28]. According to this study, with fixed 50 numbers of nodes, OSPFv3 had larger delay and throughput than AODV and GRP while load in GRP was increased and gradually exceed those of AODV and OSPFv3. AODV was found to be better in delay and smaller load than GRP and OSPFv3.

In [27], (Kaur.H and Amandeep.V, 2012), made the performance comparison of AODV, OLSR, TORA and OSPFv3 using OPNET modeler 14.0 based on delay, data dropped, media access delay, network load, retransmission attempts and throughput under fixed network size. According to this study, it was claimed that OSPFv3 was fine as compared to the other protocols with regard to the performance metrics considered and TORA was the worst in almost all parameters.

Kaur.H and Er. Jaswinder.S (2012) studied the performance comparison of OLSR, GRP and TORA using OPNET modeler by varying the number of nodes (15, 50, 100, and 150) with the performance metrics of delay, throughput, routing overhead and network load using an FTP traffic type [29]. According to this study, it was found that OLSR has a best performance in terms of load and throughput and GRP has best performance in terms of delay and routing overhead in all the scenarios. TORA was found to have the worst performance with regard to the four performance metrics considered. In conclusion, it was found that OLSR is best in terms of throughput (it has the highest throughput) as compared to GRP and TORA in all the network sizes or traffic volumes [29].

A group of researchers (Asha. A. et al, 2010) studied and compared the performance of AODV and DSR using NS-2 2.33 with respect to varying pause time (5, 10, 15, 20, 25, 30, 35 and 40 seconds) using random waypoint mobility model and constant bit rate (CBR) traffic type under a fixed network size of 100 nodes [32]. They used packet delivery ratio, packet loss ratio and routing overhead parameters to illustrate the performances of the protocols. It was found out that both AODV and DSR perform equally well until a certain limit of pause time (10 to 20 seconds). But AODV performs better for larger pause time (20 to 35) and DSR performs better for pause time ranges of 5 to 10 seconds and 35 to 40 seconds under a given scenario. The packet loss ratio and routing overhead are generally higher in AODV than in DSR. AODV performs better only for the pause times of less than 5 to 7.5 and 35 to 40 whereas DSR has a better performance in the remaining pause times in terms of both performance metrics. The authors finally concluded that AODV performs well compared to DSR for larger pause times whereas DSR performs better in a relatively lesser pause times.

In [14], (Jain. R and L. Shrivastava, 2011) analyzed and compared DSR and AODV under free space and two ray ground propagation models. Simulation was done using QualNet in an area of 1000mx100m using a constant bit rate (CBR) traffic type and different pause times. Performance metrics of packet delivery ratio, throughput, average jitter and average end to end delay were used to illustrate the overall performance. DSR was found to have a better overall performance in both models in terms of packet delivery ratio and throughput. AODV performs better in both models with respect to average jitter. In terms of end to end delay, DSR was found to be better in free space model and AODV performs better with a relatively less delay in Two Ray Ground models. The overall performance of DSR was, therefore, indicated to be better in both models except in the average jitter and end-to-end delay in which AODV is better or it takes less time to successfully deliver the packets in the Two Ray Ground model.

(AbdRahman A. H and Z. A. Zukarnain, 2009) studied and compared the performances of DSDV, I-DSDV and AODV through simulations using NS-2 under different network scenarios by varying the number of nodes, pause time and mobility speed using end to end delay, packet delivery ratio and routing overhead as performance metrics [15]. Constant Bit Rate (CBR) traffic type is used. The authors assert that AODV performs better than I-DSDV and DSDV in terms of packet delivery ratio when the number of nodes is increased as a more stable link will be created when the number of nodes is increased. I-DSDV has also a better packet delivery performance than DSDV up to a certain limit above which the performance of both start to decrease as more control packets will be generated [15]. According to the authors, I-DSDV's better packet delivery performance is due to its ability to find new routes during link breakages. AODV also has a less delay and is better than the other two. I-DSDV also has marginally better delay than DSDV. With regard to routing overhead, AODV performs better and followed by I-DSDV and DSDV. In the varying pause time scenario, I-DSDV has a highest packet delivery ratio followed by DSDV and AODV. Packet delivery ratio decreases with decreasing packet pause time. But I-DSDV has a highest delay followed by DSDV and AODV. I-DSDV also exhibits a higher routing overhead. That is, it needs more routing packets than the other two [15]. In the performance comparison with varying node speeds, it was shown in the simulation results that AODV has the highest packet delivery ratio followed by I-DSDV and DSDV. AODV has also a better (the lowest) delay followed by I-DSDV and DSDV. AODV also performs better in terms of routing overhead than the other two. I-DSDV is also indicated to have a slightly better routing overhead performance than DSDV.

Gowrishankar.S et al, (2007) studied the performances of AODV and OLSR in different scenarios using NS-2 simulator in terms of end-to-end delay, packet delivery ratio and routing overhead with respect to network size and pause time variations [21]. According to this study, AODV performs better in terms of packet delivery ratio and average end to end delay when the mobility of nodes is high and this is because since OLSR is a table driven protocol, it is not as adaptive as AODV. The authors also assert that AODV performs better in networks where the traffic is static and the number of source and destination pairs for each host is relatively small [21]. Therefore, AODV can be used in resource critical situations [21]. On the other hand, OLSR performs better in situations where the networks have dense and highly irregular traffic and particularly when the number of hosts is large [21].

Kaqr.V, (213) studied the performance comparisons of AODV, OLSR and GRP through simulations using OPNET 14.5 with FTP and HTTP traffic types [36]. Performance measurement metrics of delay, throughput, network load, traffic sent and traffic received were used. A MANET consisting of 75 wireless mobile nodes and a fixed wireless server were deployed in an area of 3.5Kmx3.5Km. According to this study, OLSR was found to outperform the other protocols in terms of throughput and delay. The author also asserted that OLSR has an overall best performance amongst the three protocols. Vadhwani et al, (2013) analyzed the performance behavior of DSR with a fixed load of HTTP traffic using OPNET 14.5 modeler in 50, 70 and 100 mobile nodes [37]. Delay, throughput, routing traffic sent and received and HTTP traffic sent and received were used as performance metrics. The authors asserted that DSR has higher throughput in the 100 nodes network than in the 50 and 70 nodes networks and the delay was found to be higher in 50 nodes than in the 70 nodes. Simulation results indicated that the routing packets sent and received and HTTP packets sent and received increase with increasing the number of nodes.

Rastogi. M and K. Kant, (2012) [38] studied the performance evaluation of AODV, DSR and DSDV based on FTP, CBR, VBR, HTTP and Multimedia traffic generators using NS-2 2.35 as a simulation tool. 20 mobile nodes were deployed in an area of 2500mx2500m and the performance evaluation was done on different pause times. Packet delivery ratio and throughput were used as performance metrics. Simulation results indicated that the performances of the three protocols with CBR are almost same in terms of packet delivery ratio. DSDV was found to have a better packet delivery ratio performance than the other two for FTP traffic while AODV outperforms for VBR traffic. It was also indicated that none of the protocols have better packet delivery ratio performance for the HTTP traffic. DSDV was also found to have a better packet delivery ratio performance for multimedia traffic using Pareto analysis. In general, it was indicated that all the protocols performed well for the CBR, VBR and exponential traffic sources and produce a throughput of more than 90% for different pause times. DSDV was found to have a better performance for FTP and Pareto traffics while all the protocols suffered from low performance for the HTTP traffic.

2.5 RESEARCH GAPS

Although different researches have been done on the performance analysis and comparison of different routing protocols in MANET, there are no adequate and comprehensive researches done on the performance analysis and comparison of the popular MANET routing protocols (AODV, DSR and OLSR) based on a broad range of control variables on which the protocols are mainly optimized such as varying FTP traffic loads, network size scaling and mobility on the literature. Most of the researches on the literature have been done based on constant bit rate (CBR) traffic type using NS-2 simulator and the scenarios based on which analysis were done is mainly based on network size variation, pause time variation and mobility variation one at a time. There are also different researches on the performance analysis and comparison of MANET routing protocols that have been done based on FTP traffic type in which the FTP traffic load was fixed to a certain single level (either to low, medium or high). There are no adequate researches done on the analysis of the effect of FTP traffic load variations on the end-to-end performances characteristics of MANET protocols. Therefore, in this research the performances of AODV, DSR and OLSR protocols will be investigated in simulated network models to study, analyze and compare the impact of FTP traffic load scaling, network size and mobility speed variations on the end-to-end performance behaviors of the protocols such as end to end delay and throughput under different network scenarios using an OPNET modeler.

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

The research was basically conducted based on two approaches in a bid to meet the objectives. In the first approach, the working principles of the selected routing protocols, which are the foundations for further analysis, were thoroughly studied through literature review. In the second approach network simulation software called OPNET Modeler was used to make a detailed performance analysis and comparisons of the MANET routing protocols in different scenarios. It is usually difficult to model and formalize routing algorithms in mathematical models. They are, therefore, studied, analyzed, evaluated and tested through simulations using simulation platforms. Extensive simulations are used to make comparative performance analysis of routing protocols. In this chapter, the overall conceptual model and the performance evaluation metrics used to analyze and compare the routing protocols and design parameters used in this research are briefly discussed. First, an overview of the performance measurement metrics used in the study is presented. Then the design and simulation environment (software or platform) used is briefly discussed and finally the simulation design is presented.

3.2 PERFORMANCE METRICS

There are various performance evaluation metrics of routing protocols which represent different behaviors of the overall performance of the protocols. In this research, the performance evaluations and comparisons of the protocols were done with respect to end to end delay and throughput which greatly determine the performance characteristics of the MANET routing protocols.

3.2.1 Packet End-to-End Delay

The packet end-to-end delay refers to the average time taken for the packet to traverse the network from the sender to the receiver [24]. This accounts all the delays from the generation of the packet in the source, the propagation, processing and buffer queuing delays in the intermediate nodes and up until it is delivered to the destination node. Mathematically, the end-to-end delay is expressed as [28]:

$$d_{End-End} = \left[d_{trans} + d_{prop} + d_{proc} + d_{queue} + d_{RDD} + d_{rt}\right] = [T_{receive} - T_{sent}] \quad (3.1)$$

Where

$d_{End-End=}$ End-to- end delay

$T_{receive}$ = Receive time

T_{sent} = sent time

d_{trans} = Transmission delay

d_{prop} = Propagation delay

d_{proc} = Processing delay

d_{queue} = Queuing delay

d_{RDD} = Route Discovery Delay

d_{rt} = Retransmission delay

3.2.2 Throughput

Throughput is defined as the ratio of the amount of data that arrives at a receiver from a sender to the time it takes for the receiver to get the last packet [24]. It is expressed in terms of bits or bytes per second (bits/second or Bytes/second) or packets per second (Packets/second). In MANETs, throughput is highly affected by the dynamic nature of the topology due to mobility of nodes, power constraints, limited bandwidth and traffic load. The higher the throughput of a network, the more effective the protocol is. Mathematically, throughput is expressed as [28]:

$$\text{Throughput} = \frac{Number\ of\ delivered\ Packets * Packet\ size * 8}{Total\ duration\ of\ simulation} \quad (3.2)$$

3.3 DESIGN AND SIMULATION ENVIRONMENT

There are different MANET simulation software platforms such as NS-2, NS-3, GloMoSim, QualNet and OPNET. In this research, OPNET 14.5 (Optimized Network Engineering Tool version 14.5) modeler was used to design, simulate and analyze mobile ad hoc network (MANET) models and protocol performance evaluations. The rationale behind to choose this tool is that [24]:

- It provides a very attractive virtual network environment that is prominent for the research studies, network modeling and R&D operations and performance analysis of routing protocols.
- It plays a key role in today's emerging technical world in developing and improving the wireless protocols such as Wi-Max, Wi-Fi, UMTS, etc.
- Suitable in evaluation and design of MANET protocols, enhancements in the core network technologies such as IPv6, MPLS, and analysis of optical network designs.
- It is more reliable, robust and efficient compared to other simulators.
- It is good for performance study among existing systems based on user conditions.
- It is relatively easy to understand the network behaviors in various scenarios.
- It is very flexible and provides a user-friendly graphical interface to view the results.

OPNET generally have the components shown in the figure bellow.

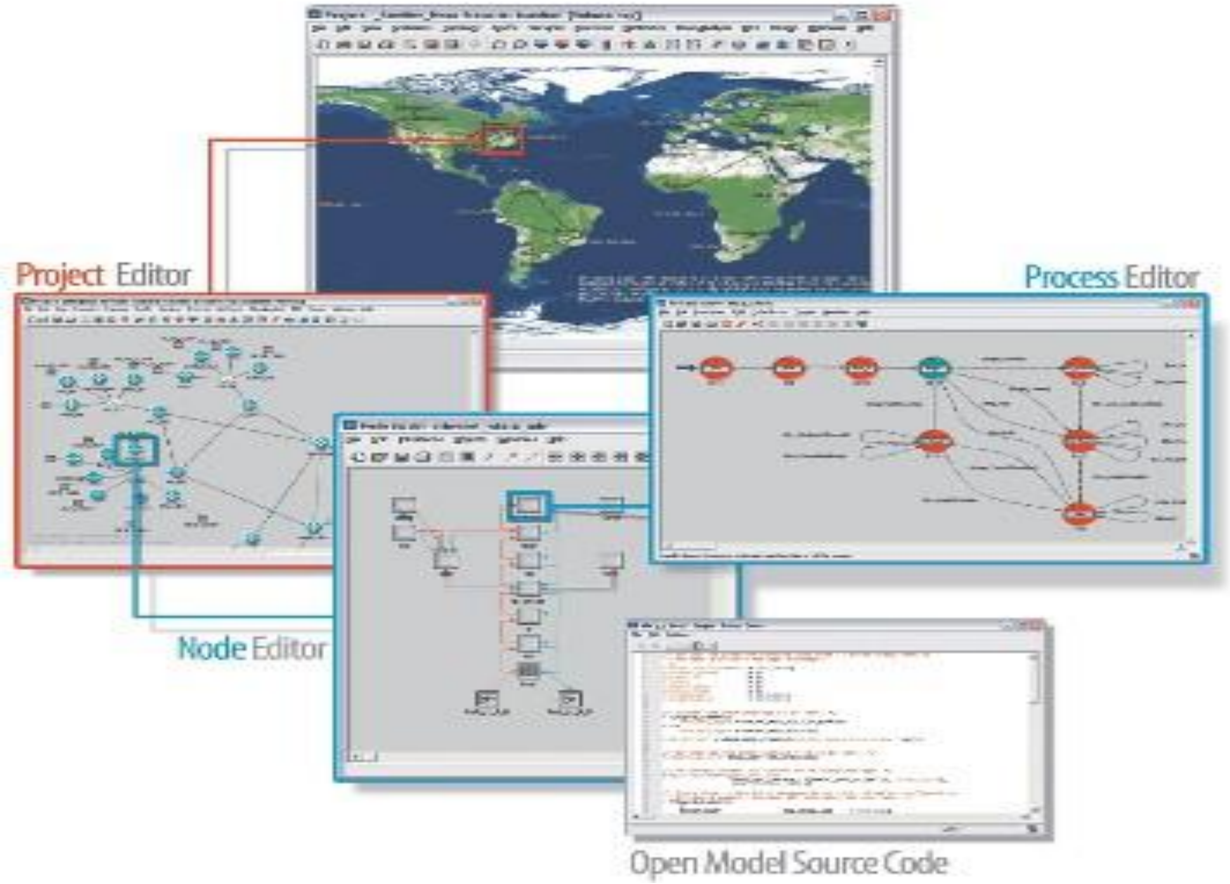


Figure 3.1: OPNET simulator components [24]

3.3.1 Modeling of MANET Scenario

The complete modeling procedure in OPNET basically has four sections- design of network model, selection of individual statistics, collection of simulation results and analysis of the results obtained, as it can be seen in the block diagram bellow.

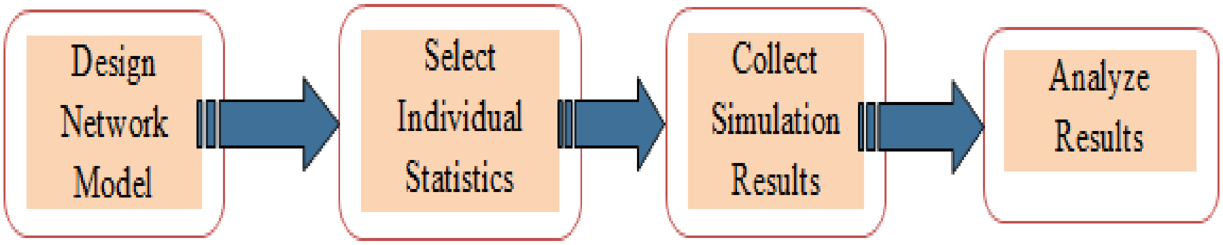


Figure 3.2: Complete overview of designing a project in OPNET Modeler

3.3.1.1 Network Modeling and system parameters

In OPNET Simulation model can broadly be categorized into two sets of scenario files as topology scenario files and traffic generation pattern files. The topology scenario files define the terrain area, with in which simulation is performed, and the mobility model of the nodes that are randomly distributed on the simulation terrain area. The traffic generation pattern files, on the other hand, define the data communication characterizing components such as the data packet type, packet size, number of traffic flows and packet transmission rate. These are specified by different configurations such as application configurations, profile configuration and mobility configuration.

Node Model- The node model specifies the internal structures of the nodes as shown in the following figure. An advanced node model, in which the internal node model detail structures are already implemented, is developed in the OPNET simulation software.

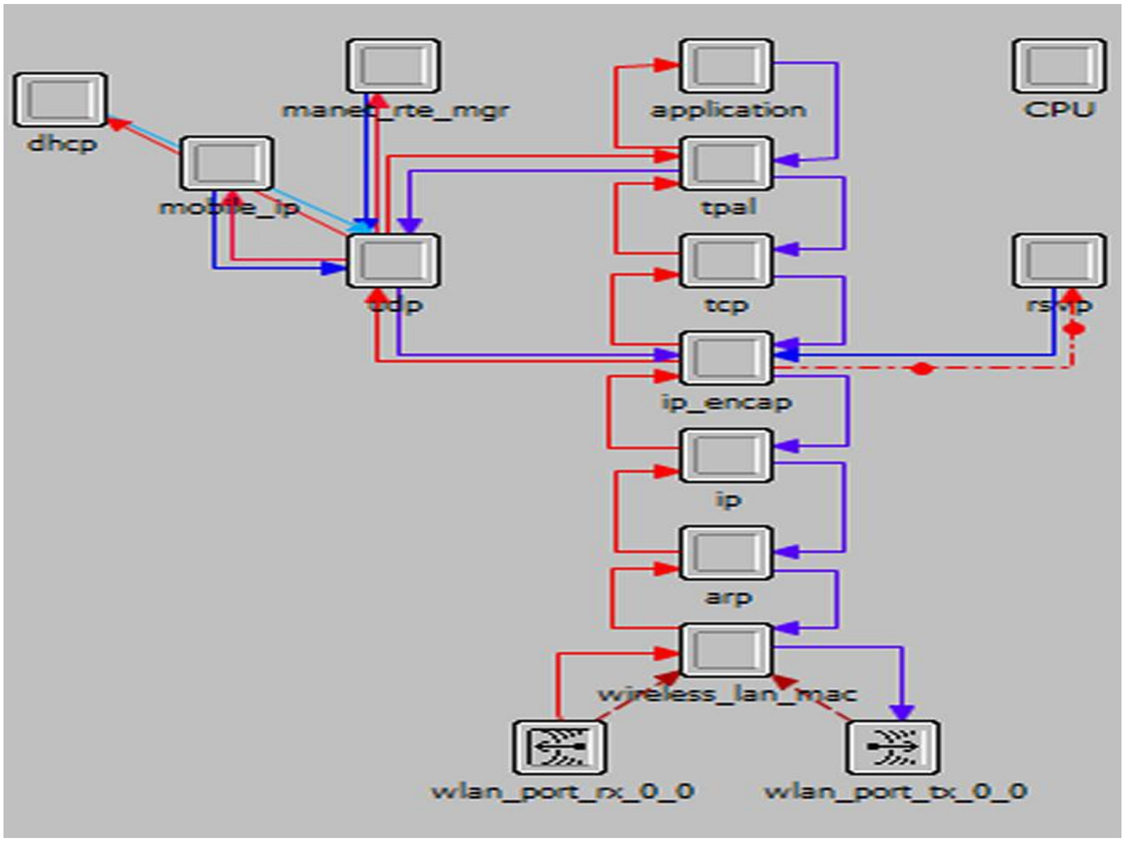


Figure 3.3: Node Model in OPNET (Source: OPNET Modeler software)

Application configuration- In the application configuration the traffic generator type, the traffic load pattern and size are specified and configured. There are different Transport Control Protocol (TCP) and User datagram Protocol (UDP) based applications. FTP, HTTP and Email are examples of TCP based applications whereas Voice over IP is an example of UDP. TCP is a connection-oriented protocol that guarantees the reliable delivery of packets and provides many advantages over others. But it sometimes takes a relatively longer time to ensure the reliable delivery of packets. Therefore it is not suitable for real time applications such as Voice over IP (VoIP). UDP is a connectionless protocol that is mainly used in communicating nodes to exchange datagrams. Unlike TCP, UDP does not provide a reliable delivery of packets and hence has a reduced delay. This makes it efficient for applications that do not require guaranteed delivery of message such as Voice over IP (VoIP), video streaming and broadcasting. FTP is most compatible in network scenarios where guaranteed delivery of packets is required [25, 26]. Therefore FTP was used in this research as application traffic generator with traffic load patterns of low load, medium load and high load with file sizes of 1000 bytes, 5000 bytes and 50000 bytes respectively.

Profile Configuration- Profile configuration describes the activity patterns of the users in terms of the applications used over a period of time. Here configuration of the profiles according the behavior required for MANETs were done. The applications configured on the application configurations were deployed on the profile configuration. That is, FTP profile was configured and deployed.

Mobility Configuration- Here the mobility patterns how the mobile nodes in the simulation area move and which mobility model it should use were defined. There are different types of mobility models such as Random waypoint and group mobility models. A random waypoint was used in this research which is the most commonly used one. A mobility domain of a 1500mX1500m rectangular region with in which a site (user) randomly selects a destination and moves towards it at specified speeds of 10 m/s and 20 m/s was defined. Each site was made to stop for 150 seconds of pause time up on reaching the destination before it repeats the process by selecting another random destination.

3.3.1.2 Selecting Individual statistics

Once the network model is designed, the statistics for different discrete events in simulations are configured. These statistics can be applied in either global or scenarios-wise statistics and object statistics for collecting data from the whole designed network model and from the individual nodes, respectively [26]. In this research a global statistics of a wireless LAN- throughput and delay were used to observe the performance of the AODV, DSR and OLSR MANET routing protocols in different network scenarios and the effect of the control variables on each protocol.

3.3.2 Simulation Setup

The simulation set up was carried out on OPNET 14.5 Modeler where multiple scenarios of MANETs were designed, simulated and analyzed. The simulations were conducted on different scenarios by varying different key design and simulation parameters where each scenario was particularly designed to study and analyze the impact of a specific network operation condition on the end-to-end performance behavior of MANET routing protocols. Control variables on which the MANET routing protocols are mainly optimized such as Traffic load, network size and Mobility speed were considered. The simulation setups for the multiple scenarios, therefore, were categorized as follows:

Impact of Application Traffic load variation: The application traffic generator used was File Transfer Protocol (FTP) whose traffic load was varied in order to see and analyze the effect of traffic load scaling on the end-to-end performance behaviors of the routing protocols. Therefore three different FTP traffic loads were used. They are FTP light load with data size of 1000 bytes, FTP medium load with data size of 5,000 bytes and FTP heavy load with data size of 50,000 bytes. The effect of these FTP traffic load variations were evaluated and analyzed in terms of the performance metrics of end-to-end delay and throughput by deploying a mobile ad hoc network of 30 nodes in a simulation area of 1500mx1500m. The performance behavior of the protocols in terms of delay and throughput as the FTP traffic load varies were therefore analyzed.

Impact of Network size variation: In this case the network size was varied by varying the number of mobile nodes deployed in the simulation area of 1500mx1500m in order to assess its impact on the overall performance of the protocols in terms of delay and throughput. Three different sets of networks with network size of 5, 20 and 30 mobile nodes were modeled and deployed in the simulation area.

Impact of Mobility speed variation: In this simulation scenario the effect of mobility on the performance of the MANET protocols in terms of delay and throughput was studied and analyzed by varying the mobility speed of the nodes within the simulation area 1500mx1500m. Two different mobility speeds (10 m/s and 20 m/s) were used to investigate the performance effects of mobility speed on the MANET routing protocols.

In each of the scenarios, a homogenous network in which all the mobile nodes are same was considered. And each node in the network is equipped with a wireless transceiver in the 802.11 (Wi-Fi) operation standards. The antenna of the transceiver is an omnidirectional antenna with a transmission power of 0.005W and data rate of 11 Mbps. A default random waypoint mobility model, by which the mobility pattern of the nodes in the MANET is defined, was used. The simulation time for each scenario was 30 minutes (1800 seconds). The statistics of simulation results were collected globally. The summary of the main simulation parameters used in this research are given in the table below.

Table 3.1: MANET Model Design and Simulation parameters

Environment Area (mxm)	1500x1500
Mobility Model	Random waypoint
Routing Protocol	AODV, DSR, OLSR
Data rate	11 Mbps
Traffic source	FTP [Low load, Medium load, High load]
Number of nodes (m/s)	5, 20, 30
Mobility speed	10, 20
Simulation time (seconds)	1800
MAC protocol	802.11b
Transmission power (W)	0.005
Node placement	Random
Pause time	150
Stations	Wlan_wkstn
Server	Wlan_server
Transceiver Antenna	Omnidirectional

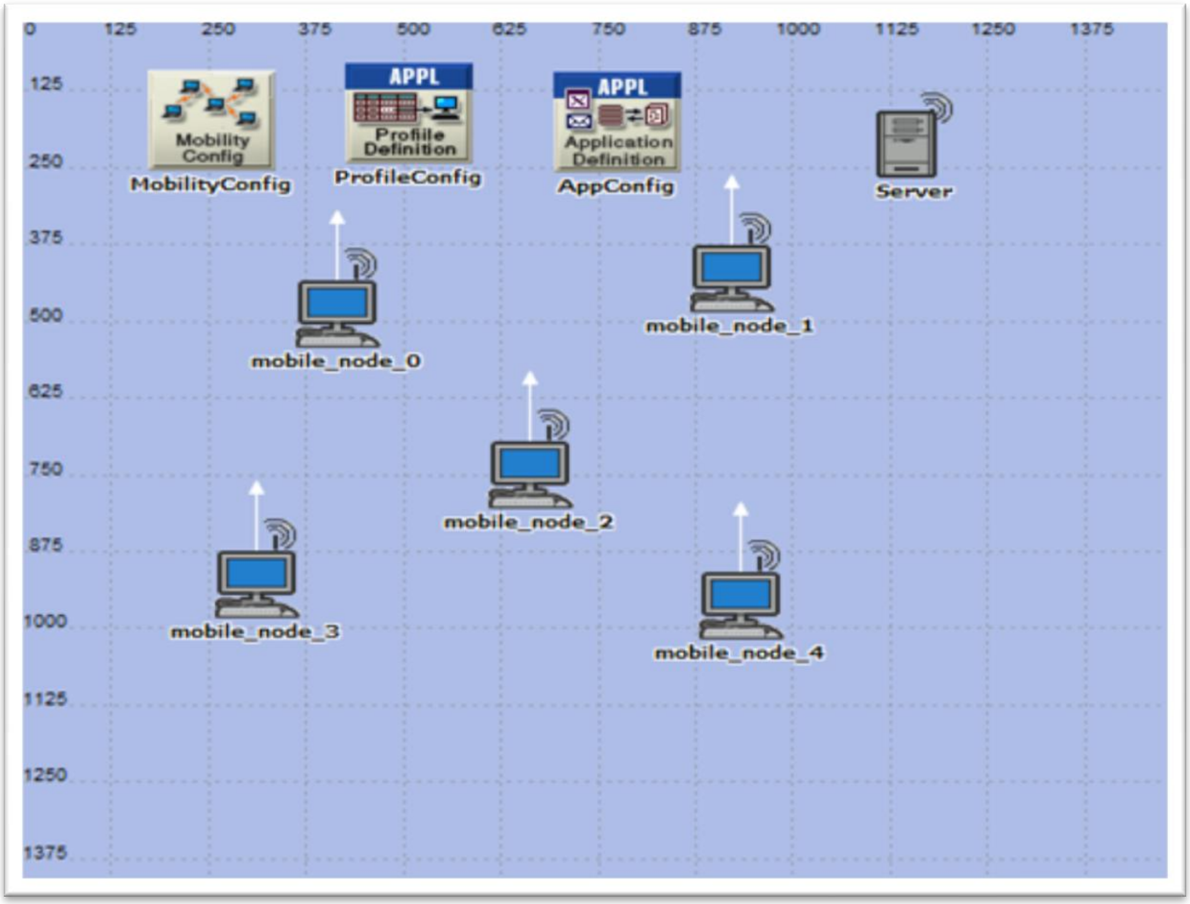


Figure 3.4: MANET Model with 5 Nodes for AODV, DSR and OLSR Protocols

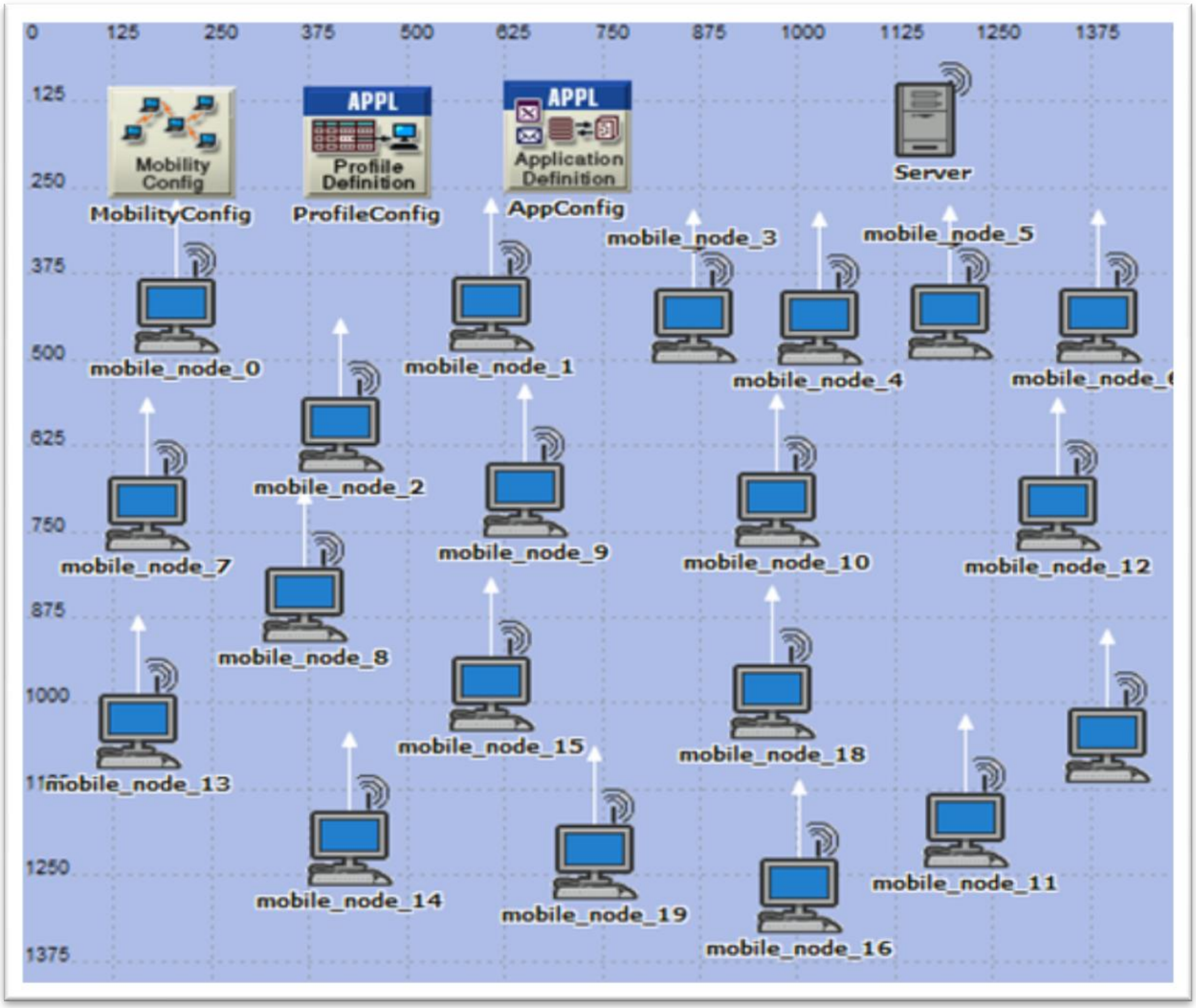


Figure 3.5: MANET Model with 20 Nodes for AODV, DSR and OLSR Protocols

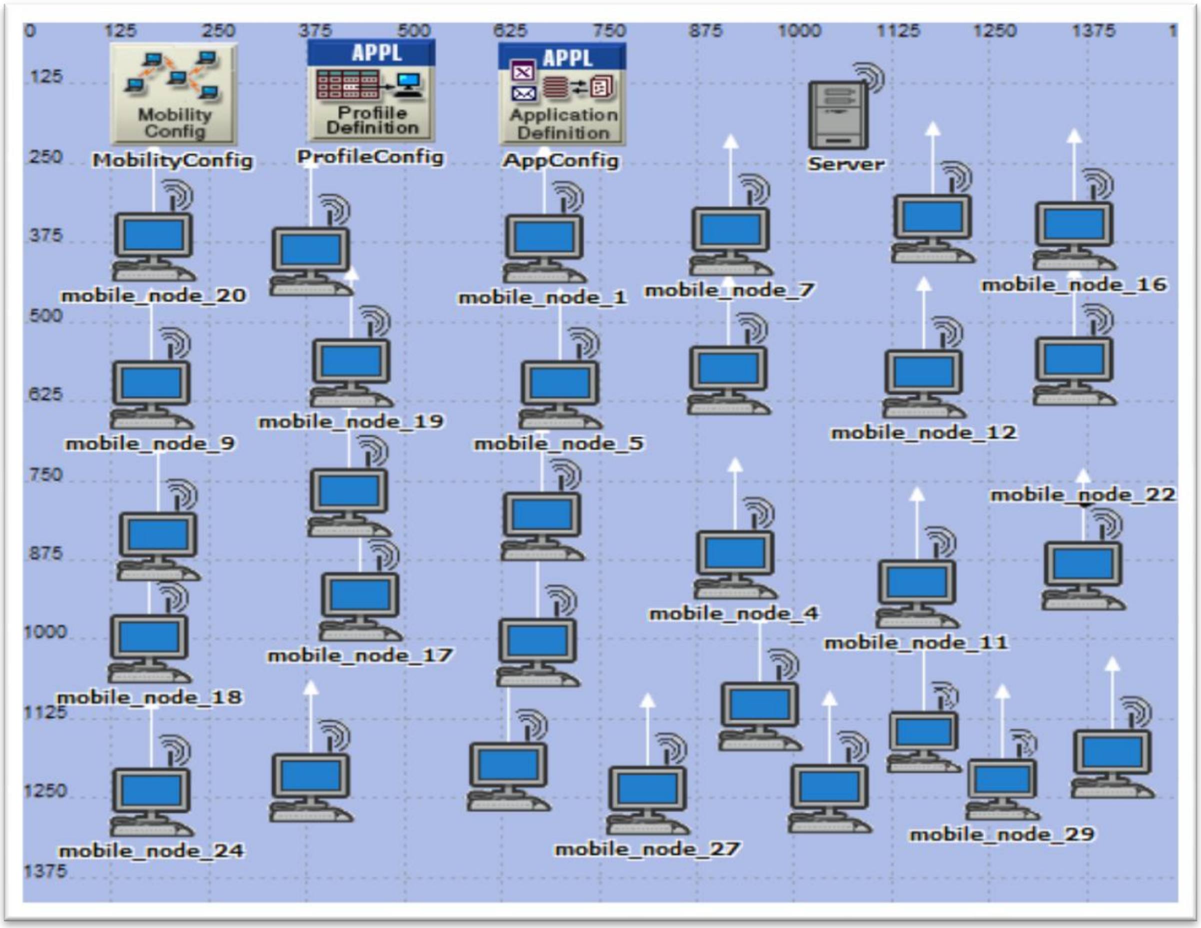


Figure 3.6: MANET Model with 30 Nodes for AODV, DSR and OLSR Protocols

Once the MANET model was done with initial specifications the overall analysis that have been done can be summarized in the following diagram.

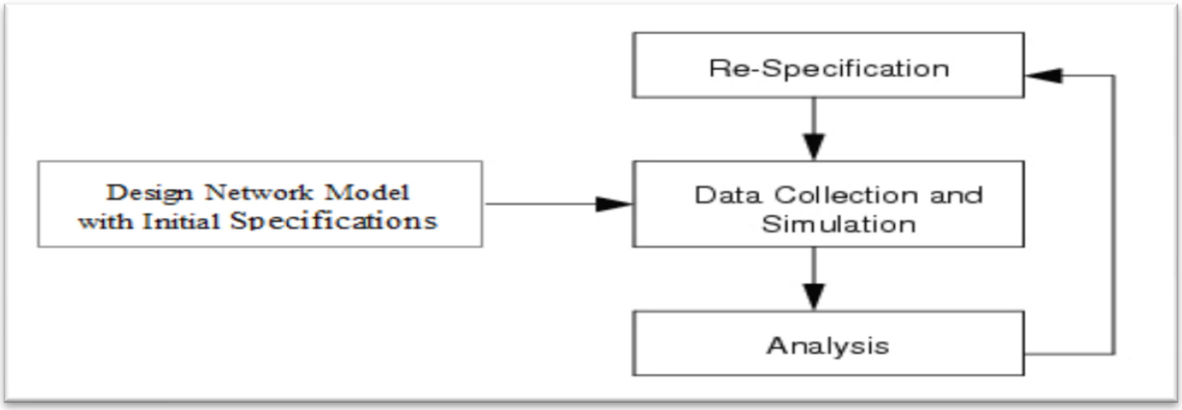
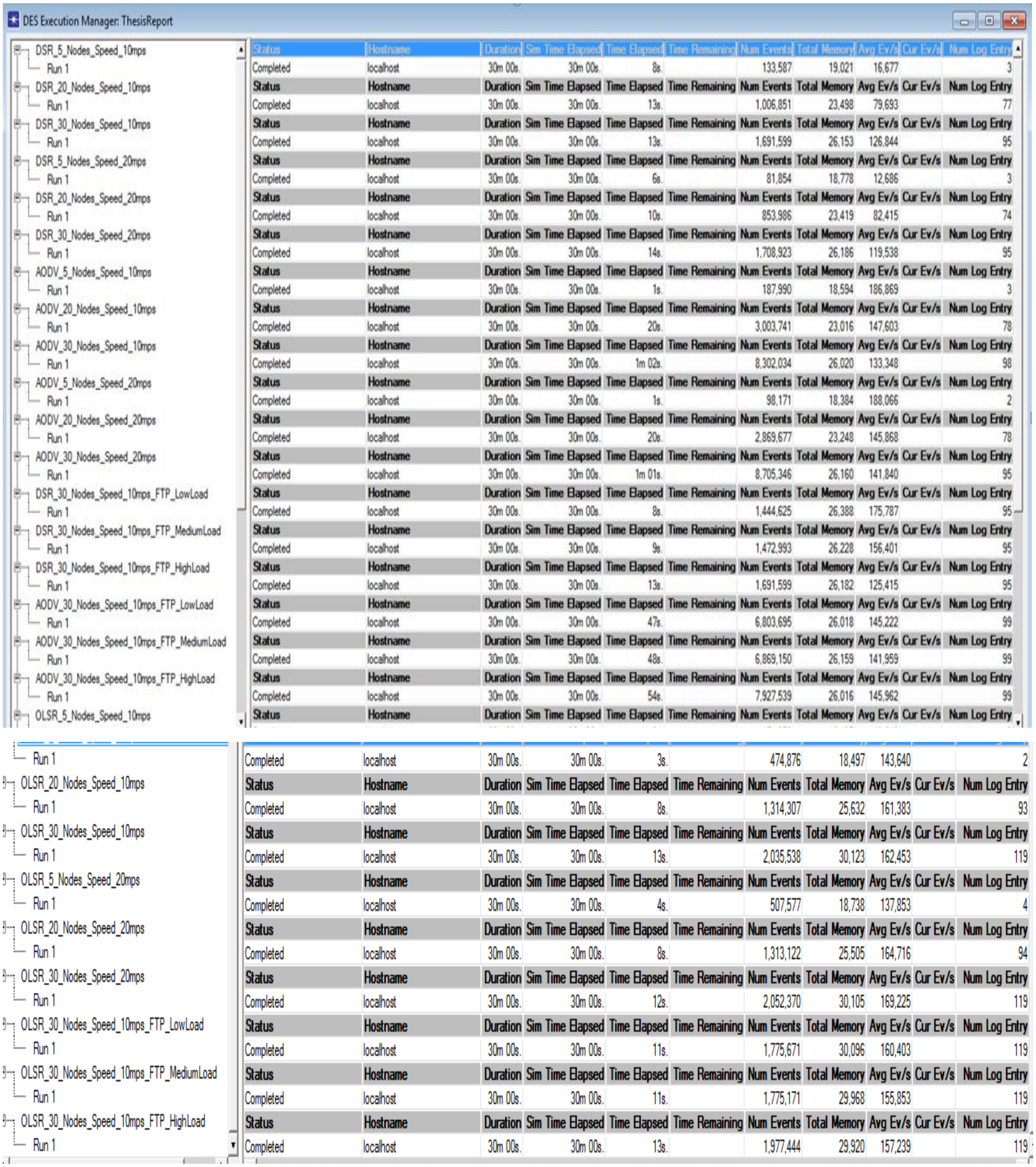


Figure 3.7: OPNET Modeler architecture – Simulation and Analysis cycle



DES Execution Manager: ThesisReport

DSR_5_Nodes_Speed_10mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	8s.		133,587	19,021	16,677		3
DSR_20_Nodes_Speed_10mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	13s.		1,006,851	23,498	79,693		77
DSR_30_Nodes_Speed_10mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	13s.		1,691,599	26,153	126,844		95
DSR_5_Nodes_Speed_20mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	6s.		81,854	18,778	12,686		3
DSR_20_Nodes_Speed_20mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	10s.		853,986	23,419	82,415		74
DSR_30_Nodes_Speed_20mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	14s.		1,708,923	26,186	119,538		95
AODV_5_Nodes_Speed_10mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	1s.		187,990	18,594	186,869		3
AODV_20_Nodes_Speed_10mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	20s.		3,003,741	23,016	147,603		78
AODV_30_Nodes_Speed_10mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	1m 02s.		8,302,034	26,020	133,348		98
AODV_5_Nodes_Speed_20mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	1s.		98,171	18,384	188,066		2
AODV_20_Nodes_Speed_20mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	20s.		2,869,677	23,248	145,868		78
AODV_30_Nodes_Speed_20mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	1m 01s.		8,705,346	26,160	141,840		95
DSR_30_Nodes_Speed_10mps_FTP_LowLoad	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	8s.		1,444,625	26,388	175,787		95
DSR_30_Nodes_Speed_10mps_FTP_MediumLoad	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	9s.		1,472,993	26,228	156,401		95
DSR_30_Nodes_Speed_10mps_FTP_HighLoad	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	13s.		1,691,599	26,182	125,415		95
AODV_30_Nodes_Speed_10mps_FTP_LowLoad	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	47s.		6,803,695	26,018	145,222		99
AODV_30_Nodes_Speed_10mps_FTP_MediumLoad	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	48s.		6,869,150	26,159	141,959		99
AODV_30_Nodes_Speed_10mps_FTP_HighLoad	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	54s.		7,927,539	26,016	145,962		99
OLSR_5_Nodes_Speed_10mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	3s.		474,876	18,497	143,640		2
OLSR_20_Nodes_Speed_10mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	8s.		1,314,307	25,632	161,383		93
OLSR_30_Nodes_Speed_10mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	13s.		2,035,538	30,123	162,453		119
OLSR_5_Nodes_Speed_20mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	4s.		507,577	18,738	137,853		4
OLSR_20_Nodes_Speed_20mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	8s.		1,313,122	25,505	164,716		94
OLSR_30_Nodes_Speed_20mps	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	12s.		2,052,370	30,105	169,225		119
OLSR_30_Nodes_Speed_10mps_FTP_LowLoad	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	11s.		1,775,671	30,096	160,403		119
OLSR_30_Nodes_Speed_10mps_FTP_MediumLoad	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	11s.		1,775,171	29,968	155,853		119
OLSR_30_Nodes_Speed_10mps_FTP_HighLoad	Status	Hostname	Duration	Sim Time Elapsed	Time Elapsed	Time Remaining	Num Events	Total Memory	Avg Ev/s	Cur Ev/s	Num Log Entry
Run 1	Completed	localhost	30m 00s.	30m 00s.	13s.		1,977,444	29,920	157,239		119

Figure 3.8: Discrete event simulation result for all the scenarios [A total of 27 scenarios]

CHAPTER FOUR

SIMULATION RESULTS AND ANALYSIS

4.1 INTRODUCTION

In this section the simulation results are discussed and analyzed. First the effects of the FTP traffic load variation on the performances characteristics of the protocols are analyzed in terms of average end-to-end delay and throughput which are explained in sections 3.2.1 and 3.2.2 respectively. Then the impact of network size and mobility speed variations on the delay and throughput performances of the protocols are analyzed. Finally, the comparison analyses of the performances of the protocols in all the scenarios are made in terms of the delay and throughput. The results for all protocols and scenarios were collected through global statistics.

4.2 IMPACT OF FTP TRAFFIC LOAD VARIATION ON THE DELAY AND THROUGHPUT PERFORMANCES OF EACH PROTOCOL

4.2.1 Impact of FTP traffic load variation on the delay performances

In the figures 4.1, 4.2 and 4.3, the effect of the FTP traffic load levels on the delay of each protocol are indicated. The graphs show how each protocol behaves when the application traffic generator (FTP) traffic load varies from low load to medium load and then to high load.

4.2.1.1 Impact of FTP traffic load variation on the delay performance of DSR

As it is indicated in the graphs in figure 4.1, the average delay of DSR increases as the FTP traffic load level is increased. That is the FTP high load has the highest delay followed by FTP medium load and FTP low load. It is observed that DSR has a higher delay in the beginning of the simulation and starts to decrease as the simulation time progresses in all the FTP traffic load levels. This is due to the fact that DSR is a reactive protocol which has an additional initial delay of route discovery and takes time to adjust to the changes in the nodes and thus send packets to stale routes until it gets relatively stable. The ability of multipath routing also helps DSR to reduce the delay as the simulation time progresses. Note that in all the graphs, the horizontal line is the simulation time in minutes on which the statistics of the end-to-end performance behavior was collected.

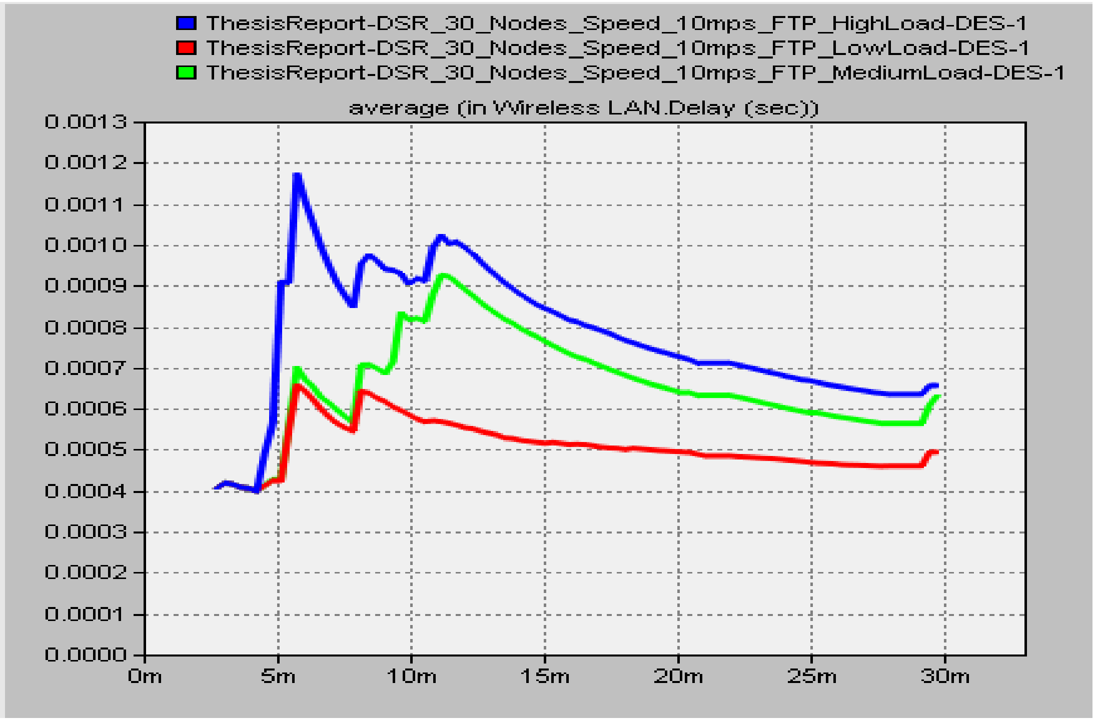


Figure 4.1: Impact of FTP Traffic load variation on the delay performance of DSR

4.2.1.2 Impact of FTP traffic load variation on the delay performance of AODV

The performance of AODV in terms of delay was observed to be better when the FTP traffic load level is neither low nor high. That is it has a lower delay when the FTP traffic load level is medium. The delay is also observed to be higher in the FTP high traffic load as compared to the delay in the other traffic load levels. It in general increases from the beginning of the simulation for small portion of the simulation above which it starts to slightly decrease. This is mainly associated with the initial route discovery delay and inconsistent routes caused by stale entries when the intermediate nodes have a higher but not the latest destination sequence number and very old source sequence number. The average delay variation as the FTP traffic load varies is indicated in the graphs in figure 4.2 below.

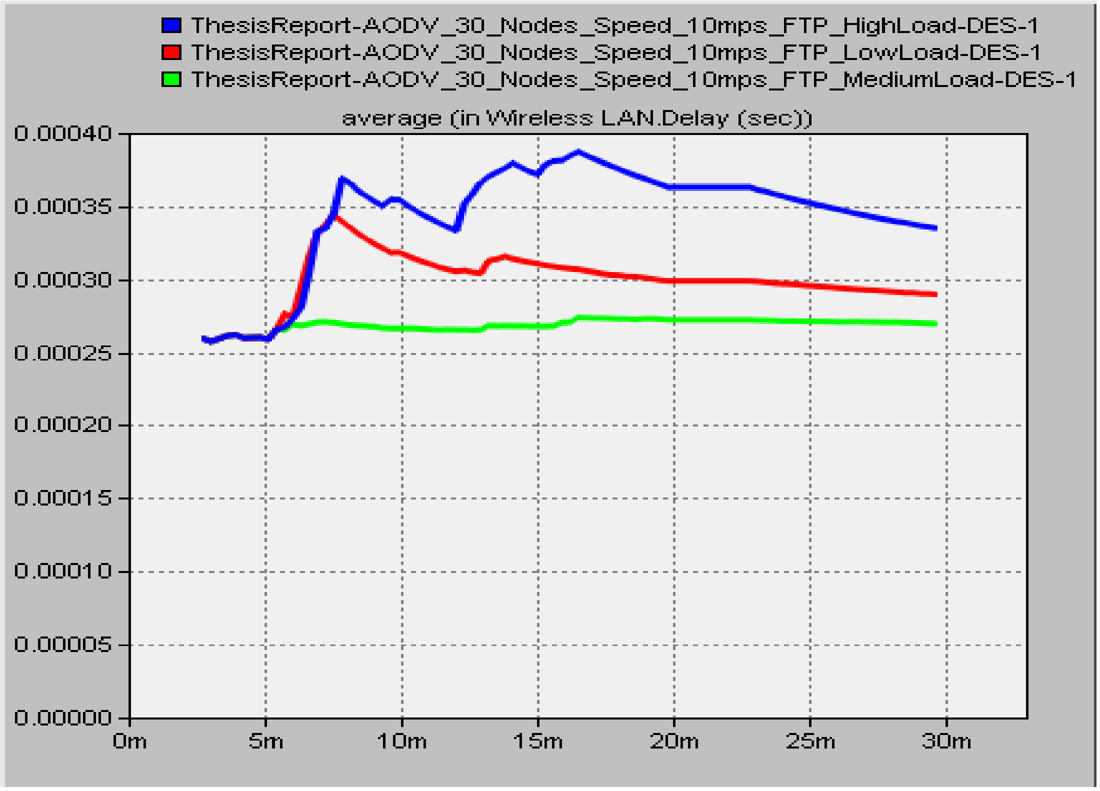


Figure 4.2: Impact of FTP Traffic load variation on the delay performance of AODV

4.2.1.3 Impact of FTP traffic load variation on the delay performance of OLSR

The delay of OLSR, as it is shown in the graphs in figure 4.3 below, is higher when the FTP traffic load level is high. But the delays in the medium and low FTP traffic load levels are overlapped. That is, OLSR performs equally well when the FTP traffic load is medium and low. It was also observed that unlike AODV and DSR, there is no increment on the delay at the beginning of the simulation in OLSR. This is because of the proactive nature of OLSR. As

OLSR is a proactive (table-driven) routing protocol, there are predefined routes to all the destinations. Therefore network nodes can use the available routes to send their messages or packets to the destination without any route discovery process. This helps OLSR to avoid the delay associated with the route discovery. But the delay slightly increases as the traffic load increment and periodic updates of routes increase the overhead and congestion.

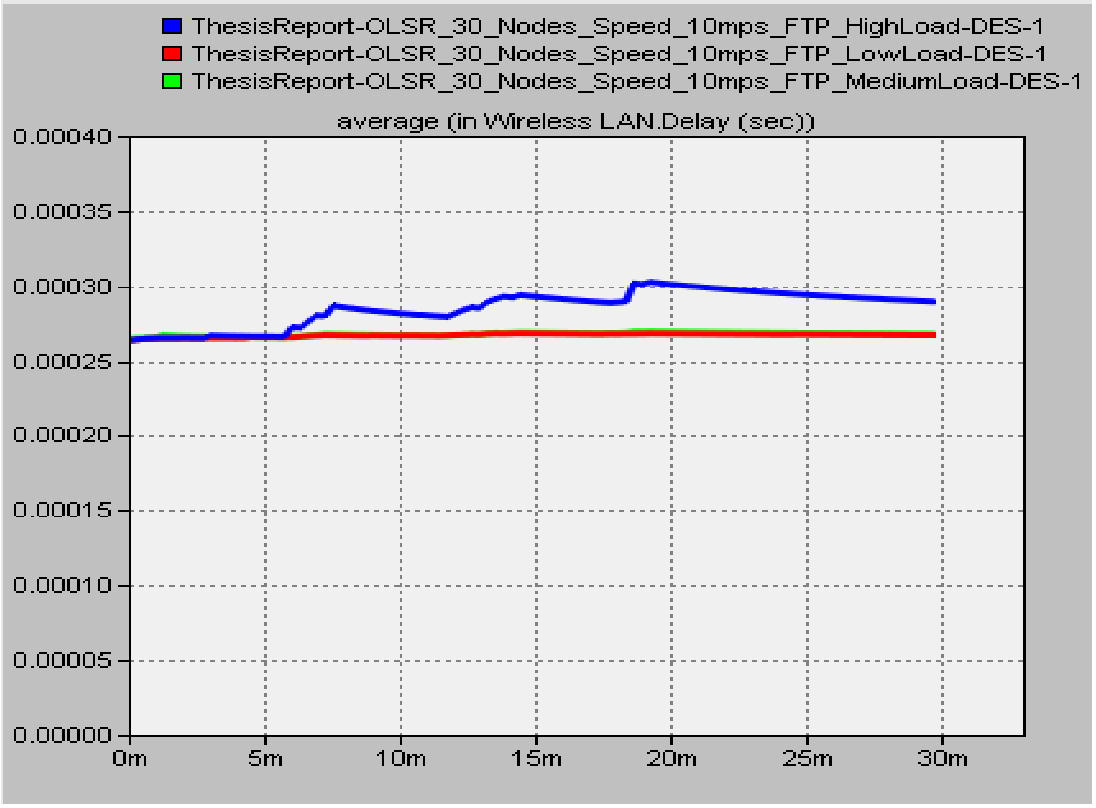


Figure 4.3: Impact of FTP Traffic load variation on the delay performance of OLSR

In summary, according to the simulation results it is observed that the performance of the three protocols (AODV, DSR and OSLR) in terms of delay is generally better when the FTP traffic levels are low. The delay in the three protocols is high when the traffic load is high as the overhead increases when the traffic volume is increased.

4.2.2 Impact of FTP traffic load variation on the throughput performances

In this subsection the effect of FTP traffic load variation on the performance of throughput of the three protocols (DSR, AODV and OLSR) are discussed. The graphs in figures 4.4, 4.5 and 4.6 show how the FTP traffic load variations affect the throughput performance of each protocol.

4.2.2.1 Impact of FTP traffic load variation on the throughput performance of DSR

The throughput performance of DSR increases as the FTP traffic load level increases according to the traffic load levels considered in this study. As it is shown in the graphs in figure 4.4, the highest throughput performance is observed in the FTP high traffic load followed by the medium and low FTP traffic load levels.

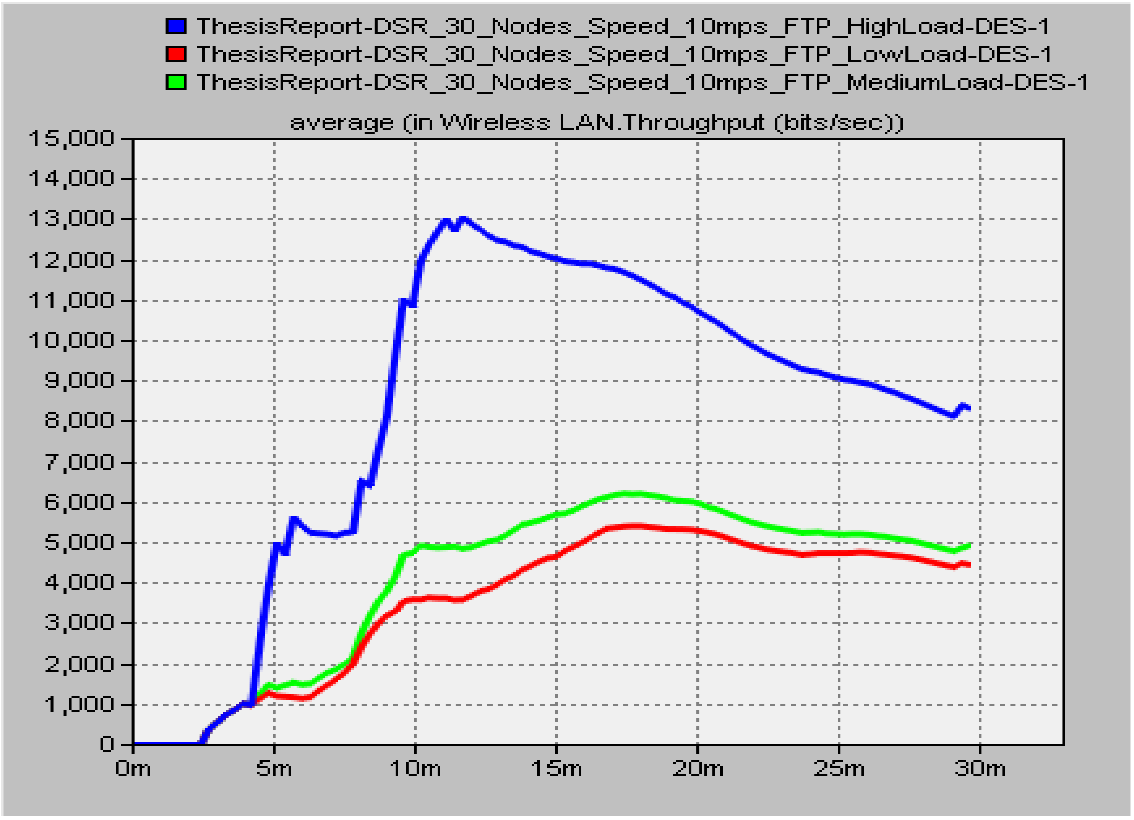


Figure 4.4: Impact of FTP Traffic load variation on the throughput performance of DSR

The throughput remains zero until around 2.5 minutes of the simulation time. This indicates that as DSR is a reactive routing protocol there will not be actual packet transfer until the route to the destination is discovered. The throughput in all the traffic load levels increases up to some portions of the simulation time above which it starts to decrease. These increasing and decreasing in throughput is due to overhead collisions and network congestions affecting at that time.

4.2.2.2 Impact of FTP traffic load variation on the throughput performance of AODV

The throughput performance of AODV generally increases as the simulation time progresses. The graphs in figure 4.5 shows the throughput performance variations of AODV on different FTP traffic load levels. It was observed that AODV performance in terms of throughput increases as the traffic load increases. The highest throughput is observed in high FTP traffic load followed by the medium and low traffic loads. However, there is no significant performance difference between the medium and low traffic loads. AODV’s throughput in the medium FTP traffic is slightly higher than in the low traffic load.

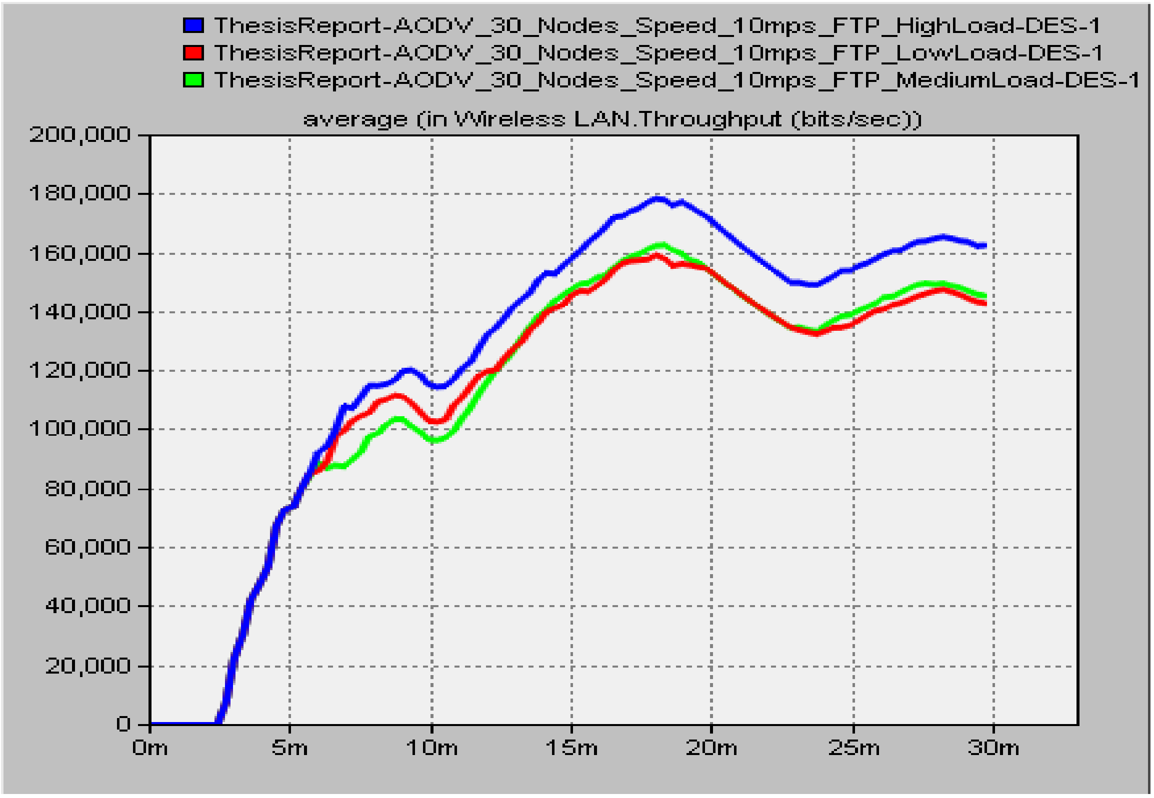


Figure 4.5: Impact of FTP Traffic load variation on the throughput performance of AODV

As it is evident from the graphs in figure 4.5, AODV attains a maximum throughput of 180000 bit/second when the FTP traffic load is high whereas it attains maximum throughput of slightly higher than 160000 bits/second and slightly lower than 160000 bit/second in the medium and low FTP traffic loads respectively.

4.2.2.3 Impact of FTP traffic load variation on the throughput performance of OLSR

The throughput performance of OLSR like in AODV and DSR is better when the FTP traffic load is high. There is no noticeable throughput performance difference between the medium and low traffic load levels. The overall throughput performance of OLSR is the second best of the three protocols. Details of performances comparisons are discussed in the next sections in this chapter. The graphs in figure 4.6 below show how the throughput performance of OLSR behaves when the FTP traffic load varies.

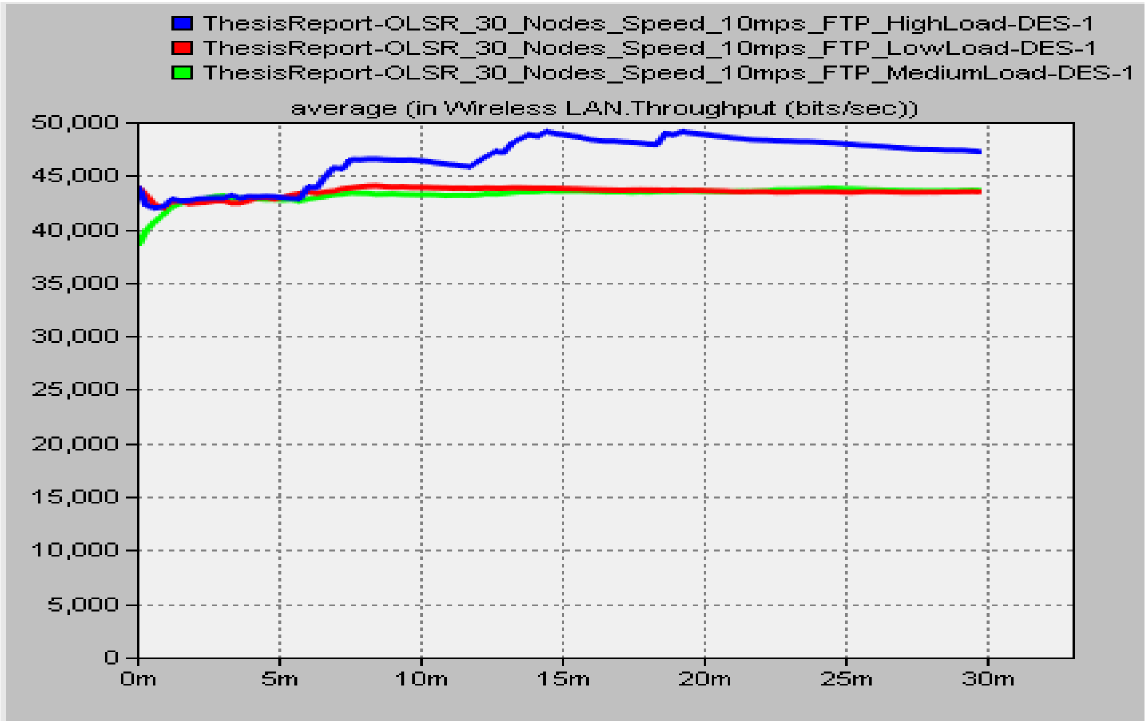


Figure 4.6: Impact of FTP Traffic load variation on the throughput performance of OLSR

In conclusion of this subsection, according to the traffic load levels considered it was observed that the throughput of all the three protocols is higher when the FTP traffic load is high. But there is no significant throughput performance difference between the low and medium FTP traffic load levels. In the next section, the impact of network size and nodes' mobility speed variations on the performances of the protocols are discussed.

4.3 IMPACT OF NETWORK SIZE AND MOBILITY SPEED VARIATIONS ON THE DELAY AND THROUGHPUT PERFORMANCES OF EACH PROTOCOL

4.3.1 Impact of Network size and Mobility speed variations on the delay performances

In this section the effects of network size and mobility speed variations on the delay performance of the three protocols is discussed. Three different network sizes with number of nodes of 5, 20 and 30 and two mobility speeds of 10 m/s and 20 m/s are used to analyze the delay performances in each protocol. In the figures 4.7, 4.8 and 4.9, the effect of network size and mobility speed on the delay of each protocol are indicated. The graphs show how each protocol behaves when the number of nodes and mobility speed of the nodes varies.

4.3.1.1 Impact of Network size and Mobility speed on the delay performance of DSR

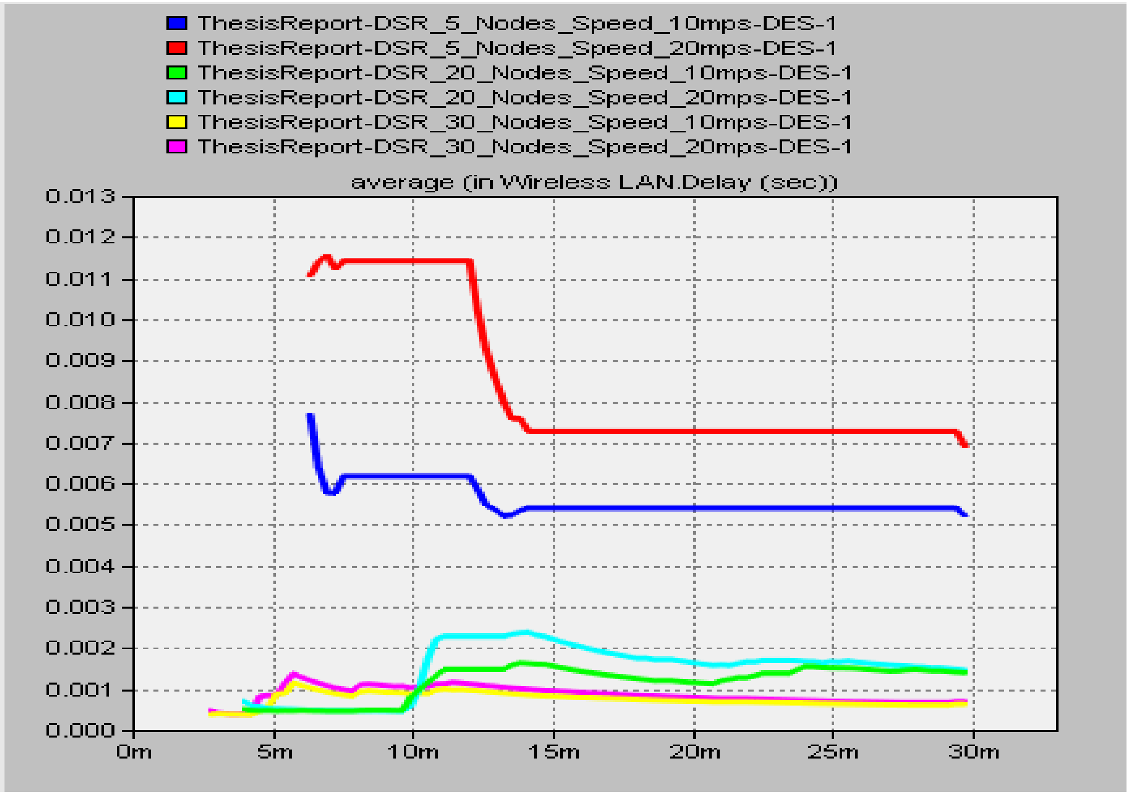


Figure 4.7: Impact of network size and mobility speed on the delay performance of DSR

Figure 4.7 indicates the effect of network size and mobility speed variations on the delay performance of DSR. The effect of the network size on the performance was done in two different mobility speeds of 10 m/s and 20 m/s each. As it is clearly seen from the graphs, the delay is highest when the number of nodes is 5 in both mobility speeds. When the number of nodes is increased to 20, the delay of DSR is observed to be the smallest from the beginning of the simulation up to the simulation time of 10 minutes. As the simulation time progresses, the delay increases and become the second highest delay. When the number of nodes is increased to 30, DSR has an overall least delay. In the 5 nodes, there is a greater inconsistency in the delay which becomes smaller as the number of nodes is increased to 20 and 30. This is because when the number of nodes increases, there will be more possible redundant links that reduce frequent link breaks and hence more stable links. When there are more stable link or routes, the delay becomes less and more consistent. According to the network sizes considered, the performance of DSR in terms of delay becomes better as the network size increases.

The effect of mobility speed variation on the delay performance of DSR is also indicated in figure 4.7 with two mobility speeds of 10 m/s and 20 m/s. The mobility speed does not have a significant effect on the delay performance of DSR when the network size is increased. As it is depicted in the graphs in figure 4.7, for the 5 nodes the delay is higher in the 20 m/s mobility speed than in the 10 m/s. In the case of 20 nodes, DSR has a slightly higher delay in the 20 m/s than in the 10 m/s mobility speed. When the network size is further increased to 30 nodes, the mobility speed has not brought about a noticeable effect on the delay of DSR. In general, according to the mobility speeds considered, the effect of mobility speed variation on the delay of DSR is insignificant when network size is increased

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4.3.1.2 Impact of Network size and Mobility speed on the delay performance of AODV

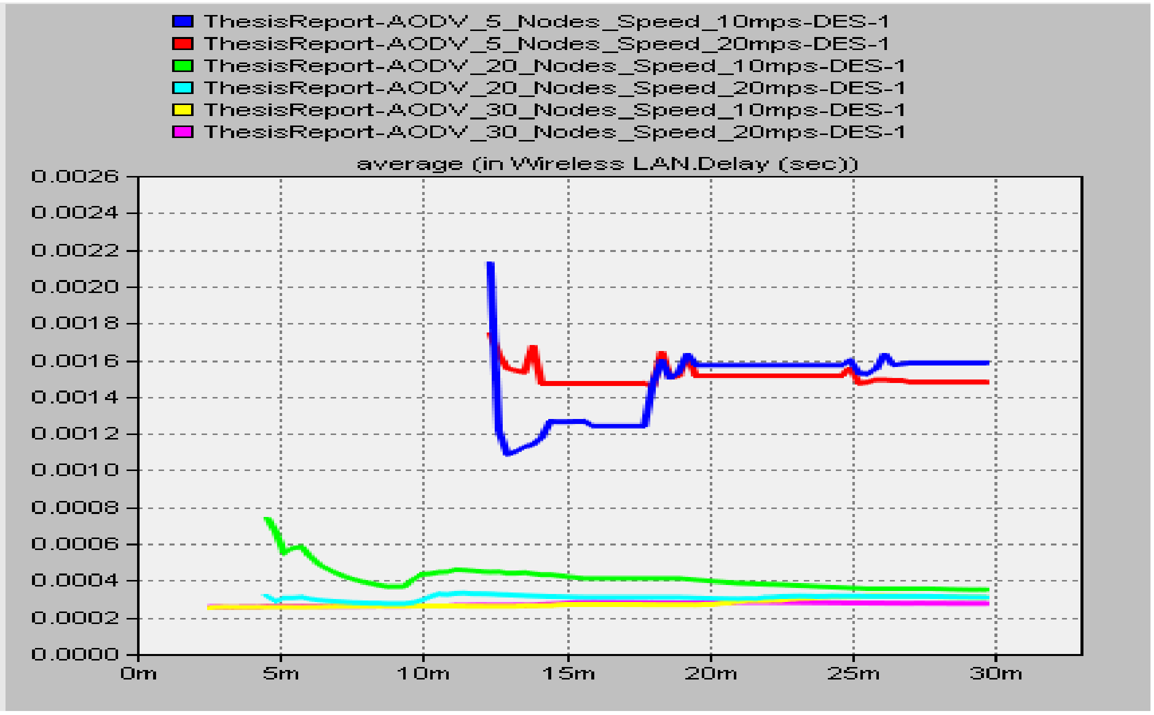


Figure 4.8: Impact of network size and mobility speed on the delay performance of AODV

The graphs in figure 4.8 indicate the impact of network size and mobility speed variations on the delay performance of AODV. Like in DSR, the delay in AODV is high when the number of nodes is low and decreases as the number of nodes increases. As it is shown in the graphs the delay of AODV for the 5 nodes is higher than the delay for the 20 and 30 nodes. The delay in the 20 nodes is also slightly higher than that of the 30 nodes. The inconsistencies in the delay in the beginnings of the simulation times are due to the route discovery process. When the number of nodes is increased, there will be more possible links so that the AODV can easily discover a route and hence the delay will be more consistent and smaller. It was therefore, generally observed, according to the network sizes considered, that AODV performs better when the network size is bigger regardless of the mobility speed variations.

The mobility speed variation has not caused a significant difference on the delay performance of AODV despite the small and inconsistent delay variations at the beginning of the simulation times and mostly when the network size is small. As it is shown in the graphs in figure 5.8, the delay of AODV for the 5 nodes is higher in 10 m/s mobility speed than in the 20 m/s in the beginning of the simulation time and sharply drops down and stays smaller up to around 20 minutes of the simulation time after which it again starts to be slightly higher. In the case of the 20 nodes, AODV has a slightly higher delay when the mobility speed is 10 m/s than it has when the mobility speed is 20 m/s. When the number of nodes is increased to 30, the delay remains essentially constant and equal in both mobility speeds. In conclusion, according to the mobility speeds considered here, although there are slight overall performance increments as the speed increases in the small network sizes, it was observed that the mobility speed does not cause a significant impact on the delay performance of AODV.

4.3.1.3 Impact of Network size and Mobility speed on the delay performance of OLSR

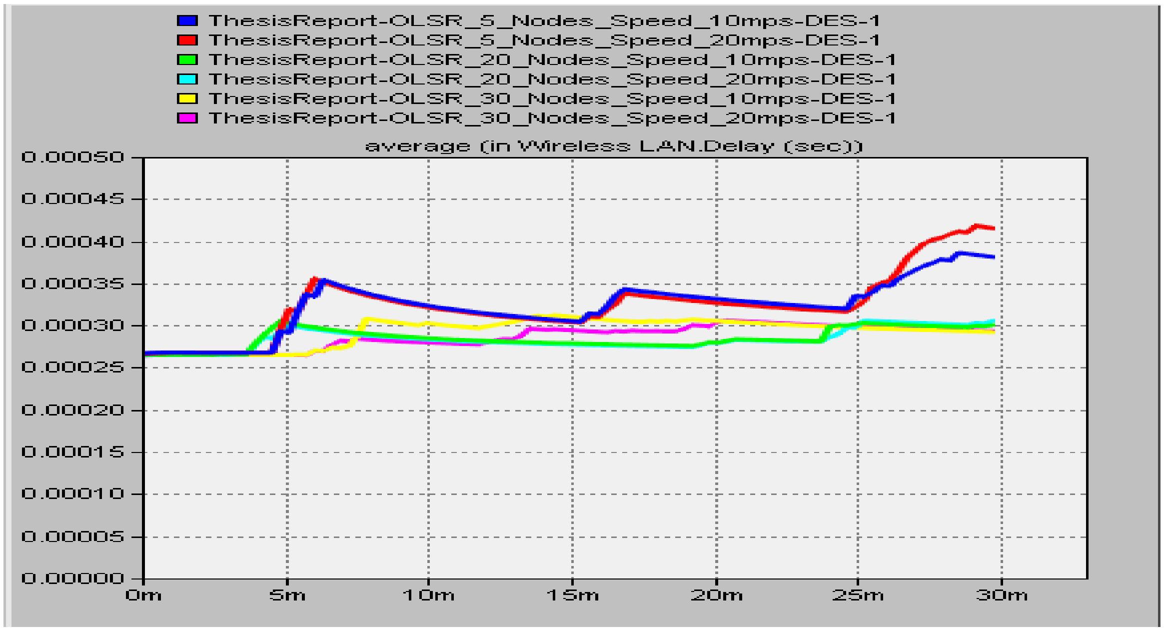


Figure 4.9: Impact of network size and mobility speed on the delay performance of OLSR

As it is depicted in the graphs in figure 4.9, the delay of OLSR is slightly higher in the 5 nodes than it is in the 20 and 30 nodes. There is no consistent and significant delay difference between the 20 and 30 nodes network sizes. At the beginning of the simulation, there are no variations and inconsistencies on the delay. This is because that since OLSR is a proactive routing protocol where routes are always ready through the periodic transmission of route update tables, there will not be a delay associated with a route discovery process. In OLSR, according to the mobility speeds considered in this study, the mobility speed variations have not any significant effect on the delay in the entire network sizes considered.

4.3.2 Impact of Network size and Mobility speed variations on the throughput performances

In this subsection the effects of network size and mobility speed variations on the throughput performance of the three protocols is discussed. Three different network sizes with number of nodes of 5, 20 and 30 and two mobility speeds of 10 m/s and 20 m/s are used to analyze the delay performances in each protocol. In the figures 4.10, 4.11 and 4.12, the effect of network size and mobility speed on the throughput of each protocol are indicated. The graphs show how each protocol behaves when the number of nodes and mobility speed of the nodes varies.

4.3.2.1 Impact of Network size and Mobility speed variations on the throughput performances of DSR

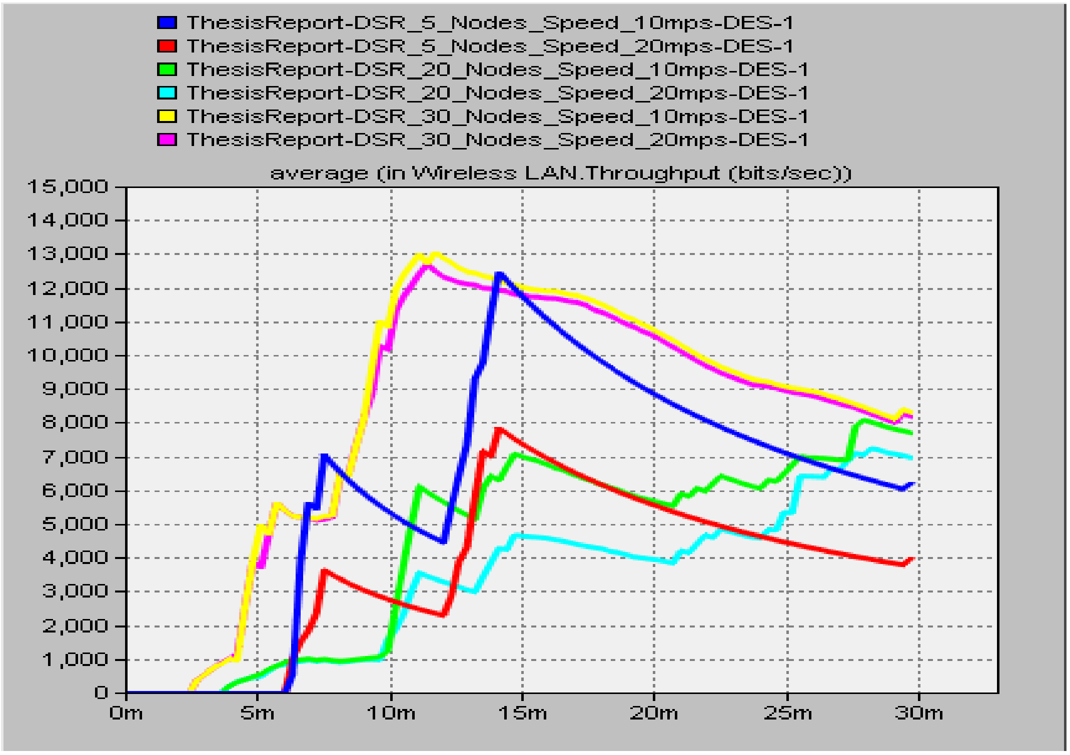


Figure 4.10: Impact of network size and mobility speed on the throughput of DSR

The graphs in figure 4.10 indicate the impacts of network size and mobility speed variations on the throughput performance characteristics of DSR. As it is seen in the graphs, the throughput of DSR is highly inconsistent in the small size networks relative to the throughput in the larger networks. The throughput performance of DSR is generally better when the network size is high in both the 10 m/s and 20 m/s mobility speeds. The impact of mobility speed variation is also observed to be higher in the small networks than it is in the large networks. As it can be seen in the graphs in figure 4.10, the maximum approximated throughput difference between 10 m/s and 20 m/s for the 5, 20 and 30 nodes network sizes are 4500 bits/second, 2000 bits/second and 200 bits/second respectively. Therefore, this indicates that the mobility speed variation does not cause a significant change on the throughput performance of DSR. The overall throughput performance of DSR, however, is better in low mobility speeds according to the network sizes and mobility speeds considered.

4.3.2.2 Impact of Network size and Mobility speed variations on the throughput performances of AODV

The graphs in figure 4.11 indicate the effects of network size and mobility speed variations on the throughput performances of AODV. It is observed from the graphs that the throughput performance of AODV increases as the number of nodes are increased from 5 to 20 and then to 30. That is, the throughput performance of AODV is by far better in the 30 nodes network size than it is in the 5 and 20 nodes network sizes. The throughput in the 20 nodes network size is also better than it is in the 5 nodes network size. Therefore, according to the network sizes considered, the throughput performance of AODV is better in larger network sizes. This indicates that when there are more nodes, there will be redundant links and less link failures and hence less packet drop. But this is up to certain number of nodes above which the network will be congested.

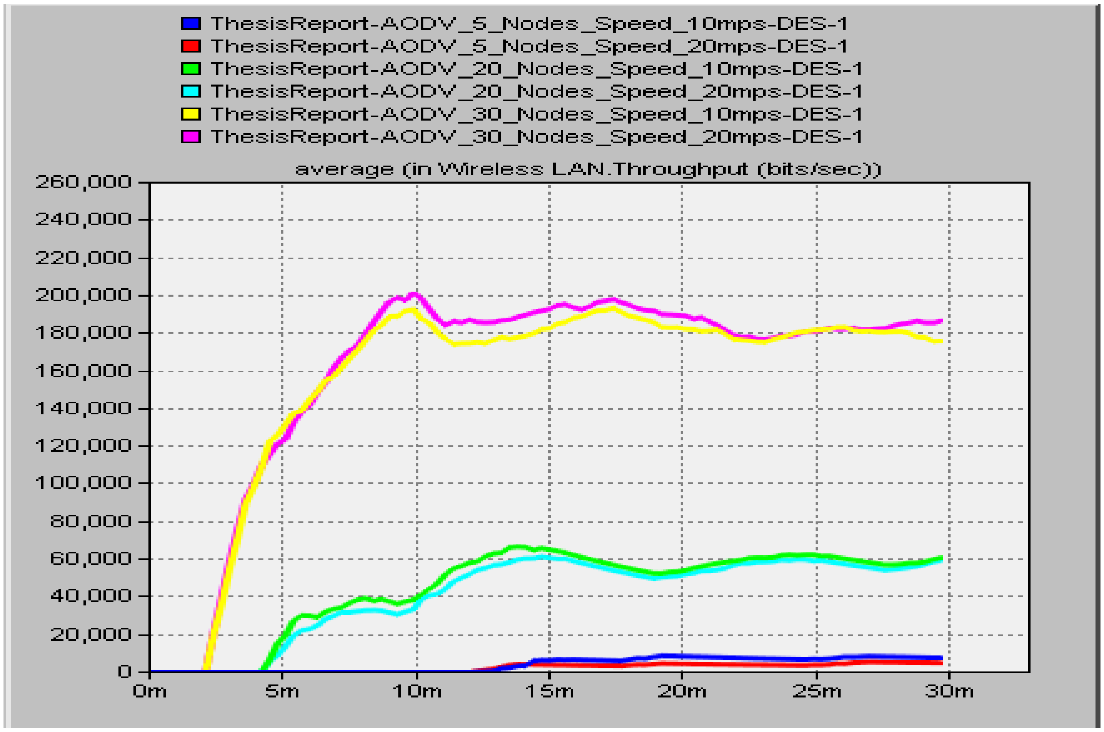


Figure 4.11: Impact of network size and mobility speed on the throughput of AODV

It was observed that there is no significant mobility impact on the throughput performance of AODV. As it is indicated in the graphs, in the 5 and 20 nodes network sizes, the throughput is marginally higher in 10 m/s mobility speed than it is in the 20 m/s mobility speed. In the 30 nodes network size, the throughput becomes slightly higher in the 20 m/s than in the 10 m/s.

4.3.2.3 Impact of Network size and Mobility speed variations on the throughput performances of OLSR

The graphs in figure 4.12 indicate the impacts of network size and mobility speed variations on the throughput performance of Optimized Link State Routing (OLSR) Protocol. As it is seen from the graphs, it was observed that the throughput performance of OLSR increase as the number of nodes increases regardless of the mobility speed variations. The highest throughput performance of OLSR was observed when the number of nodes is 30 followed by that of the 20 nodes network size. The least throughput performance of OLSR was observed in the 5 nodes' network size.

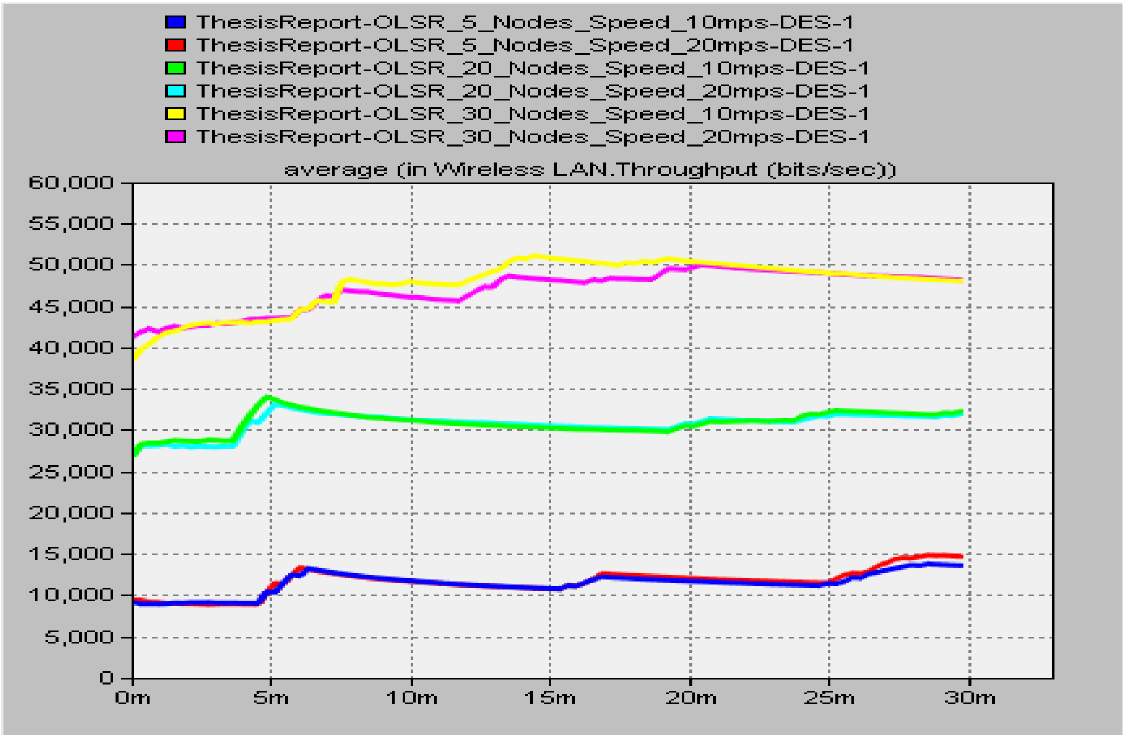


Figure 4.12: Impact of network size and mobility speed on the throughput of OLSR

The impact of the mobility speed variation is also indicated in the graphs in figure 4.12. Two different mobility speeds of 10 m/s and 20 m/s were used to analyze how the throughput performance of the OLSR protocol behaves when mobility speed of the nodes varies. Therefore, according to the mobility speeds considered, it was observed, in the simulation results indicated in the graphs in figure 4.12, that the mobility speed variation has no noticeable effect on the throughput performance of OLSR.

4.4 PERFORMANCE COMPARISON OF AODV, DSR AND OLSR PROTOCOLS

In this subsection the comparative performances analysis of the three protocols in terms of the performance measurement metrics of delay and throughput is presented. The comparison analysis is done in different scenarios based on the FTP traffic load, network size and mobility speed variations to identify the scenario in which one protocol perform better or worse than the others.

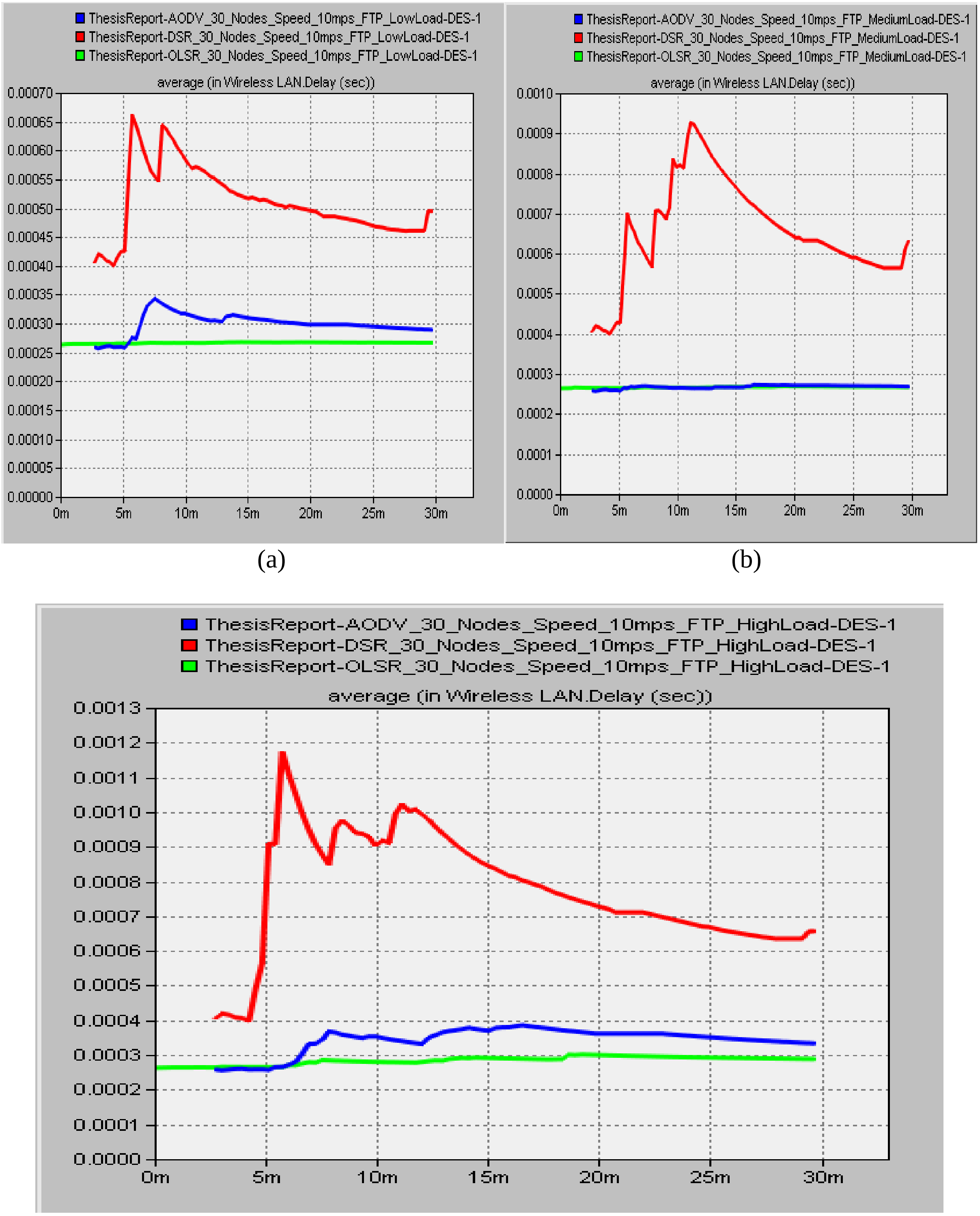
4.4.1 Performance comparison of AODV, DSR and OLSR with respect to FTP Traffic Load variations in terms of delay and throughput

Here the performance comparisons of the three protocols are analyzed in three different traffic loads in terms of delay and throughput. First, the comparative performance analysis is presented in terms of delay and then the throughput comparative performance analysis is discussed.

4.4.1.1 Performance comparison of AODV, DSR and OLSR with respect to FTP Traffic Load variations in terms of delay

The graphs in Figure 4.13 (a) to (d) show the delay performance comparisons of the three protocols under different FTP application traffic generator traffic load levels. It was observed that DSR has the highest delay in all the traffic loads and hence poor performance. AODV has the second highest delay in all the FTP traffic loads except in the medium FTP traffic load whereas OLSR has the least delay and hence best performance. AODV and OLSR have equal latency when the FTP traffic load is medium. AODV and DSR are reactive routing protocols whereas OLSR is a proactive routing protocol. Reactive protocols generally have a higher delay because of the latency in discovering the route to the destinations on a need basis whereas proactive routing protocols have a relatively smaller delay due to the fact that there are no delays associated with a route discovery process as the routes are already available in the routing tables.

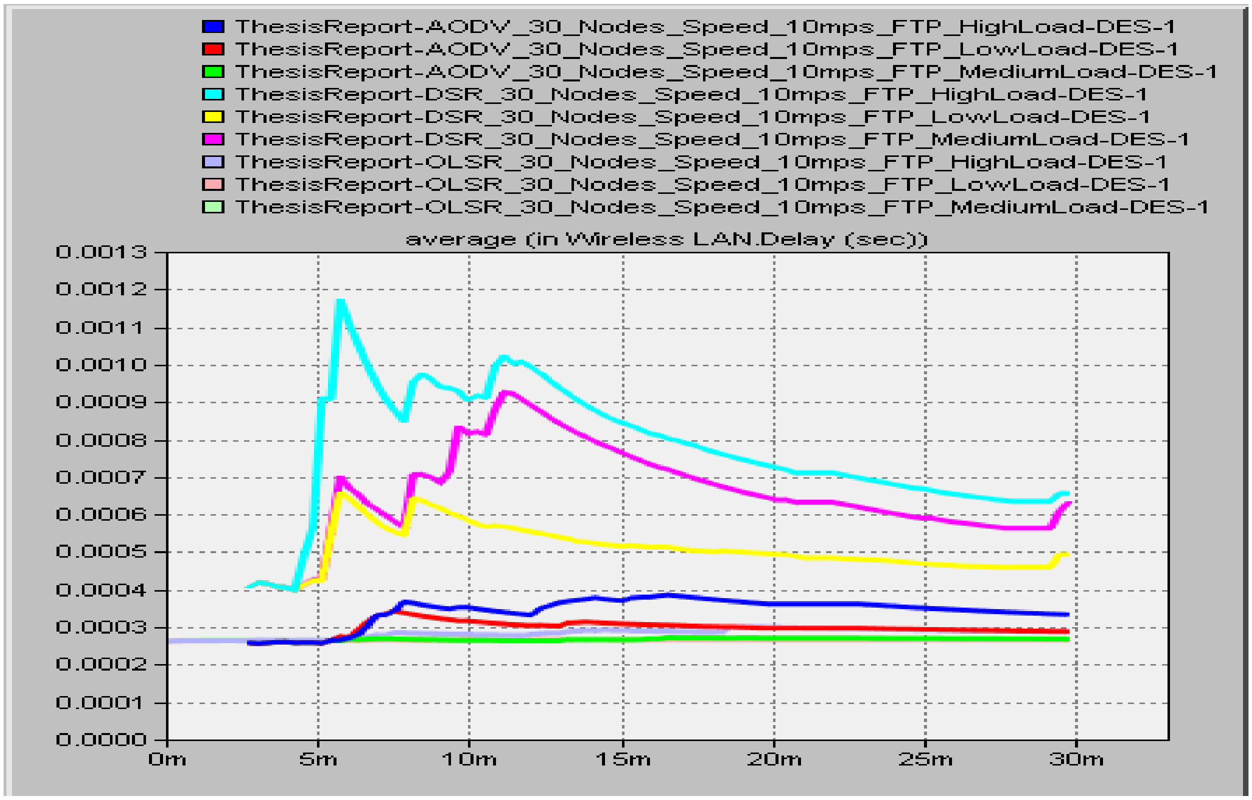
Therefore, OLSR has a better delay performance than the other two protocols in all the FTP traffic loads.



(a)

(b)

(c)

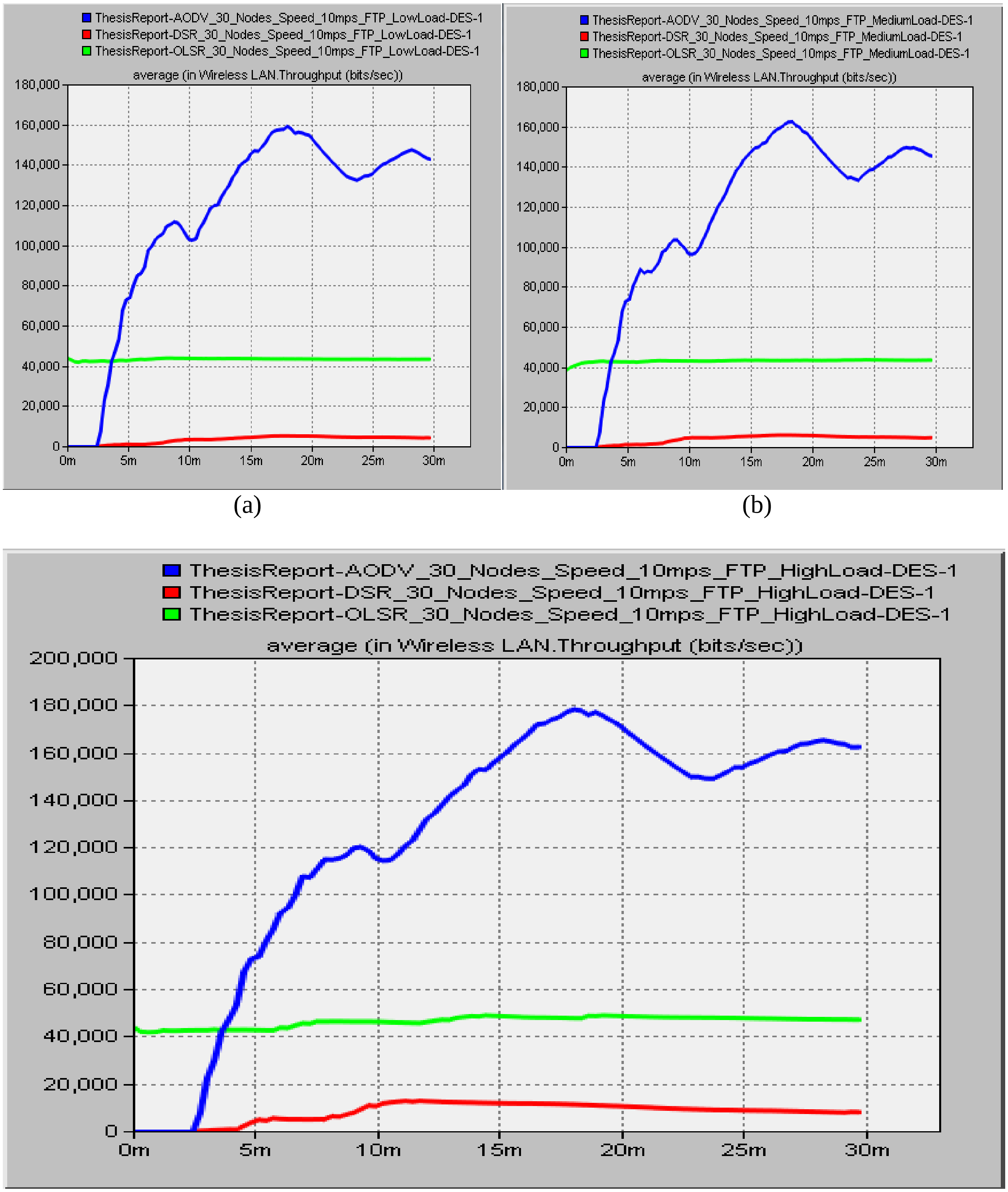


(d)

Figure 4.13: Delay comparisons of AODV, DSR and OLSR with 30 nodes for FTP Traffic load variations. (a) FTP Low traffic load (b) FTP medium traffic load (c) FTP high traffic load (d) combination of low, medium and high loads.

During route discovery process in DSR, each Route Request (RREQ) packet carries full information of the route from the source to the destination and the route replies (RREP) also need to have the address of the entire nodes in the route. This makes the RREQs and RREPs of DSR larger and hence a larger delay. In the case of AODV, the source node and intermediate nodes store the next-hop information for packet transmission corresponding to each flow. This hop-by-hop routing makes AODV perform better than DSR. It is also observed from the graphs in figure 4.13 that DSR has a lot of inconsistencies in the delay compared to AODV and OLSR whereas OLSR has a consistent (constant) delay in all the traffic load levels. The inconsistencies in the reactive protocols are due to the time delay to rebuild the routes during route breakages.

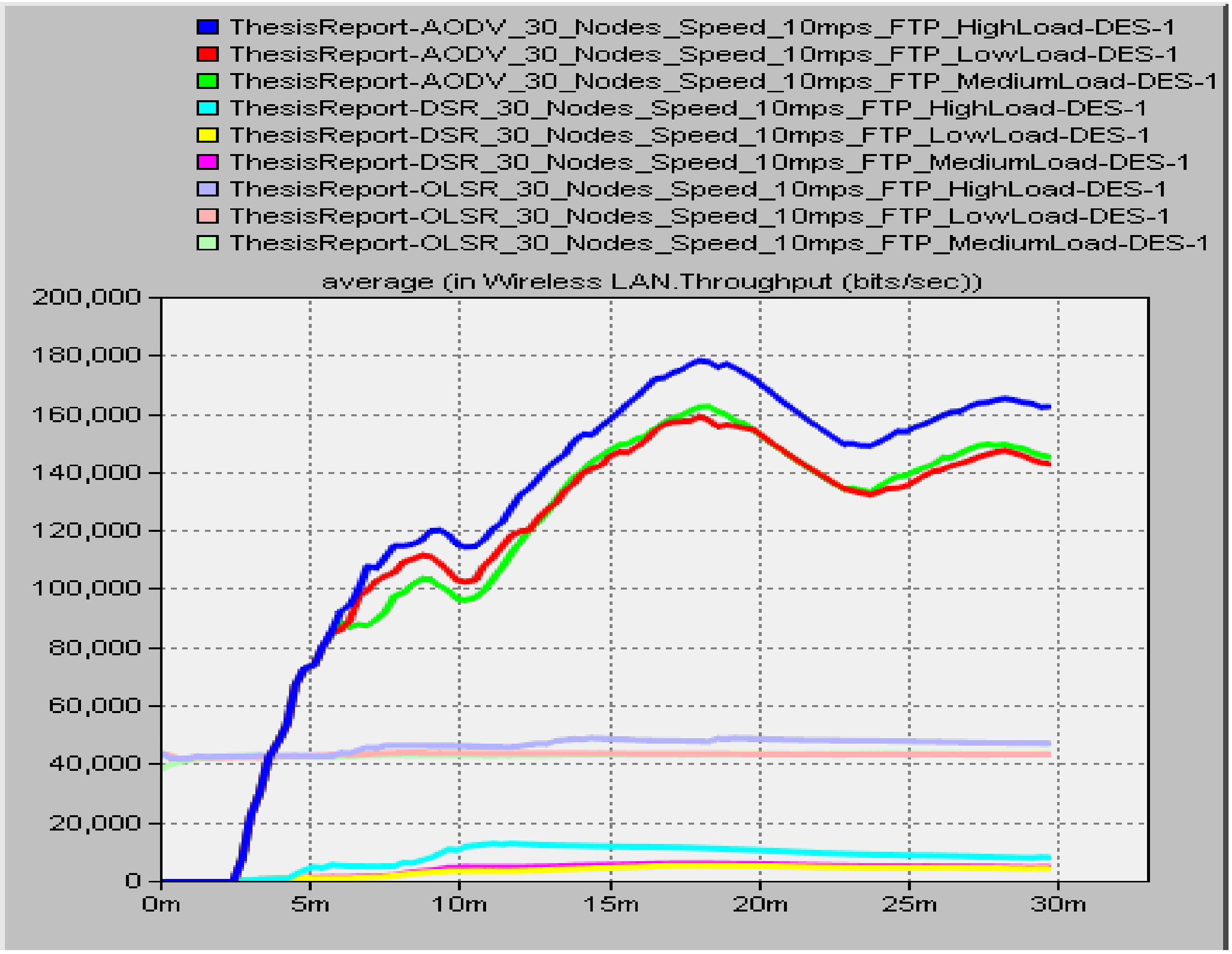
4.4.1.2 Performance comparison of AODV, DSR and OLSR with respect to FTP Traffic Load variations in terms of throughput



(a)

(b)

(c)



(d)

Figure 4.14: Throughput comparisons of AODV, DSR and OLSR with 30 nodes for FTP Traffic load variations. (a) FTP Low traffic load (b) FTP medium traffic load (c) FTP high traffic load (d) combination of low, medium and high loads.

The graphs in figure 4.14 from (a) to (d) indicate the throughput performance of the protocols in three different FTP traffic loads. As it is seen from the graphs in all scenarios, the throughput performance of AODV is far better than the other two protocols. OLSR has also better throughput performance than DSR which has the least throughput performance. AODV, as a reactive protocol, has no big overhead for global routing table maintenance as in proactive routing protocols. Instead it has a quick reaction for node failure and network restructure. Therefore, it has a better throughput performance than OLSR which is a proactive protocol. In

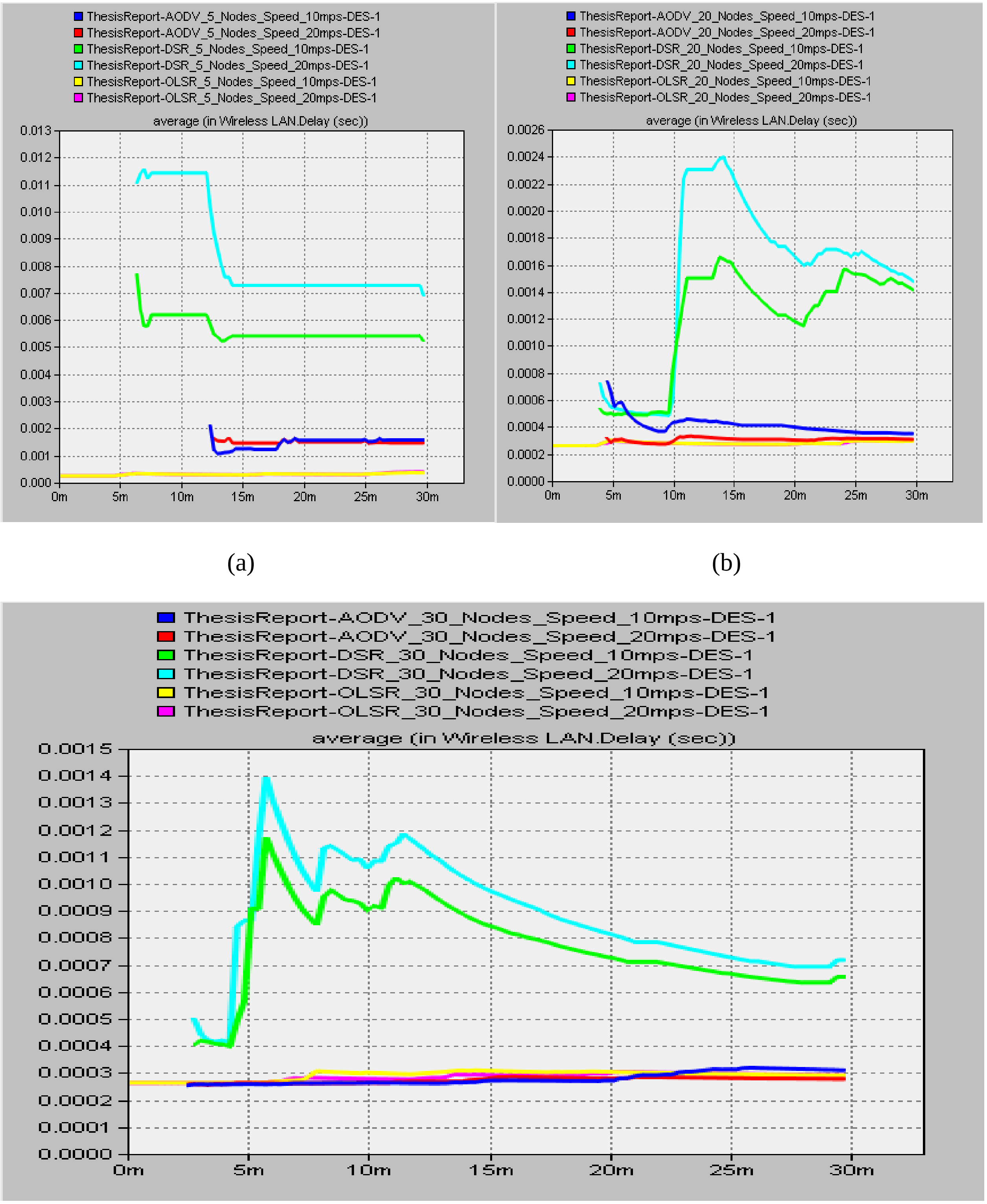
AODV, the source node and intermediate nodes store the next-hop information for packet transmission corresponding to each flow whereas in DSR the source node should know the complete hop-by-hop route information to the destination. Therefore a frequent link breakage is more likely to happen. This can also cause a packet drop and therefore decreased throughput. This makes DSR to have a lower throughput performance than AODV and OLSR in the scenarios considered. The Throughput performance in OLSR is observed to be more consistent than it is in AODV and DSR. This is because of OLSR's proactive nature.

4.4.2 Performance comparison of AODV, DSR and OLSR with respect to Network Size variations in terms of delay and throughput

In this subsection the comparative performances analysis of the three protocols in terms of the performance measurement metrics of delay and throughput is presented. The comparison analysis is done in different scenarios based on the network size variations in two different mobility speeds to identify the scenario in which one protocol performs better or worse than the others so that it will ease the choice of efficient protocols for particular scenarios and further optimizations will be possible.

4.4.2.1 Performance comparison of AODV, DSR and OLSR with respect to Network Size variations in terms of delay

Here the delay performance comparison of the three protocols is analyzed in three different network sizes with 5, 20 and 30 nodes in two different mobility speeds of 10 m/s and 20 m/s. The graphs in figure 4.15 show the delay performances of the AODV, DSR and OLSR in different network sizes in two mobility speeds.



(a)

(b)

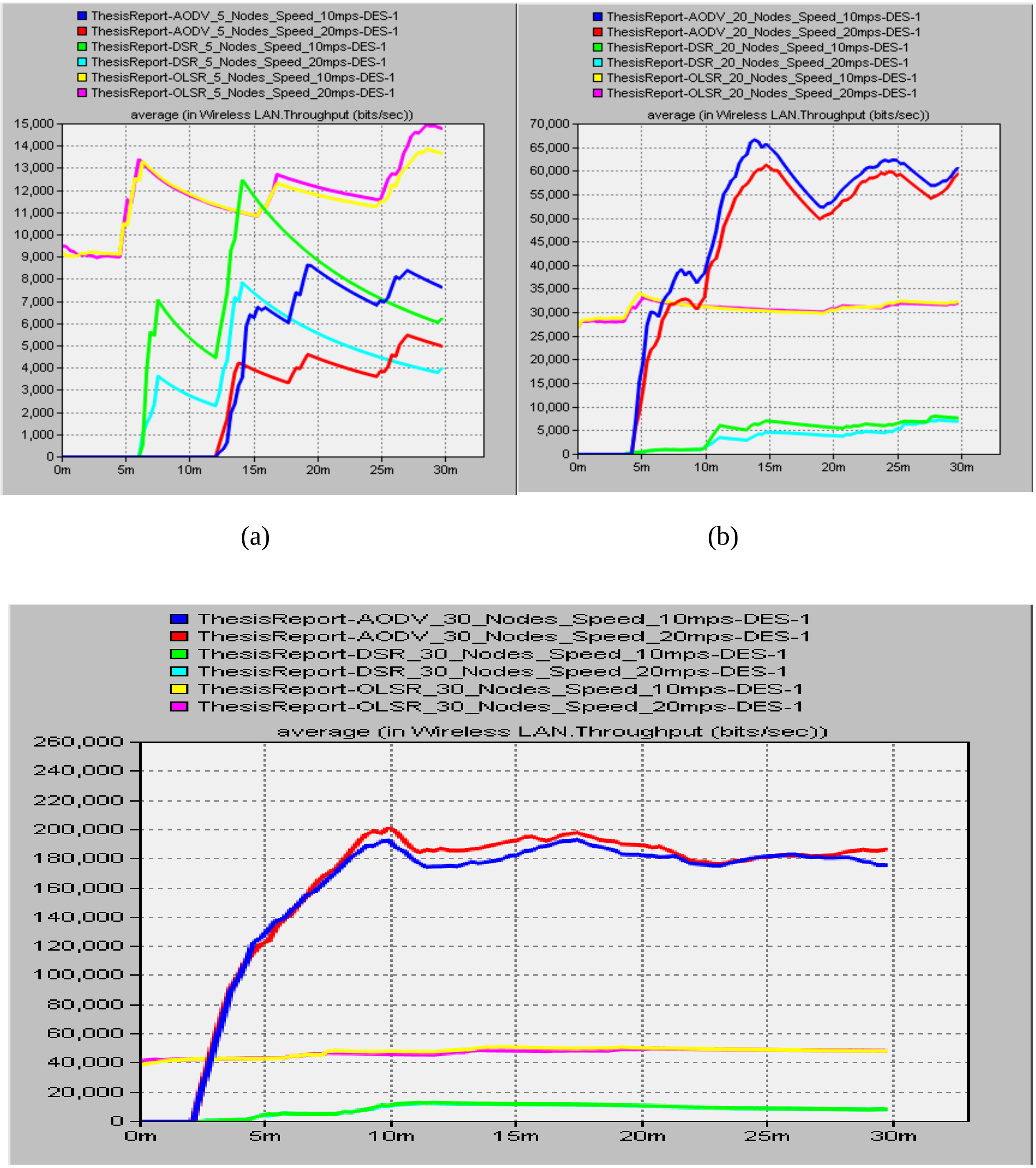
(c)

Figure 4.15: Delay performance comparisons of AODV, DSR and OLSR with network size variations (a) 5 nodes (b) 20 nodes and (c) 30 nodes for mobility speeds of 10 m/s and 20m/s.

As it is shown in figure 4.15 (a), the delay in DSR is higher than the delays in the other two protocols in both mobility speeds. AODV has the second highest delay while OLSR has the least delay. This shows that OLSR is best choice for networks where a lower delay is an issue of concern. It can also be observed from the graphs that the delay in DSR and AODV are higher and inconsistent at the beginning of the simulation. These are mainly due to the time taken in discovering the route and the link breakages during the route discoveries. The consistency in OLSR is due to its proactive nature. That is, since the routes are already available there will not be route discovery inconsistencies. It was also observed in figure 4.15 (b) that in the 20 nodes network DSR performs the worst followed by AODV. OLSR was observed to have a consistent and least delay and hence best performance. The delay in AODV is slightly higher than that of OLSR especially when the mobility speed is 10 m/s.

Figure 4.15 (c) indicates the delay performance comparison of the three protocols in 30 nodes network size. Here also DSR was observed to have the most inconsistent and highest delay in both the mobility speeds. AODV and OLSR have no noticeable delay performance difference. Both of them perform equally well compared to DSR and have a consistent delay in both mobility speeds. The delay in DSR is higher up to around 10 minutes of the simulation time and starts to decrease linearly as it is indicated in the figure 4.15 (c) in both mobility speeds. In conclusion, OLSR, generally, has the best delay performance followed by AODV in all the scenarios considered except in the 30 nodes network size where the delays of OLSR and AODV are essentially equal while DSR has the worst delay performance in all the scenarios considered.

4.4.2.2 Performance comparison of AODV, DSR and OLSR with respect to Network Size variations in terms of throughput



(a) (b)

(c)

Figure 4.16: Throughput performance comparisons of AODV, DSR and OLSR with network size variations (a) 5 nodes (b) 20 nodes and (c) 30 nodes for mobility speeds of 10 m/s and 20m/s

The graphs in figure 4.16 from (a) to (c) depict the throughput performance comparisons of AODV, DSR and OLSR in different network sizes. When the network size is 5 nodes, as it is indicated in the graphs in (a), the throughput is relatively higher in OLSR than the other two in both the mobility speeds. The overall throughput performance of DSR is the second while that of AODV's is the least although there are a lot of inconsistencies. Since OLSR is a proactive protocol, routes are already available prior to the actual packet transmission. That is why the throughput of OLSR is 9000 to 9500 bits/second at the beginning of the simulation and remains constant up to around 5 minutes of the simulation time after which it again starts to increase. On the other hand the throughputs of DSR and AODV remain zero up to around 6 and 12 minutes respectively. This is due to the fact that AODV and DSR are reactive protocols and need to discover the route to the destination when a source node needs to send a packet to the destination. That is, the route discovery process is done prior to the actual packet transmission and therefore the throughput remains zero until the route is discovered. As it is shown from figure 4.16 (b), the throughput performance of OLSR in the 20 nodes network size is the highest of the three protocols' performances up to around 8 minutes of the simulation time above which the performance of AODV becomes the highest. DSR was observed to have the lowest throughput performance.

Similar to the performances of the three protocols in 20 nodes network, OSLR has the highest throughput performance up to around 3 minutes of the simulation time above which AODV starts to outperform in the 30 nodes network. DSR was observed to have the worst performance as it is clearly indicated in figure 4.16 (c) in both the mobility speeds considered. The throughput of the protocols was observed to be more consistent with increasing the number of nodes in the network. As it can be seen from the graphs in figure 4.16 (a) to (c), the throughputs of the three protocols are more consistent in 30 nodes network than the 20 and 5 nodes network. The 20 nodes network has also consistent throughputs than the 5 nodes network. In general, according to the scenarios considered in this study, AODV has the best performance followed by OLSR when the network size is relatively larger whereas OLSR performs best when the network size is relatively small since increasing the network size can increase the overhead of OLSR due to periodic route updates.

4.4.3 Performance comparison of AODV, DSR and OLSR with respect to Mobility Speed variations in terms of delay and throughput

Here the delay and throughput performance comparisons of the three protocols in two different mobility speeds of 10 m/s and 20 m/s are analyzed and presented. The analysis is done based on the three network sizes of 5, 20 and 30 nodes which are considered in this study.

4.4.3.1 Performance comparison of AODV, DSR and OLSR with respect to Mobility Speed variations in terms of delay

As it is observed from the graphs in figure 4.15 (a) to (c), the effect of mobility on delay is greater in smaller networks than in larger networks. The delay variation when the mobility speeds vary is greatest in the 5 nodes network followed by the 20 nodes network. It was also observed that the effect of mobility on the delay performance of DSR is the highest of the three protocols' delay performance. In all the scenarios considered in figure 4.15 (a), (b) and (c) the delay performance of DSR is worse in the 20 m/s mobility speed than it is in the 10 m/s. There is no noticeable delay performance difference in AODV and OLSR as the mobility speeds vary from 10 m/s to 20 m/s except the small and inconsistent delay variations in AODV at the beginning of the simulation time in the 5 and 20 nodes networks. The mobility variation does not affect the delay performance of OLSR. In general, OLSR has the best delay performance regardless of the network size and mobility speed variations followed by AODV. DSR has a better delay performance when the mobility speed of the nodes is lower. Despite the small delay performance variations as the mobility speeds vary, the mobility speed does not cause any profound effect on the performance of the protocols. This indicates that the design technology of the protocols was implemented in a way that they can handle the dynamic and unpredictable nature of the MANET topology.

4.4.3.2 Performance comparison of AODV, DSR and OLSR with respect to Mobility Speed variations in terms of throughput

The throughput performances of the reactive protocols (DSR and AODV) vary as the mobility speed of the nodes varies from 10 m/s to 20 m/s while that of the proactive protocol (OLSR) remains almost the same in both mobility speeds when the network size is small as it can be observed from the graphs in figure 4.16 (a). In both AODV and DSR the throughput is higher when the mobility speed is 10m/s than when it is 20 m/s. OLSR has the highest throughput performance in both mobility speeds when the network size is low. DSR also has a better throughput than AODV up to around 26 minutes of the simulation time above which AODV starts to outperform DSR. With increasing the network size, the effect of mobility speed becomes marginally small or almost negligible. In the network with 20 nodes which is shown in figure 4.16 (b), the throughput is slightly higher in the 10 m/s mobility speed than it is in the 20 m/s in both AODV and DSR while that of OLSR remains the same in both mobility speeds. When the network size is increased to 30 nodes, there is no throughput performance difference except a slight variation in AODV as depicted in figure 4.16 (c). In general, according the scenarios considered in this study, the mobility has no profound effect on the performance behaviors of the MANET routing protocols.

CHAPTER FIVE

CONCLUSIONS AND RECOMMONDATIONS

5.1 INTRODUCTION

In this chapter, a conclusion is drawn with reference to the results obtained in chapters three and four. And also, recommendations for future works and possible enhancement techniques are presented.

5.2 CONCLUSION

In this research, the performance analysis and comparisons of three popular MANET routing protocols have been carried out with respect to the performance metrics of throughput and average end-to-end delay. The performance evaluations and comparisons were analyzed in different network scenarios by varying the control variables along which MANET routing protocols are mainly optimized. The impact of each control variable on the performance behaviors of each protocol has been analyzed. Two well-known reactive routing protocols (AODV and DSR) and one well-known proactive protocol (OLSR) have been analyzed and compared through simulations using a simulation tool called OPNET Modeler 14.5.

The control variable based on which the performance analysis and comparisons were carried out are application traffic load, network size and mobility speed of nodes. FTP application traffic was used. The performance and comparison analysis have been, therefore, carried out in three categories as the impact of FTP traffic load scaling, network size variation and mobility variation. The FTP traffic load levels, the network size and mobility of nodes have been varied to observe their effects on the performance behaviors of the MANET routing protocols. Three different FTP traffic loads with low, medium and high traffic load levels, three network sizes and two mobility speeds of nodes have been considered.

With respect to the FTP traffic load variation, OLSR outperforms DSR and AODV in terms of delay whereas AODV outperforms OLSR and DSR in terms of throughput. DSR has the least performance in terms of both delay and throughput in all the traffic load levels. But there is a general throughput performance increment while delay performance reduces with traffic load increment in all the protocols. The sensitivity response to the traffic load variation of DSR was observed to be higher than the other two protocols in terms of both the performance metrics considered.

In case of the network size variation, OLSR has the lowest delay and hence the best performance followed by AODV. DSR has the worst performance in terms of delay among the three protocols considered. The lowest delay in OLSR is due to its proactive nature that it maintains a route from the destination to the source before actual data is transmitted. When the network size is small, OLSR performs well in terms of throughput. But as the network size is scaled up, AODV have the best throughput performance. DSR has an overall least performance both in terms of delay and throughput whereas AODV and OLSR have overall best performances of throughput and delay respectively.

The effect of mobility on the performance of the protocols is generally greater when the network size is smaller and has a noticeable impact on the reactive routing protocols. The effect of mobility on the delay performance of DSR is the highest of the three protocols' delay performances. The mobility has no noticeable effect on the delay performance of OLSR which has the best delay performance followed by AODV. There is no also a significant difference on the throughput of the protocols as the mobility speed is varied. This indicates that the technology design of the routing protocols was made to accommodate and handle the dynamic topology of MANET networks.

In summary, it can be concluded from this research that in all the scenarios considered the proactive protocols particularly OLSR has the best performance in terms of delay and therefore it is the best choice in applications where delay is the main issue of concern, for example, in real-time applications. AODV which is reactive protocol on the other hand has the best overall throughput performance in almost all the situations considered in this research. It is therefore desirable in situations where throughput is the main issue of concern.

5.3 RECOMMENDATIONS AND FUTURE WORK

In this research, the weaknesses and strengths of popular reactive and proactive protocols have been identified in different scenarios. Their performance behaviors in terms of end-to-end delay and throughput in different network scenarios have been well articulated. In the future research, we will optimize and enhance the performance of the protocols for reliable and efficient routing with a minimum possible delay using soft computing techniques such as artificial intelligence, neural networks and genetic algorithms. The scenarios considered in this research are not exhaustive. Therefore, other researchers can do further researches by taking other variables such as different traffic types and load levels and expanding scenarios considered in this research.

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APPENDICES

APPENDIX I: PUBLICATIONS

1. G. K. Abraha, S. Musyoki and S. Kimani – “**Analysis of the effect of Application traffic load variation on the throughput performance of MANETs**”, Proceedings of 2014 International conference on Sustainable Research and Innovation, ISSN 2079-6226, Volume 5, PP 262-266, 7th – 9th May, 2014.

2. Gebrehiwot K. Abraha, S. Musyoki and S. Kimani **–** “**Comparative Impact Analysis of Application Traffic Load Scaling on the End-to-End Performance Behaviors of MANET Routing Protocols**”, International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, Volume 4, Issue 4, PP 944-950, April 2014

3. G. K. Abraha, S. Musyoki and S. Kimani – “**Comprehensive OPNET based Scalability Analysis and Performance Evaluation of MANET Routing Protocols**”, International Journal of Advances in Engineering and Technology (**Accepted for publication**)