Research and investigation on routing mechanisms for wireless mobile ad hoc networks

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Individual Project

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Abstract

This project focuses on the full study of mobile ad hoc networks and their characteristics. Significant developments in the technology over the last years has led researchers to create a broad variety in the mobile ad hoc networking in order to benefit from the exclusive communication opportunities presented by devices. Mobile ad hoc network is an autonomous collection of two or more nodes or devices that have wireless communication between each other, yet no any centralized infrastructure is required for communication or information exchange that considerably distinguishes any MANET from fixed IP network. In this paper those differences will be analyzed as well as the performance of two selected protocols (i.e., OLSR and AODV) will be evaluated using an open source network simulator called NS-3.

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Contents

Chapter 1

Introduction

Developments in technology over the past few years have led to significant advancements in the communications industry as well. Wireless network is the most obvious segment growing in the communications industry from day to day and changing lives of people considerably [1]. In general, there are two basic wireless network categories. Firstly, infrastructure-based wireless network is the more popular type and the most common example for that is Wi-Fi. In such mode of networking, there is a central point also known as access point and information firstly goes through it in the case of communication between two or more devices [2]. On the other hand, there are self-organized wireless networks, namely mobile ad hoc networks (i.e., MANET), which will be analyzed in this paper. During last years, researchers have focused on creating a variety in the mobile ad hoc networking in order to benefit from the exclusive communication opportunities presented by devices [3]. Mobile ad hoc network is a collection of two or more equal nodes or hosts that form a temporary communication over wireless links without the need of any fixed infrastructure that is the main characteristic differentiating the MANET from an IP network. Nodes are devices such as laptop, mobile phone or MP3 player, which may act as host/router or even both simultaneously. It ought to be outlined that communication is sustained as a result of transmission of data packets through a wireless channel [4]. The most substantial factor increasing the demand towards mobile ad hoc networks is the fact that they are self-configuring, adaptive and autonomous making them suitable to be used in diverse emergency and military situations when the existing infrastructure is down [5].

1.1 Motivations

As a result of the increased demand towards MANETs, creating effective routing algorithms becomes more necessary issue to be fixed. In general, routing is the transmission of data packets between computer networks that is performed by routers. Accordingly, routing protocol stands for the most appropriate paths for forwarding packets to the intended final destinations [6]. Yet, ensuring efficient routing has been the most significant challenge for ad hoc networks. To be more specific, the nodes move arbitrarily at any time in mobile ad hoc networks on the grounds that there is not any fixed infrastructure. This leads to rapid and random changes of the network topology in any MANET. Diverse problems occur in routing because the topology is regularly changing and nodes do not have constant data storage. This results with the loss of packets and hence communication that can cause considerable problems on networks [7]. It should be noted that there have been proposed a variety of protocols to routing problems in mobile ad hoc networking. In addition to the above-mentioned problem, those protocols were introduced to deal with other challenges such as limited bandwidth and energy consumption of nodes. Nevertheless, it ought to be outlined that there is no consensus in terms of the best routing protocol for mobile ad hoc networks on the strength of the fact that all of them are designed to solve a specific problem, yet they have challenges at the same time. Thus, instead of focusing on the best routing protocol, the most suitable strategy should be considered for any specific scenario [8]. Motivated by the challenges in creating effective routing algorithms for ad hoc networks, this research paper will provide a close comparison of systematic performances of two main routing protocols in ad hoc networks operating in the same environment.

1.2 Scope and Objectives

It should be noted that this paper aims to broadly analyze the features of mobile ad hoc networks as well as their advantages and disadvantages when compared to fixed IP networks. Generally, there are three basic groups of routing protocols in wireless ad hoc networks: reactive routing protocols, proactive routing protocols and hybrid routing protocols. In reactive routing protocols, nodes make the route between the source and destination based on demand. Yet, routes are regularly maintained to all destinations by nodes in proactive routing protocols. Finally, hybrid routing protocol is the combination of other two protocols that takes best characteristics from both [9]. Hence, the project will focus on the performance comparison of two major routing protocols in ad hoc networks selected from the two basic classes, reactive routing protocols and proactive routing protocols respectively: AODV (i.e., ad hoc on-demand distance vector) and OLSR (i.e., optimized link state routing). It must be determined that it is not obvious how various routing protocols operate in different environments. More precisely, the protocol considered as the best option to operate in the mobility and network topology, might not be an appropriate choice in other scenarios. Therefore, this project aims to evaluate and compare proactive (i.e., OLSR) and proactive (i.e., AODV) routing protocols with respect to the same performance parameters and under the same simulation scenarios through an open source network simulator called NS-3. The performance metrics through which the two selected routing protocols will be compared are throughput, packet delivery ratio, routing overhead, total energy consumption and average end-to-end delay. The performance of routing protocols can differ considerably depending on the simulation environment. Therefore, three different simulation scenarios will be created and the number of nodes, mobility speed and number of packets will be varied in scenarios 1-3 respectively in the experiment in order to achieve more comprehensive results.

In the next chapter, the main benefits and challenges of mobile ad hoc networks will be discussed in comparison to the fixed IP networks. All types of routing protocol groups in mobile ad hoc networks will be analyzed in details and background information will be provided in terms of selected routing protocols (i.e., OLSR and

AODV). Additionally, the paper will be compared with several existing works as well as NS-3 overview will be given. The background chapter will be followed by the requirements and specification chapter, where the required hardware and software for the project are discussed. In the design and implementation chapter, we will review the installation and building process of NS-3, selected simulation parameters for all scenarios, definition of used performance metrics and the implementation ways of routing protocols. The chapter followed by the design and implementation, will present the results achieved from simulation of routing protocols in all scenarios, which will be evaluated afterwards. Finally, the conclusion chapter will summarize the whole project and propose possible improvements of the conducted experiment,

Chapter 2

Background

2.1 Wireless Networks

Wireless networking has gained a significant popularity all over the world as a result of the developments in technology in the 21st century. It should be noted that such networks use radio frequencies to transmit and receive data. The main advantage of wireless networking is its cost efficiency as there is no need for cables. Therefore, users can move with their devices around the network area and still keep the connection. In general, wireless networks are classified into two broad groups: infrastructure wireless networks and ad hoc networks [10].

2.1.1 Infrastructure Wireless Networks

In infrastructure mode wireless networks there is an access point or base station enabling all devices to communicate through it and called a wireless router. It should be pointed out that the access point is connected to main network by both wireless or wired link. The communication between devices in such mode of networking is indirect on the strength of the fact node sends packets to the access point in the first step and following this further the wireless router sends packets to the intended node [11]. Figure 2.1 shows wireless network operating in the infrastructure mode.

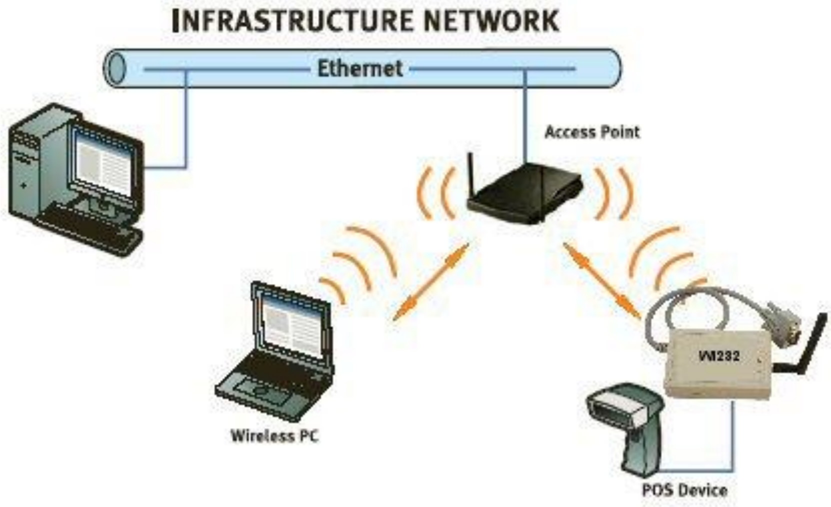


Figure 2.1: Infrastructure-based Wireless Networks

2.1.2 Ad Hoc Networks

Ad hoc networks are also called infrastructure-less networks due to the fact that there is not any access point or base station in such mode of networking. More precisely, in ad hoc networks nodes communicate over the wireless links without the need of fixed infrastructure. It must be determined the communication between two hosts in ad hoc networks is not always direct. To be more specific, a number of nodes may be present in the communication on the grounds that each node requests data from previous nodes and acts as routers by forwarding the data to another node. Unlike infrastructure-based networks, the topology is not fixed and changes randomly in ad hoc networks because nodes move arbitrarily at any time. This results with the loss of packets and consequently communication that can cause considerable problems on networks [7]. In general, ad hoc networks are divided into two basic groups: mobile ad hoc networks (MANET) and static ad hoc networks (SANET). In mobile ad hoc networks, nodes move arbitrarily across the network area, yet in SANET they are fixed [6]. The demand towards the ad hoc networks has increased recently due its flexibility and the applications that are used through them [5]. Figure 2.2 demonstrates an infrastructure-less wireless network.

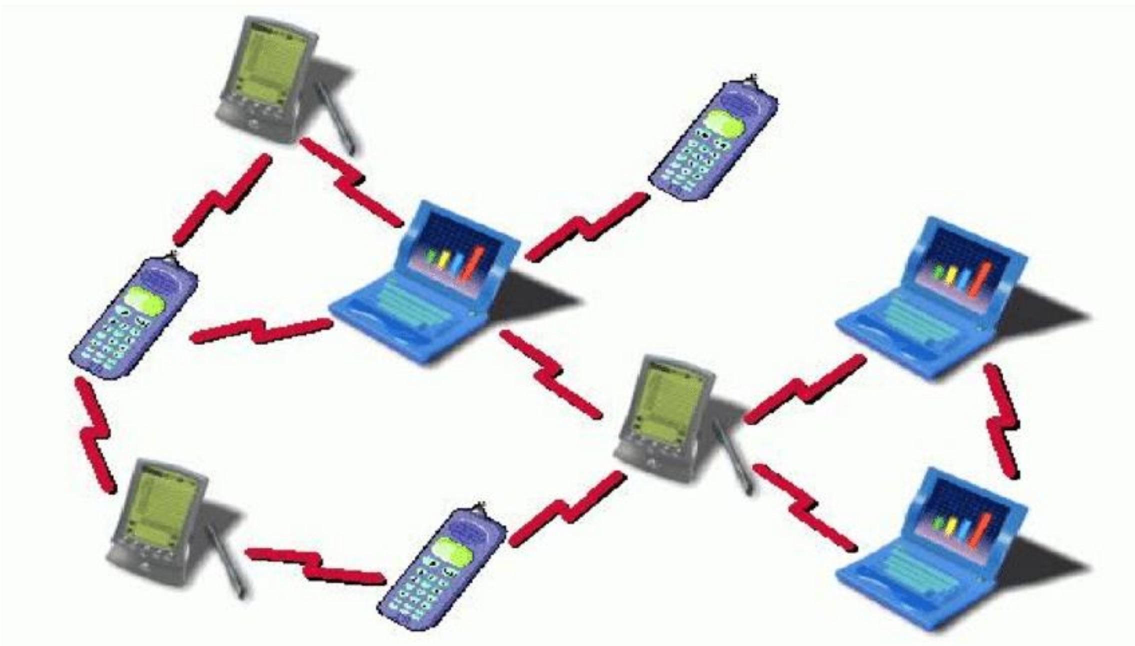


Figure 2.2: Infrastructure-less Wireless Networks

During the last years, researchers have focused on the development of MANETs to benefit from their communication opportunities. As has been mentioned before, the most significant factor increasing demand towards the mobile ad hoc networks is their flexibility and self-organization, which means that the network can be configured immediately with some wireless devices even in the areas where it is impossible to establish an access point or base station. MANETs were initially utilized in emergency situations, yet they are currently used for diverse purposes such as during meetings, lectures or conferences. The nodes in MANETs are self-configuring enabling any node to connect to all other nodes across wireless network's coverage area [12]. The costs in the mobile ad hoc networking are much lower on the strength of the fact that there is no need for any base station, configuration training, system maintenance and cabling. Additionally, the wireless chip with IEEE 802.11 standards used in MANETs is quite cheap [13]. However, due to the fact that the topology is not fixed in mobile ad hoc networks, it has been significant challenge ensuring efficient and reliable routing protocols. Accordingly, the use ad hoc networks have diverse challenges that are listed below.

- **Dynamic topology**: unlike IP networks, in ad hoc networks nodes are mobile and move arbitrarily, making the removal and establishment of wireless links in a dynamic way. Changes in the network topology may result with the loss of packets and communication [8].
- **Security:** the absence of infrastructure and mobility of nodes may reduce the security significantly in ad hoc networks. Thus, ad hoc networks are vulnerable to attacks that are divided into two basic groups: passive and active attacks. In passive attacks, the transmitted data cannot change, yet can be discovered by an unauthorized user. On the other hand, active attacks may lead to the modification of messages by an authorized user [14].
- **Energy constrained**: nodes in MANETs operate with the battery power because of the absence of the fixed infrastructure. It ought to be outlined that energy of nodes, playing substantial role in the communication, depends on the battery. Nevertheless, the battery has limited power supply and nodes consume considerable energy making mobile ad hoc networks useless for the permanent use. Therefore, ensuring energy-efficient algorithms is the only way to solve the above-mentioned problem [15].
- **Bandwidth constrained:** wireless networks have more varying and significantly lower bandwidth than wired networks. The lower capacity of wireless connection is due to diverse effects such as interference, noise or fading. As a result, the received signal degrades and bit error rate (BER) becomes much higher, increasing the probability of packet to be received in error [5].

2.2 Routing Protocols in Ad Hoc Networks

Routing is the transmission of data packets between hosts across the network that is performed by routers. It should be pointed out that routing protocols play significant role in the communication as they control the routing process [11]. Routing protocols in MANETs are responsible for searching and finding the most appropriate paths in order to forward the packets to the intended final destinations [9]. It must be determined that routing is implemented through the routing tables. The wireless communication can be implemented in three ways in mobile ad hoc networks: unicast, multicast and broadcast. In unicast node, data packets are transmitted from the source node to a specific destination in the network. Multicast mode indicates the transmission of information from the source node to different final destinations. Finally, in broadcast mode, the source node transmits data packets to all other nodes in the routing table [16]. In ad hoc networks, nodes entering the network are unaware of the topology and instead they try to discover it. More specifically, while a new node enters the network, it makes announcement about its presence and listens to announcements in neighbors in order to find the network topology. It ought to be outlined that diverse routing protocol algorithms discover the route in different ways. Accordingly, routing protocols are classified based on strategies they use and are divided into 3 main groups: proactive routing protocols, reactive routing protocols and hybrid routing protocols [5].

2.2.1 Reactive Routing Protocols

Reactive routing protocols are also known as on-demand protocols on the grounds that the route is created upon the request of the source node. More precisely, the route search process is only initiated when packets need to be forwarded. The route discovery process is over when the route is determined and following this further, the source node sends data packets to the intended node through the discovered route. Routing overheads in these protocols have two major aspects, i.e. route discovery and route maintenance. Reactive routing protocols are based on flooding technique during the route discovery process, which employs on the technique that the route request is distributed to the entire network. When a route is discovered, the route maintenance process will maintain it until the destination becomes inaccessible throughout all possible paths [3]. Reactive routing protocols have smaller communication overhead because there is no need for route maintenance. However, they have much higher delay due to route search for all unknown destinations and dynamic calculations for every route. A number of routing protocols are associated with this classification such as dynamic source routing (DSR), ad hoc on-demand distance vector (AODV), associativity based routing (ABR) or temporarily ordered routing algorithm (TORA) protocols [17].

2.2.2 Proactive Routing Protocols

On the other hand, proactive routing protocols are also called table-driven protocols because they regularly update information in the routing table by continuously evaluating all existing routes. Regardless there is need for data transmission or not, each node in network regularly maintains updated routes to all other nodes making proactive protocols useless for large-size networks. Therefore, each node in the network becomes aware of all other nodes in advance; hence the route is implemented immediately when there is a need for data transmission. Once the network topology changes, routing table is accordingly updated and each node sends a broadcast message to all other nodes in the routing table. In comparison to reactive routing protocols, table-driven protocols have greater routing overhead on the grounds that all routes in network are defined before the transmission of packets. Yet, due to the fact that all routes are continuously maintained up-to-date, proactive routing protocols have much lower delay than on-demand protocols [18]. In other words, every route is calculated instantaneously in proactive protocols. The obvious disadvantage of proactive protocols is that the table maintenance process results with considerable costs. There is a number of existing on-demand routing protocols such as global state routing (GSR), optimized link state routing (OLSR) or destination sequence distance vector (DSDV) protocols [5].

2.2.3 Hybrid Routing Protocols

Hybrid routing protocols are based on table-driven and on-demand protocols that take the best characteristics from both enabling them to discover the route much quicker in the routing zone. Zone routing protocol (ZRP) is the basic example for hybrid routing protocols [19].

2.3 Existing work

Several studies have been conducted to examine the performance of different routing protocols in ad hoc networks over the past few years. For instance, in their study, Broch et al. (1998) have compared diverse routing protocols (i.e., DSDV, TORA, AODV and DSR) according to two main performance metrics, packet delivery fraction and routing overhead by setting up the number of nodes to 50 and varying pause times. The simulations were conducted under mobility scenarios using NS-2. They concluded that AODV and DSR perform much better with all movement speeds and mobility rates [20]. Moreover, Ahmed & Alam (2006) have conducted a study by evaluating the performance of the routing protocols (i.e., DSR, TORA and AODV) using the discrete-event simulator. It was concluded that that TORA performs better than other protocols under the specific parameters [21]. The study of Divecha et al. (2007) compares the performance of two routing protocols (i.e., DSR and AODV) under different simulation parameters. The results demonstrate that performance of protocols considerably depend on the simulation parameters such as number of hops and network load [22]. Although a number of studies have evaluated performances of routing protocols, quite few of them have implemented it only in terms of AODV and OLSR, which is the aim of the current paper. It can be observed that few projects have analyzed the routing protocols in respect of several performance metrics such as average end-to-end delay, throughput, routing overhead, packet delivery fraction and total energy consumption. Furthermore, it must be determined that an open-source network simulator called NS-3 is used in this project that has not been common in the MANET projects. Additionally, it can be observed that only few papers have considered the mobility speed as an important variable in networking. Few papers have conducted comprehensive study in terms of routing protocols in MANETs by varying number of packets and number of nodes that have significant impact on the performance of routing. Taking for an example, Bertocci et al. (2003) have conducted an investigation into the performance of routing protocols (i.e., DSR, AODV and OLSR) by comparing the standard Djikstra algorithm with a fixed number of nodes. They concluded that the performance of protocols were high as more than 90% of packets were delivered correctly. Yet, in the above-mentioned study, variation of node density is not considered that may decrease packet delivery fraction considerably [23]. The paper of Adam et al. (2011) provides a comprehensive comparison of routing protocols (i.e., AODV, DSR and DSDV) in terms of performance metrics. However, the mobility model is not considered and constant number of nodes is used in this research [24]. As a result, the research of Adam et al. (2011) implements Manhattan Grid model opposing the random waypoint model followed by our research where the mobility model is considered. Ehsan & Uzmi (2004) state that pause time is a significant factor that needs to be taken into account due to the fact that the mobility rate depends on it as mobility rate jumps with the increase of pause time [25]. Despite the fact that routing protocols in the study of Dos et al. (2000) are compared according to similar performance metrics and under similar simulation parameters as in our project, it only focuses on reactive routing protocols, AODV and DSR [26].

2.4 Selected routing protocols

2.4.1 OLSR

As has been mentioned before, optimized link state routing (OLSR) protocol is a proactive routing protocol and on account of its nature, the routes are instantly available when required. The reason for the above-mentioned protocol to be called such is the fact that it is an optimized version of the pure link state protocol tailored to satisfy the requirements of wireless networks. Optimized link state routing protocols are very useful for the traffic patterns where a significant number of nodes communicate with each other as in such protocols routes are regularly maintained to all final nodes in the network [27]. It must be determined that OLSR protocols utilize the multipoint relays (MPR) technique for transmitting packets during the flooding process. Each node in the network determines one or more nodes as its MPRs with which it has symmetric 1-hop neighborhood. Accordingly, the collection of nodes that are selected by a single node in the map is called MPR set. It must be determined that the nodes in the set selected by node N, read and process the packets, yet they do not participate in the retransmission process of the broadcast packet. Therefore, each node maintains data about a number of neighbors called MPR selectors of that node, enabling all messages coming from MPR selectors of node N to be retransmitted by that node [28]. It ought to be outlined that all multipoint relays must have bi-directional one hop neighborhood with node N selecting them and two hops distance among each other. MPR is a specific characteristic differentiating optimized link state routing protocols from others and providing them with two substantial benefits. First of all, only a subset of links is flooded across the network to provide the shortest paths that decreases the size of control packets. To be more specific, only the nodes designated as MPRs announces links to its neighbors that are their multipoint relay selectors. Secondly, the MPR concept significantly reduces the overhead from flooding of control traffic. This can be explained by the fact that unlike regular link state routing protocols where each node has to retransmit packets to the entire network, in OLSR protocols, only the nodes allocated as MPRs are in charge of that. This eventually results with the considerable decrease of retransmissions in the broadcast process. The use of OLSR protocols can be appropriate in dense and large networks since optimization is successfully implemented through the MPR technique [29]. Figure 2.3 demonstrates the flooding process in OLSR protocols through MPR.

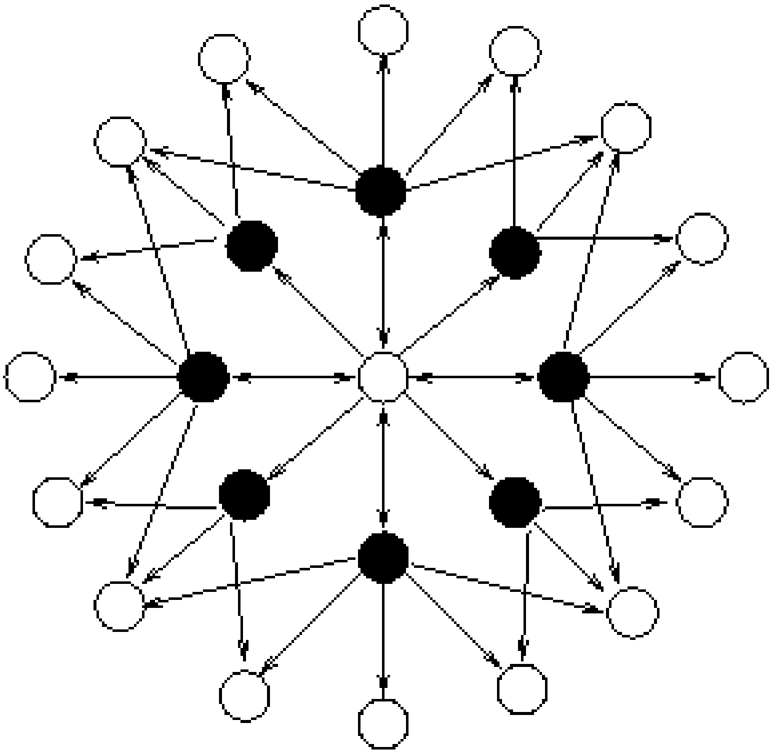


Figure 2.3: Multipoint Relay Flooding

Optimized link state routing protocols are differentiated for having link sensing, neighbor detection and MPR selection features. In general, four types of control messages can be used in OLSR protocols: HELLO (Hello), TC (Topology Control), HNA (Host or Network Announcement) and MID (Multiple Interface Declaration) messages. The HELLO messages are periodically transmitted in the processes such as MPR selection, neighbor detection and link sensing. It ought to be outlined that neighbor detection is a process where any node detects its neighbor node with which it must only have symmetrical link. To implement this process, each node forwards a HELLO message including data about their neighbors as well as their link status. The control messages are received by all neighbors within one hop neighborhood, yet they are not transmitted to other nodes. The message provides neighbors' addresses of any node up to two hops to which there may exist both valid and invalid bi-directional links [30]. Moreover, continuous exchange of link set information about links between nodes is called link sensing. The packets are transmitted using HELLO messages in link sensing process, which maintains up-to-date information on all links between a node and its neighbors [5]. The selection of multipoint relays could only be implemented after the neighbor detection and link sensing processes on the grounds that it uses information of each hop for the route calculation. When any node in the network receives a HELLO message, it creates or updates routes to all known destinations. It should be noted that the link state information is transmitted from MPR nodes to the network through TC messages. Unlike HELLO messages, TC messages are capable of broadcasting topological information along the entire network. The messages in OLSR protocols are distinguished through sequence numbers. As has been mentioned before, each node in network maintains up-to-date routing table containing information about destination address, next-hop address and estimated distance to destination. The routing calculation is implemented through the above-mentioned information by utilizing algorithm with the shortest path [31].

2.4.2 AODV

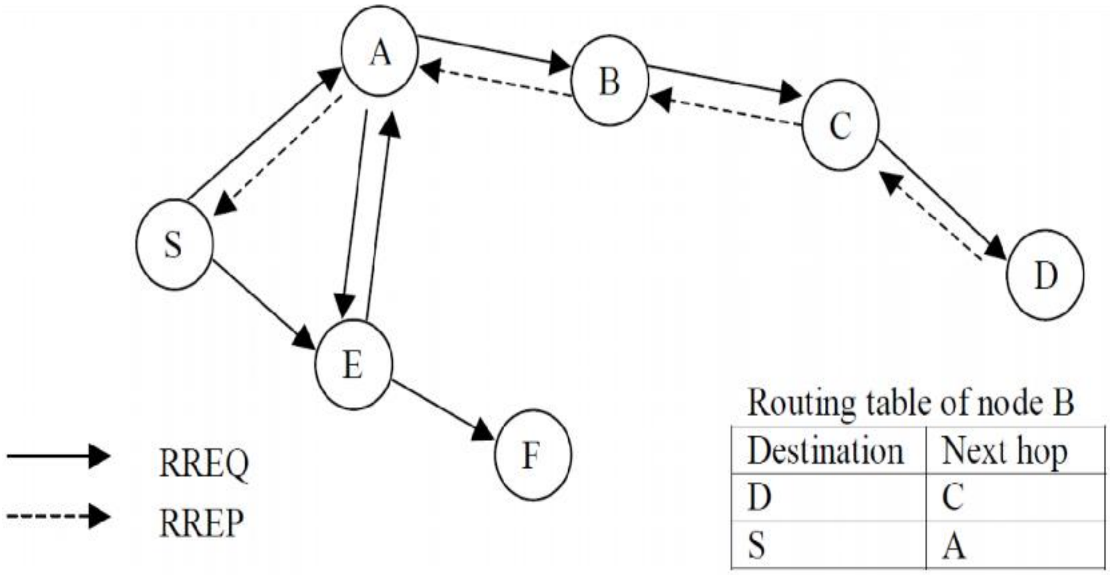
Ad hoc on-demand distance vector routing (AODV) protocol is an improved version of DSDV and differentiated for creating routes in an on-demand manner. AODV routing protocols are characterized for being dynamic, self-configuring and utilizing Bellman-Ford algorithm during route calculations. It uses both bi-directional and unidirectional links as well as supports multicast and unicast modes. AODV routing protocols are suitable for large networks and belong to the reactive category of ad hoc networks, yet it also uses few characteristics that are common to proactive protocols [32]. Due to its reactive nature, the source node in AODV routing protocols requests or creates the route for forwarding packets when needed. This characteristic provides ad hoc on-demand distance vector routing protocols with considerable advantage over others on the grounds that it considerably decreases the size of routing table and the broadcast process. In other words, the routing information is only maintained about the active paths. Therefore, the nodes that are outside of the path, do not participate in the maintenance of the routing information [33]. It should be noted that routing tables are used at all nodes where the routing information is maintained. Yet, the routing table entry expires when it is not used for specific expiration period. AODV routing protocols utilize the sequence numbering strategy in order to ensure that all routes towards the destination are loop-free and fresh. Furthermore, nodes in AODV routing protocols periodically broadcast Hello messages in order to keep the neighborhood topology updated. It must be determined that AODV routing protocols have two basic mechanisms: route discovery and route maintenance [34]. Three common messages are involved in these mechanisms, i.e. Route Errors (RERRs), Route Replies (RREPs), and Route Requests (RREQs).

2.4.2.1. Route Discovery and Route Maintenance

It ought to be outlined that the source node must search its routing table to find path to the destination node before making communication with that node. When there is no existing path to the destination, the route discovery process is initiated. Due to the discovery process, the protocol becomes active. However, if there is a valid entry to the destination node, the AODV routing protocol stays passive because it is not involved in any process [32].

The source node broadcasts RREQ messages when it does not know the route to the final destination. RREQ messages are received by the neighbors of the source node and have unique identifier. They contain source address, sequence number of the source node, destination address, hop count and broadcast ID. The combination of broadcast ID and source address distinguishes the message. Before broadcasting RREQ messages, the source node implements the sequence numbering to avoid possible problems that can be derived from routing loops. To be more specific, it monotonically increases the sequence numbers to guarantee loop freedom as well as fresh route. Two types of paths could be observed during the routing in AODV protocol. Forward path indicates the routing from the source node to the destination node, yet reverse path is the routing from the destination node to the source node [5].

The RREQ message can be delivered either to the intermediate node or the destination node. It must be determined that if the node receiving the RREQ message is the destination node or knows the route to the destination, it generates RREP messages to finalize the process. Otherwise, the node rebroadcasts the RREQ messages to neighbors. Therefore, if the destination node receives the message, the node sends the RREP message back to the source node. Due to the fact that the RREP message is passed through intermediate nodes during this process, they update the routing table enabling future messages being delivered to the final destination through these nodes. Yet, the process becomes much complicated when the intermediate node receives the message. The intermediate node transmits the message to the nodes in neighborhood if it has not received that message before. Nevertheless, the situation changes if the intermediate node has already received the same RREQ message. More precisely, the node ignores the message if it has less sequence number than the previous one. Nevertheless, if the sequence number of the current message is equal or greater than the previous message, the node checks the routing table for a valid route to the destination. Following this further, the intermediate node sends the RREP message either back to the source node or to the next hop node with the information about the route. It should be noted that each node receiving the RREQ message has to store the information included in order to respond to that message when required [32]. Figure 2.4 clearly demonstrates how the source node broadcasts RREQ messages and destination node unicasts the RREP message. As illustrated in figure 2.4, the nodes knowing the route to the destination and destination node itself transmits RREP messages in the reverse direction. Yet, the RREQ message is broadcasted to all nodes in the forward path.



Destination	Next hop
D	C
S	A

Figure 2.4: Flow of RREQ and RREP messages

AODV routing protocol initiates the route maintenance process once the route is discovered. HELLO and route error (RERR) messages are used at this stage. The HELLO message is used in a periodic manner in order to avoid expiry of forward and backward pointers. The RERR message is generated during a link break by the node upstream of the break. The message is propagated to the source node, which informs that the destination is unreachable due to the link failure. As a result of link failures during data transmissions, route repair is executed either utilizing either local or global repair. The local repair occurs when the intermediate node upstream of the break repairs the link with the own conditions. Whereas, global repair represents the case where the source node reinitiates the route discovery process [3]. Figure 3.5 demonstrates the case where link failure occurs between C and D nodes. As a result, node C, the upstream node of the break produces RERR message.

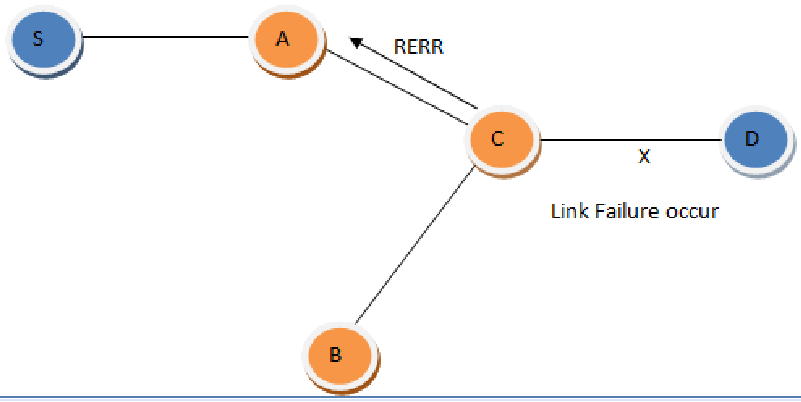


Figure 3.5: Link break and flow of RERR message

2.5 NS-3 Overview

In general, simulation is the procedure whereby the real-world process or system is imitated during specific period of time. Simulation can be applied to various areas such as training, education, video games or safety engineering. Network simulation is a computer network modeling process, which is implemented as a result of identifying the relationship between the software and diverse network devices. There are various existing network simulators such as QualNet, OMNET++, NetSim or NS. It must be determined that NS is the most popular network simulator. NS-3 is the latest type of NS, which is used in our experiment for the performance evaluation of routing protocols in MANETs. NS-3 is a free and open source discrete-event network simulator, which is suitable for educational and research use. The NS-3 software has been designed to contribute to the modern networking research by developing open simulation environment. NS-3 supports the use of various visualization tools and external animators. It should be noted that NS-3 is written in the programming languages C++ and Python. Although NS-3 is mainly utilized on Linux systems, it also supports other tools such as Cygwin, FreeBSD or Windows Visual Studio, which is the main feature distinguishing NS-3 from other network simulators. NS-3 has the capability to simulate both IP and non-IP based wireless networks such as Point-to-Point CSMA, WiMAX, Wi-Fi, LTE. The use of NS-3 is appropriate for the comparison of routing protocols on the grounds that the simulator supports various building and mobility models as well as routing algorithms in MANETs such as OLSR or AODV [35].

Chapter 3

Requirements and Specification

The current project aims to compare the proactive (i.e., OLSR) and reactive (i.e., AODV) routing protocols in terms of various metrics using the network simulator called NS-3. There are a number of hardware and software specifications required in order to obtain and analyse the performance-based results of routing protocols. Firstly, it should be noted that the simulator required is supported by Linux based operating systems. Therefore, VirtualBox has been downloaded to the MacBook Pro. It must be determined that VirtualBox can run versions of Linux inside another operating system [36]. Hence, Linux distribution-based Ubuntu 16.04.3 (64 bit) was installed and run through the VirtualBox. Following this further, the latest version of the required network simulator (i.e., NS-3.27) was installed and built on the Linux based operating system.

Chapter 4

Design and Implementation

4.1 NS-3 Installation and Building

In the first step, the latest version NS-3.27 was downloaded and installed to Ubuntu 16.04.03 in order to implement the simulations and achieve the results required to compare the routing protocols (i.e., OLSR and AODV) with respect to diverse performance metrics. After successfully installing NS-3.27 (wget http://www.nsnam.org/release/ns-allinone-3.27.tar.bz2), building the examples successfully (./build.py --enable-examples --enable-tests), finishing the building process through waf builder (./waf –d debug --enable-examples --enable-tests configure) and testing that the installation is ready to work (./test.py), the simulation environment was setup.

4.2 Simulation Setup

It should be noted that NS-3 simulation tool is used on Linux operating systems and is written in C++ and Python. In this research, the routing protocols (i.e., OLSR & AODV) were compared according to five performance parameters, i.e. average end-to-end delay, routing overhead, throughput, packet delivery fraction and total energy consumption. Simultaneously, diverse simulation parameters were applied affecting the results significantly. It ought to be outlined that three totally different simulation scenarios were created in order to make the study much more comprehensive. The following subsections will clearly demonstrate the simulation parameters and performance metrics used in all three scenarios.

4.2.1 Scenario 1

In the first scenario, the routing protocols were investigated in regard to throughput, packet delivery fraction, routing overhead and average end-to-end delay by varying node density. The simulations were implemented by setting the number of nodes to 15, 25 and 50 respectively. Additionally, random waypoint mobility model was utilized for the evaluation of protocols. According to the model, nodes move towards randomly chosen destination nodes with a random speed and do not have restrictions or dependence. The model is flexible for simulations and can be controlled by users through setting maximum and minimum speed [37]. The nodes move with a speed of 15m/s and zero pause time within a 600m*600m simulation area. It must be determined that the simulation totally runs for 200 seconds and nodes move after 50 seconds the simulation starts. The simulations were performed with packet sizes of 64 to 512 bytes to avoid possible network congestion that can occur on the strength of large packets. Through the use of NS-3 On-Off application, Constant Bit Rate (CBR) was generated, which is needed for traffic management during packet transmission in MANETs. The Wi-Fi performed in ad hoc mode and 802.11b was used with a Friis loss model and 2 Mb/s rate. DSSS rate and data rate of 11 Kbps and 2048 Kbps were used respectively for the current simulation scenario. Finally, it should be noted that the simulations were implemented by setting up the transmit power to 7.5 dBm. The simulation parameters used in the first scenario are illustrated in table 4.1 below:

Table 4.1: Selected Parameters for Scenario 1

Parameters	**Values**
Number of Nodes	**15, 25, 50**
Wireless LAN	**IEEE 802.11b**
Simulation Area	**600*600**
Performance Metrics	**Packet Delivery Fraction, Throughput, Routing Overhead, Average End-To-**

	End Delay
Movement Model	**Random Waypoint Mobility Model**
Traffic	**Constant Bit Rate (CBR)**
DSSS Rate	**11 Mbps**
Simulation Time	**200 seconds**
Number of Packets	**4**
Packet Size	**64-512 bytes**
Network Simulator	**NS-3**
Node Mobility Speed	**15 m/s**
Routing Protocols	**AODV, OLSR**
Transmit Power	**7.5dBm**
Data Rate	**2048 Kbps**
Wi-Fi Mode	**Ad Hoc**

4.2.2 Scenario 2

In the second scenario, the routing protocols were analyzed with respect to throughput, packet delivery fraction, total energy consumption and average end-to-end delay by varying node density. In addition to the number of nodes (10, 30, 50), the mobility speed of nodes (10-50 m/s) was also varied in this scenario in order to examine speed effects on the performance of AODV and OLSR. Moreover, the packet size was increased to 1024 bytes and 150 packets were used. Random direction mobility model was selected in order to remove the flaw. Mobile nodes select random direction instead of random destination in such mobility model, which is the main characteristic differentiating the current model from the random waypoint mobility model. More precisely, any mobile node starts to move towards the border of the simulation area in the direction it has selected at the beginning of the process. The mobile node stops for a while after reaching the boundary and the process is repeated after choosing another direction [38]. The total running time of the simulation was 180 seconds. Furthermore, the nodes move within a 500*500 simulation area. Finally, it should be noted that DSSS rate and data rate were 11Mbps and 164Kbps respectively. The selected simulation parameters are demonstrated in table 4.2 below:

Table 4.2: Selected Parameters for Scenario 2

Parameters	**Values**
Number of Nodes	**10,30,50**
Wireless LAN	**IEEE 801.11b**
Simulation Area	**500*500**
Performance Metrics	**Throughput, Packet Delivery Fraction, Total Energy Consumption, Average End-To-End Delay**
Movement Model	**Random Direction Mobility Model**
Traffic	**Constant Bit Rate (CBR)**
DSSS Rate	**11Mbps**
Simulation Time	**180 seconds**
Number of Packets	**150**
Packet Size	**1024 bytes**
Network Simulator	**NS-3**
Node Mobility Speed	**10,20,30,40,50 m/s**
Routing Protocols	**AODV, OLSR**
Transmit Power	**7.5dBm**
Data Rate	**164 Kbps**
Wi-Fi Mode	**Ad Hoc**

4.2.3 Scenario 3

In the last scenario, the selected routing protocols were compared in respect of total energy consumption, throughput, packet delivery fraction and average end-to-end delay. In the current scenario, traffic size (100-500) was varied simultaneously with the node density (5, 15, 25). Yet, all nodes move in the same direction with a fixed mobility speed of 2m/s. Therefore, Gauss-Markov mobility model was created, which adapts various levels of randomness via one tuning parameter. In such type of mobility model, all nodes are allocated with an initial direction and speed at fixed time intervals [38]. The packet size was increased to 4096 bytes in the current simulation scenario. Additionally, the nodes move within the area of 1000*1000. The DSSS rate and data rate were assigned with values of 11Mbps and 2200Kbps respectively. As in the previous scenario, the simulation totally runs for 180 seconds The selected simulation parameters are demonstrated in table 4.3 below:

Table 4.3: Selected Parameters for Scenario 3

Parameters	**Values**
Number of Nodes	**5,15,25**
Wireless LAN	**IEEE 801.11b**
Simulation Area	**1000*1000**
Performance Metrics	**Throughput, Packet Delivery Fraction, Total Energy Consumption, Average End-To-End Delay**
Movement Model	**Gauss-Markov Mobility Model**
Traffic	**Constant Bit Rate (CBR)**
DSSS Rate	**11Mbps**
Simulation Time	**180 seconds**
Number of Packets	**100,200,300,400,500**
Packet Size	**4096 bytes**
Network Simulator	**NS-3**
Node Mobility Speed	**2m/s**

Routing Protocols	**AODV, OLSR**
Transmit Power	**7.5dBm**
Data Rate	**2200 Kbps**
Wi-Fi Mode	**Ad Hoc**

4.3 Performance Metrics

As noted above, the routing protocols were compared according to five performance parameters, i.e. throughput, routing overhead, average end-to-end delay, total energy consumption and packet delivery fraction.

1. Packet Delivery Ratio (PDR) – It is a performance measuring parameter, which is calculated by the ratio of the number of packets received by the destinations to the number of packets produced by the sources. The term packet delivery fraction (PDF) is also used to indicate this ratio. It ought to be outlined that higher packet delivery ratio indicates that the routing protocol has better performance or vice versa [3].

$$PDR = \frac{\Sigma\ \text{Number of packets received}}{\Sigma\ \text{Number of packets sent}} * 100$$

2. Throughput – It can be defined as the successfully transmitted data packets over the total simulation time observed. Generally, throughput is a performance metric measuring the effectiveness of a routing protocol, which is typically measured in bits/second [5].

$$Throughput = \frac{Total\ Packet\ Size\ Received * 8}{Total\ Simulation\ Time}$$

3. Average End-To-End Delay (EED) – It is another performance metric measuring the average time it takes for a data packet to be delivered to the destination node and is measured in seconds. It must be determined that a number of possible delays such as transmission delay, processing delay, propagation delay and queuing are also included in the average time for a packet to arrive at the destination. Lower end-to-end delay

indicates that the routing protocols perform better or vice versa. Mathematically, EED is calculated by the subtraction of the time at which the first packet is delivered (D_n) to the destination and the time at which the first packet is sent (S_n) by the source node. Average end-to-end delay can be calculated by dividing the achieved subtraction result to the total number of data packets received (N) by the destination node [34].

$$Average\ End - To - End\ Delay = \frac{\Sigma\ (\mathrm{Dn} - \mathrm{Sn})}{N}$$

4. Normalized Routing Overhead (NRO) – It can be defined by the ratio of the sum of the transmitting control messages to the sum of delivered data at destination and is measured in bytes. The performance of the routing protocol is considered to be higher when the routing overhead is low or vice versa. The performance metric measuring efficiency of protocols is also called normalized routing load [5].

$$Normalized\ Routing\ Overhead\ (NRO) = \frac{\Sigma\ \text{Normalized Control Packets}}{\Sigma\ \text{Data Packets Delievered}}$$

5. Total Energy Consumption – It refers to the total energy preserved by mobile devices [15].

4.4 Implementation of Routing Protocols

After determining simulation parameters and creating the simulation environment, the implementation plan of NS-3 was realized. First of all, the file "manet-routing-compare.cc" was copied and pasted into the scratch folder. This section demonstrates the basic implementation of selected routing protocols with simulation parameters discussed in the "scenario 1". It should be noted that the terminal was used in order to run the required file and obtain results. An access to the location of scratch folder was obtained through the command shown in figure 4.1.

Figure 4.1: Access to scratch folder

Following this further, the command shown in figure 4.2 was used to run the file "manet-routing-compare.cc" where the number of nodes had been set up to 50 and all the simulation parameters matched with those discussed the simulation scenario 1.

Figure 4.2: Running the file "manet-routing-compare.cc"

In this step, OLSR based network was analyzed, which was configured in the protocol based program (manet-routing-compare.cc). As a result, the output shown in figure 4.3 appeared in the terminal.

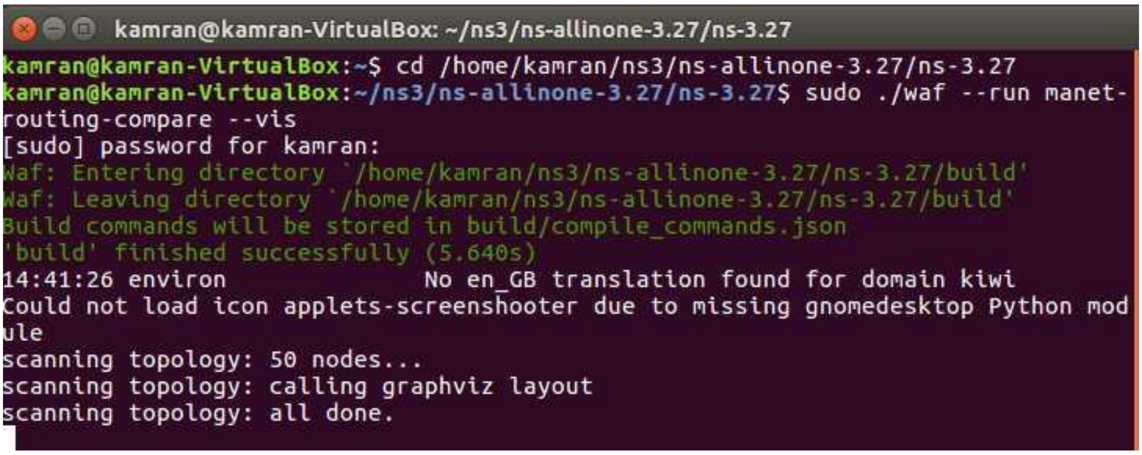


Figure 4.3: Output from running MANET Network

The graphical setup for the OLSR based network with 50 nodes is demonstrated in figure 4.4, which was captured as a result of executing the commands shown above.

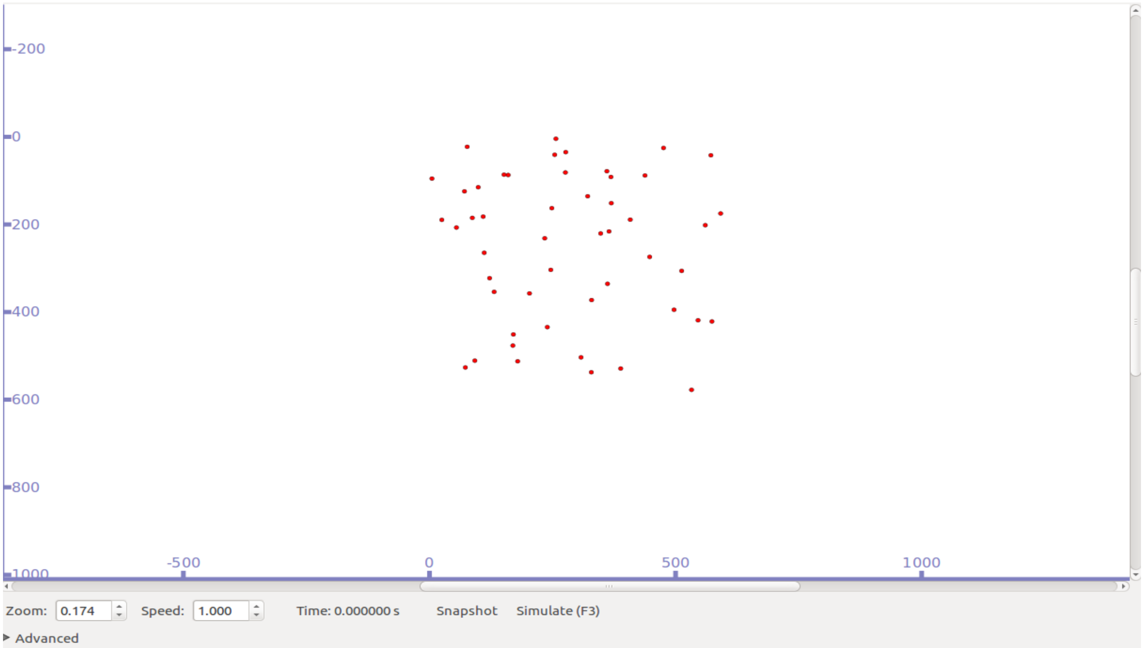


Figure 4.4: Graphical Network Setup of OLSR for 50 nodes

Hence, the network was simulated for 200 seconds that is shown in figure 4.5.

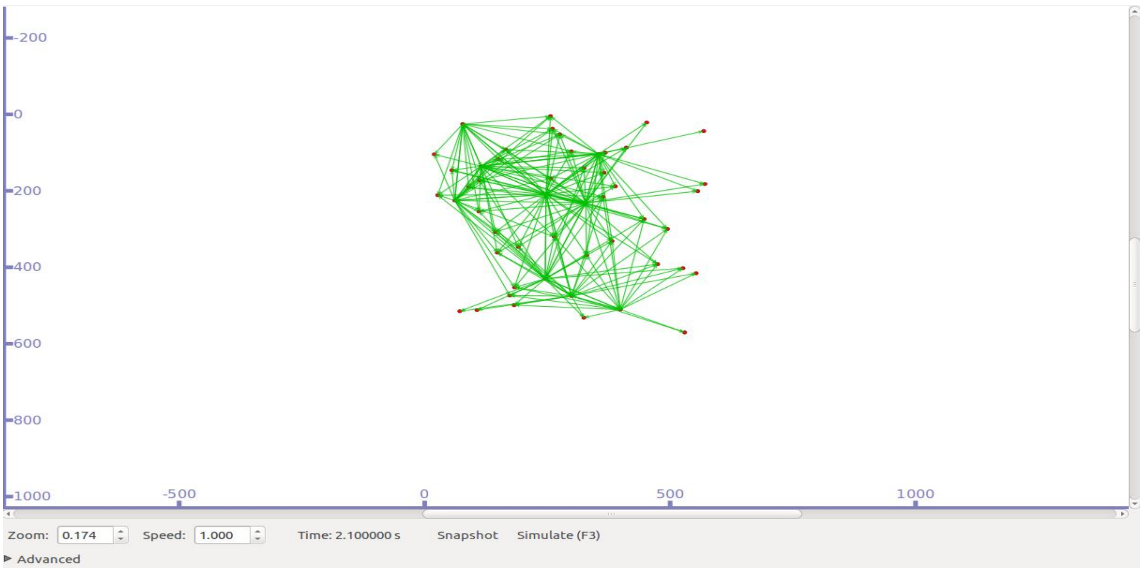


Figure 4.5: Packet transmissions in OLSR routing protocol

Following this further, AODV protocol was run by changing "m_protocol (1)" to "m_protocol (2)" in the "manet-routing-compare" file. The graphical setup for the AODV based network with 50 nodes and same simulation parameters as in the OLSR case is demonstrated in figure 4.6.

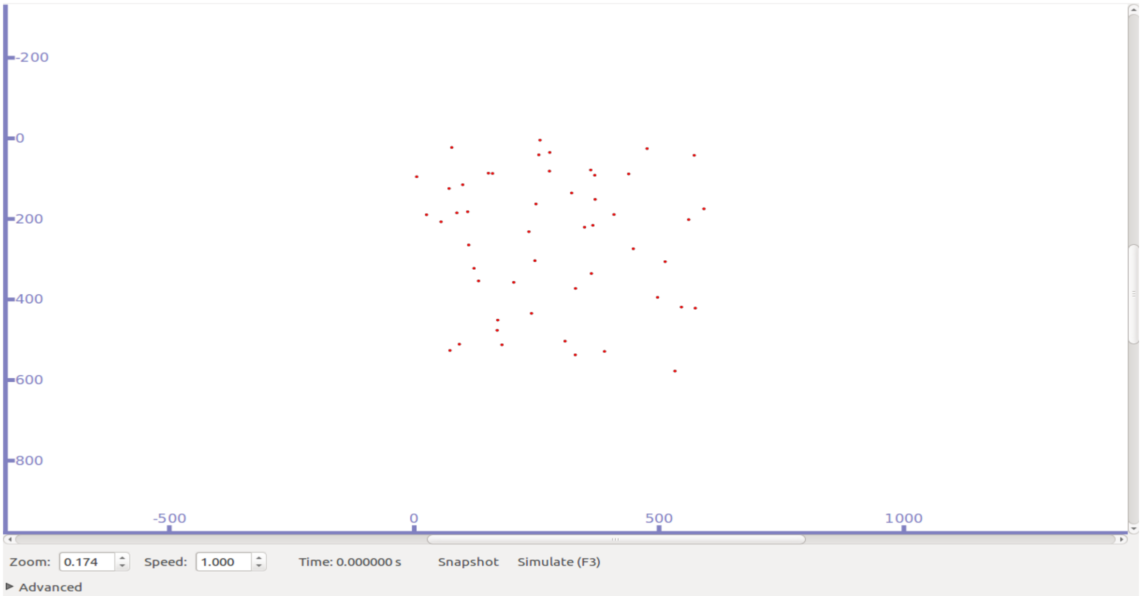


Figure 4.6: Graphical Network Setup of AODV for 50 nodes

As in previous case, the simulation was run for 200 seconds that is demonstrated in figure 4.7.

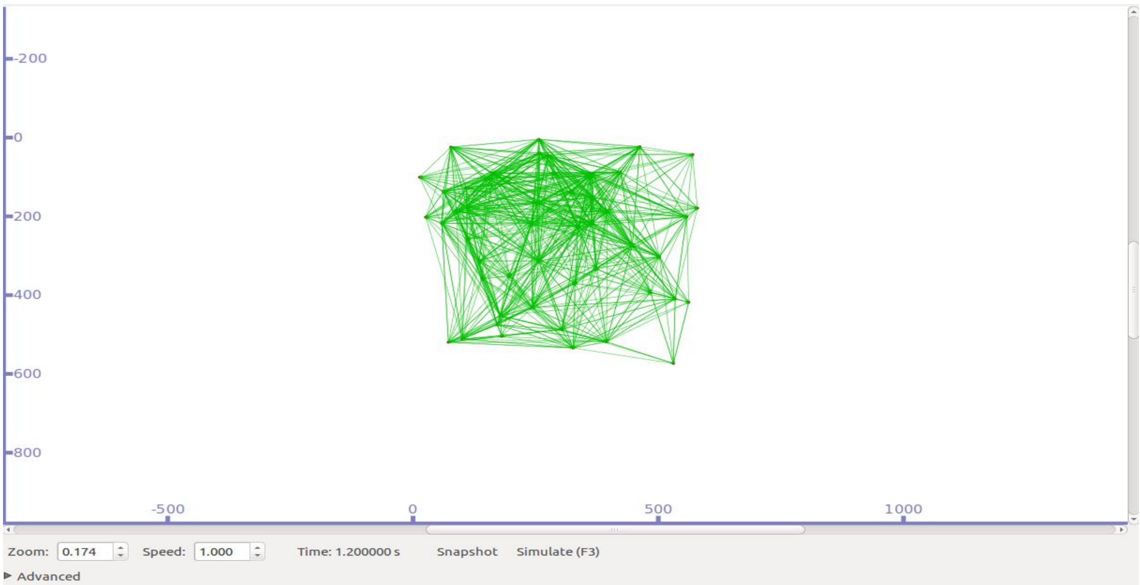


Figure 4.7: Packet Transmissions in AODV routing protocol

This section demonstrated the implementation of routing protocols to achieve results with the most basic simulation parameters discussed in “Scenario 1” part above where the number of nodes had been set up to 50. The same process was repeated by using 15 and 25 nodes as well as setting up the simulation parameters as in “Scenario 2” and “Scenario 3”. It should be pointed out that all the simulation parameters could be modified from the “manet-routing-compare.cc” file in NS-3. It includes the code written in C++ script where several parameters have been assigned with initial values (e.g. number of nodes equal 50). As a result, the values of various measuring parameters in different simulation scenarios were achieved, which will be clearly demonstrated in the next chapter.

Chapter 5

Experimental Results

This section demonstrates the values of various performance metrics of AODV and OLSR routing protocols in all three scenarios, which were achieved through NS-3.

Scenario 1 Results:

As discussed in chapter 4, in the first scenario the routing protocols were compared in regard to routing overhead, throughput, packet delivery fraction and average end-to-end delay by varying the node density. Table 5.1 demonstrates PDR results of AODV and OLSR when the number of nodes is set up to 15, 25 and 50. According to table 5.1, it can be observed that AODV outperforms OLSR in all cases, which indicates that AODV has higher communication reliability. The PDR value of both protocols climbs with the rise in the number of nodes. AODV reaches its maximum 100% in terms of PDR when nodes are 50, while OLSR reaches 80% in the same scenario. It must be determined that the values of packet delivery ratio, throughput and delay are rounded to whole numbers; however, throughput values are provided in fractions as they are too small.

Packet Delivery Ratio (%)		
Number of Nodes	**AODV**	**OLSR**
15	80	52
25	87	56
50	100	80

Table 5.1: PDR vs. Number of Nodes

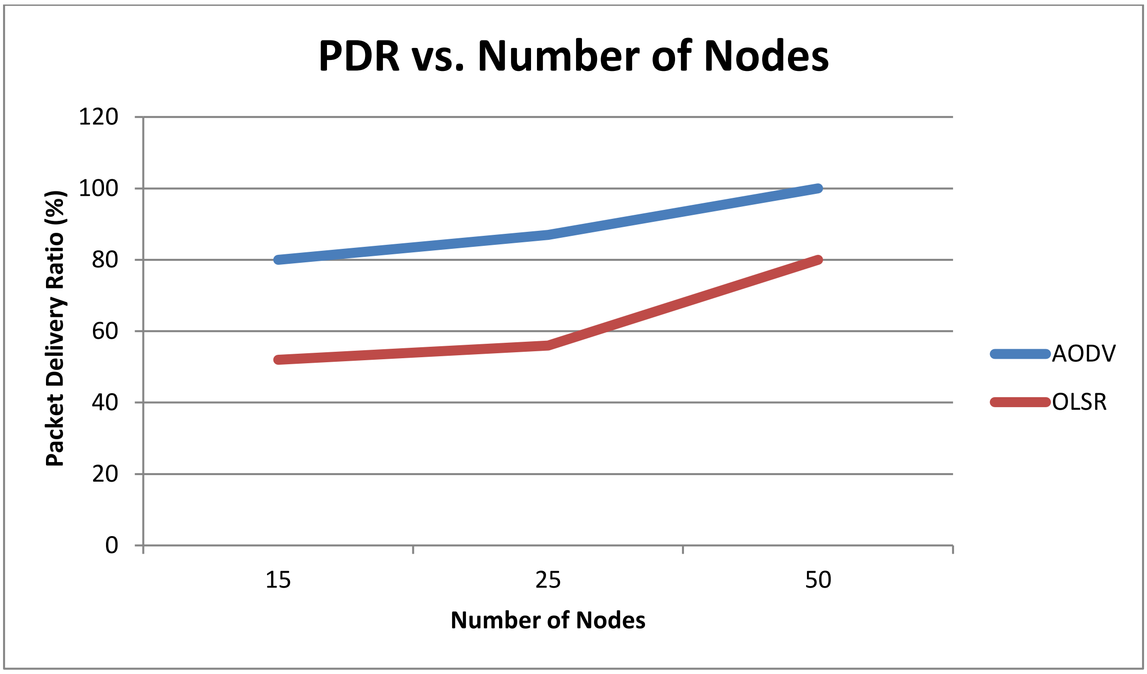


Figure 5.1: PDR vs. Number of Nodes

Furthermore, table 5.2 and figure 5.2 clearly show average end-to-end delay for both protocols with the network size of 15, 25 and 50 nodes respectively. Expectedly, OLSR outperforms AODV with less delay in all cases as the information in routing table is regularly updated in proactive routing protocols, which automatically minimizes delay. It is clear-cut evidence that delay of both protocols increases sharply with the extension in the network size.

Average End-To-End Delay (sec)		
Number of Nodes	**AODV**	**OLSR**
15	105	70
25	125	100
50	190	160

Table 5.2: Average EED vs. Number of Nodes

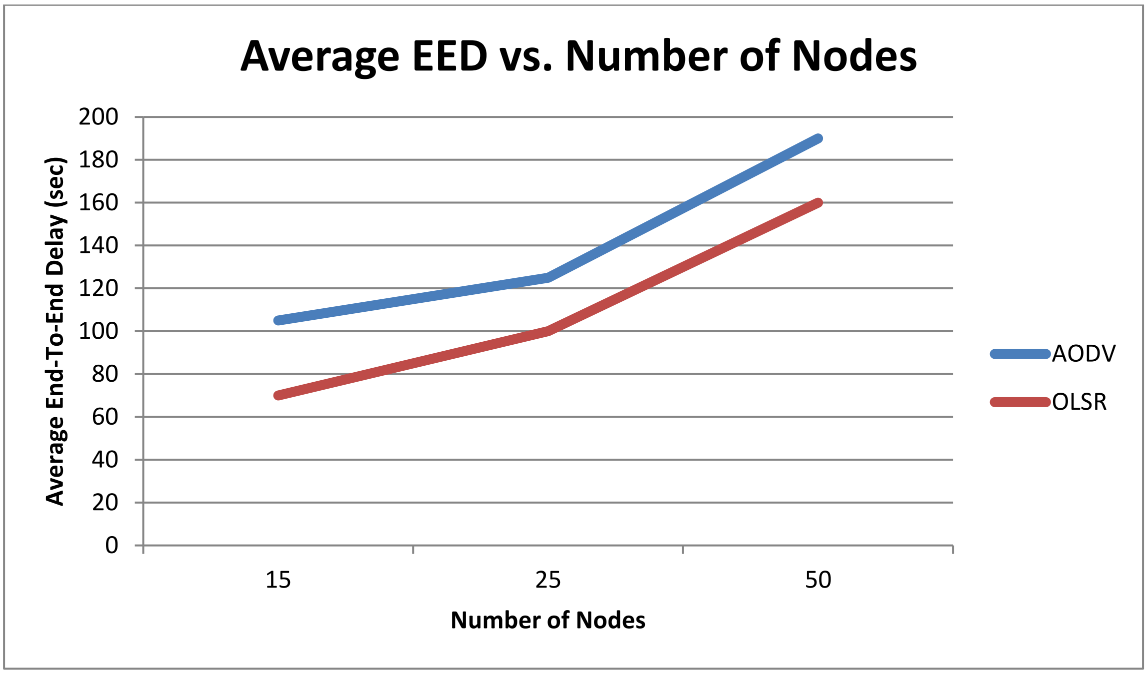


Figure 5.2: Average EED vs. Number of Nodes

According to table 5.3, AODV outperforms OLSR in all node variations as it has lower routing overhead. This is due to the fact that all routes are defined before packet transmissions in table-driven routing protocols, yet they are created upon demand in reactive routing protocols. Normalized routing overhead of both protocols rises when the number of nodes is set up to 25, yet it decreases steadily with network size of 50 nodes. It can be observed that OLSR has its best performance with the least number of nodes, whereas the best performance of AODV matches with the highest number of nodes, which supports the argument that reactive routing protocols are useful for large-size networks.

Normalized Routing Overhead (bytes)		
Number of Nodes	**AODV**	**OLSR**
15	0.52	1.14
25	0.7	1.39
50	0.5	1.35

Table 5.3: NRO vs. Number of Nodes

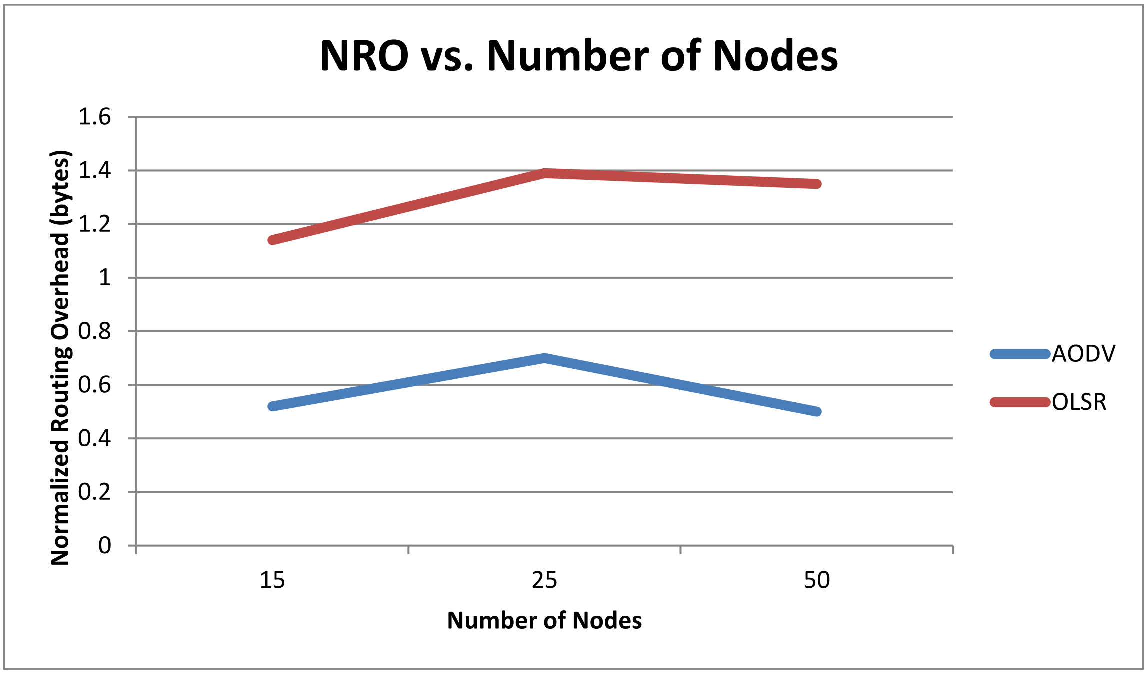


Figure 5.3: NRO vs. Number of Nodes

As has been mentioned before, throughput refers to the successfully transmitted data packets over the total simulation time observed. In our simulation scenario, throughput is compared at DSSS rate of 11Mbps. Table 5.4 shows that AODV is more effective than OLSR because it appears to have higher throughput in every case. Figure 5.4 clearly demonstrates that throughput of both protocols increases steadily when the network size becomes larger.

Throughput (Kbps)		
Number of Nodes	**AODV**	**OLSR**
15	215	172
25	250	218
50	305	225

Table 5.4: Throughput vs. Number of Nodes

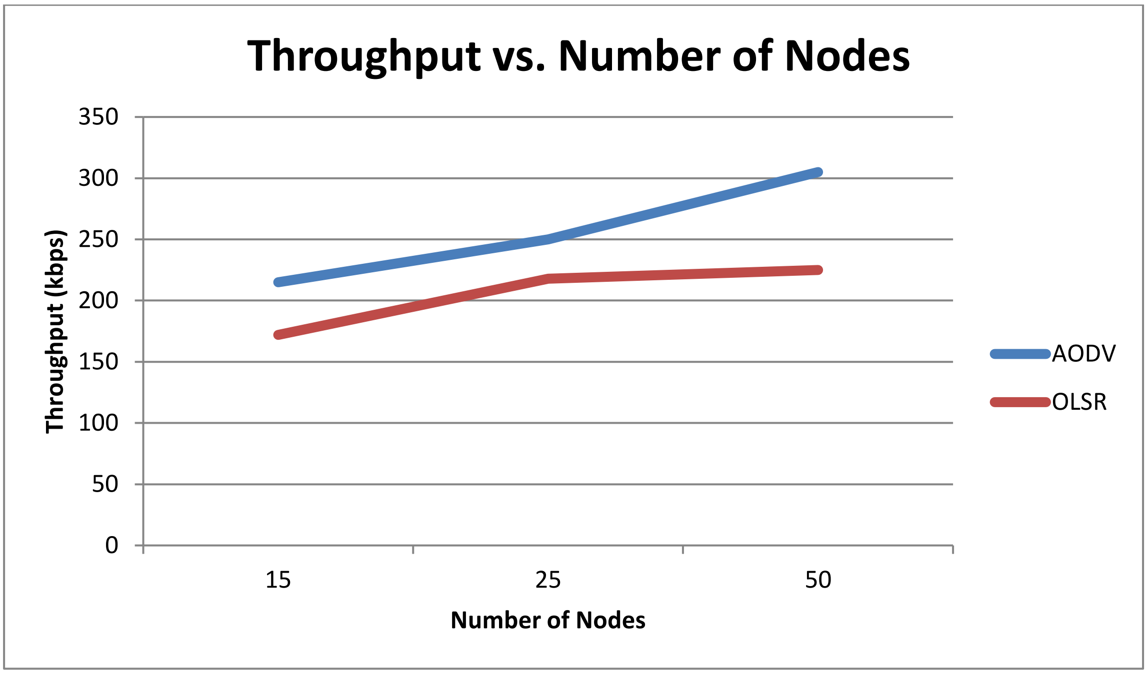


Figure 5.4: Throughput vs. Number of Nodes

Scenario 2 Results:

In the second scenario, the routing protocols were examined with regard to throughout, average end-to-end delay, total energy consumption and packet delivery ratio a by varying both node density (10, 30, 50) and mobility speed (10, 20, 30, 40, 50). As in the previous section, the values of packet delivery fraction and throughput are rounded to whole numbers, yet total energy consumption and delay results are provided in decimal numbers as they are quite small. This pattern is also applicable to the next scenario. According to table 5.5, OLSR shows maximum performance with PDR of 100% and outperforms AODV in all cases. However, AODV also shows a good performance with the PDR value around 95% and has quite reliable communication. There can be observed steady fluctuations in the PDR value of AODV with the increase in the speed.

Packet Delivery Ratio (%) – 10 Nodes		
Speed (m/s)	**AODV**	**OLSR**
10	96	100
20	94	100
30	95	100

40	95	100
50	93	100

Table 5.5: PDR vs. Speed with Network Size of 10 Nodes

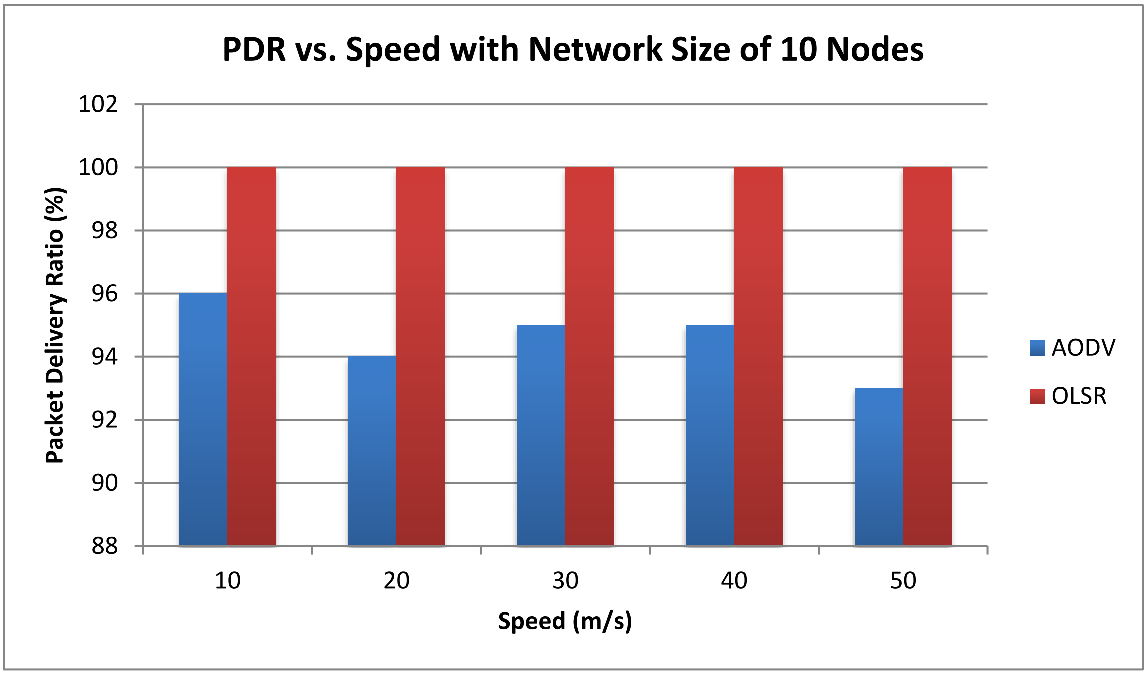


Figure 5.5: PDR vs. Speed with Network Size of 10 Nodes

As can be seen from the table 5.6 below, the communication reliability of AODV protocols decreases sharply when the network size becomes larger. More precisely, the PDR value of AODV is degraded to around 60% for all speed variations when the number of nodes is set to 30. Besides, OLSR remains its maximum performance with 100% PDR.

Packet Delivery Ratio (%) – 30 Nodes		
Speed (m/s)	**AODV**	**OLSR**
10	61	100
20	59	100
30	59	100
40	60	100
50	58	100

Table 5.6: PDR vs. Speed with Network Size of 30 Nodes

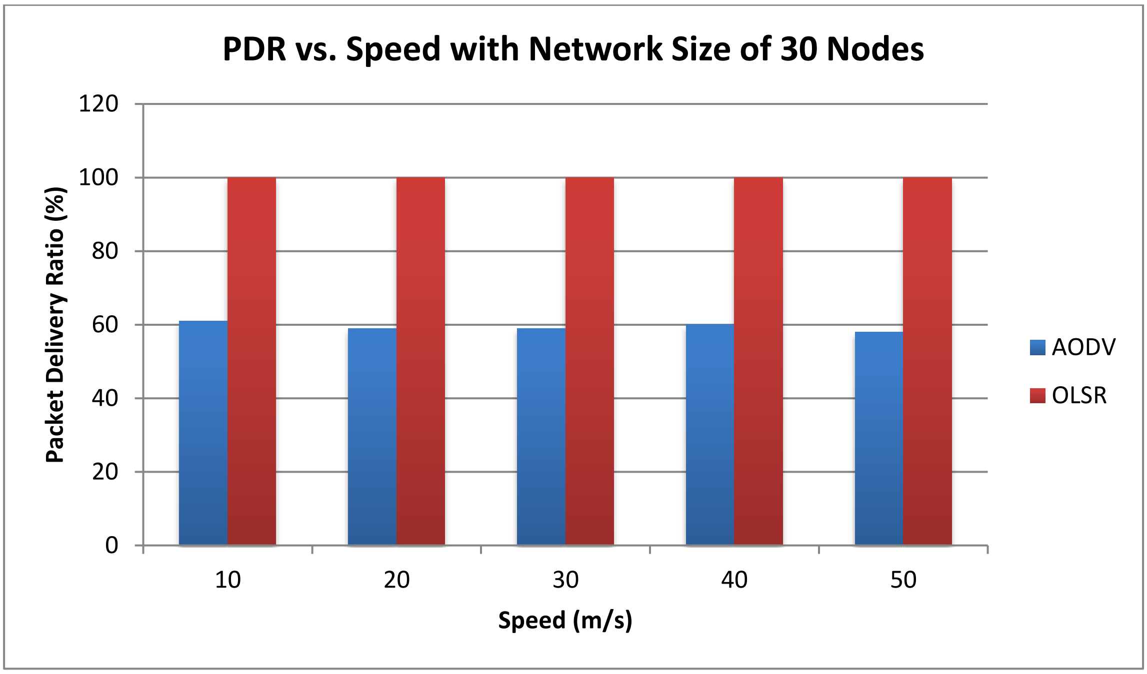


Figure 5.6: PDR vs. Speed with Network Size of 30 Nodes

Although OLSR continues to remain its performance, AODV performs much worse with the extension in the network size. To be more specific, it has now twice less communication reliability with approximately 24-30% PDR in comparison to the case discussed above. As illustrated in table 5.7, the increase in the node speed also affects AODV performance negatively.

Packet Delivery Ratio (%) – 50 Nodes		
Speed (m/s)	**AODV**	**OLSR**
10	30	100
20	29	100
30	27	100
40	26	100
50	24	100

Table 5.7: PDR vs. Speed with Network Size of 50 Nodes

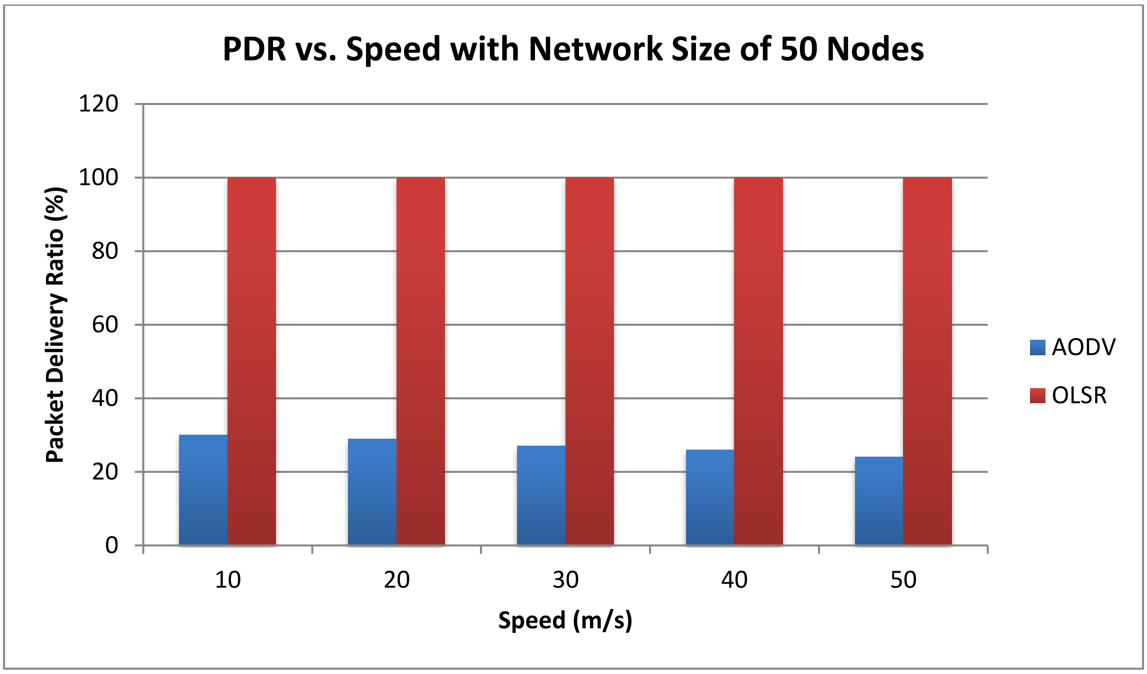


Figure 5.7: PDR vs. Speed with Network Size of 50 Nodes

Additionally, table 5.8 provides the differences between AODV and OLSR with respect to average end-to-end delay where the mobility speed is varied and the number of nodes is set up to 10. Expectedly, OLSR outperforms AODV that has average delay of 0.006 seconds.

Average End-To-End Delay (sec) - 10 Nodes		
Speed (m/s)	**AODV**	**OLSR**
10	0.017	0.006
20	0.017	0.006
30	0.016	0.006
40	0.017	0.006
50	0.018	0.006

Table 5.8: Average EED vs. Speed with Network Size of 10 Nodes

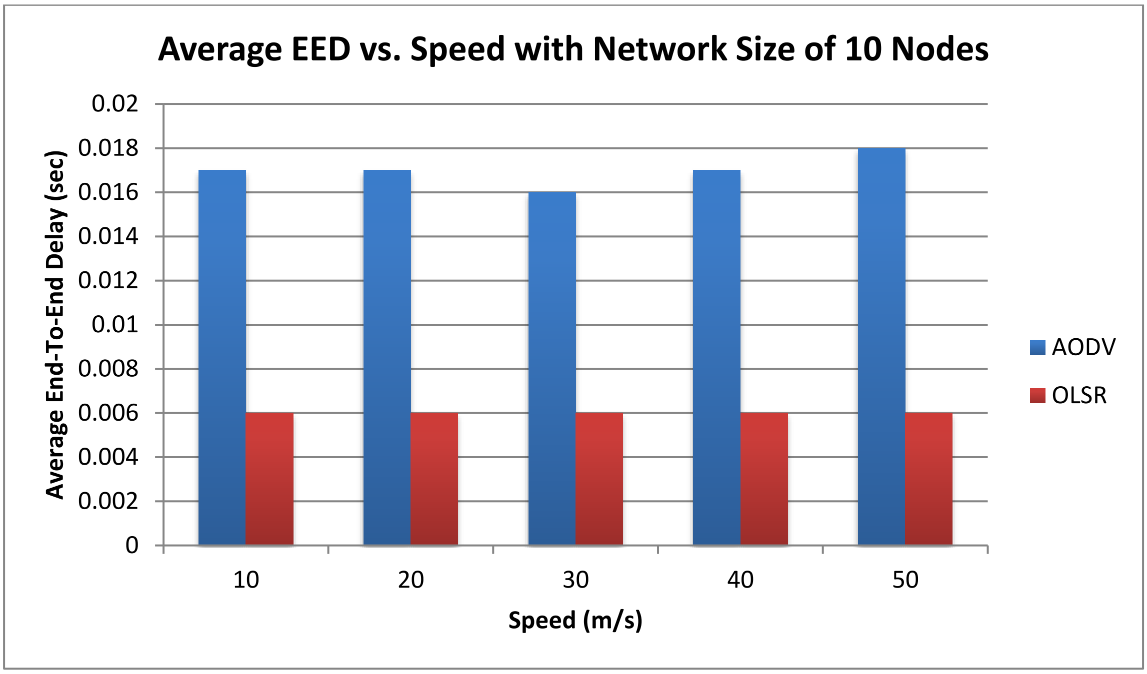


Figure 5.8: Average EED vs. Speed with Network Size of 10 Nodes

Table 5.9 presents how the average delay of AODV jumps significantly when the number of nodes is 30. Yet, the OLSR protocol appears to have almost zero delay with all speed diversities. This is due to its proactive nature that periodically maintains routes to all destination nodes.

Average End-To-End Delay (sec) - 30 Nodes		
Speed (m/s)	**AODV**	**OLSR**
10	3.8	0.001
20	4.1	0.001
30	3.9	0.001
40	3.9	0.001
50	4.1	0.001

Table 5.9: Average EED vs. Speed with Network Size of 30 Nodes

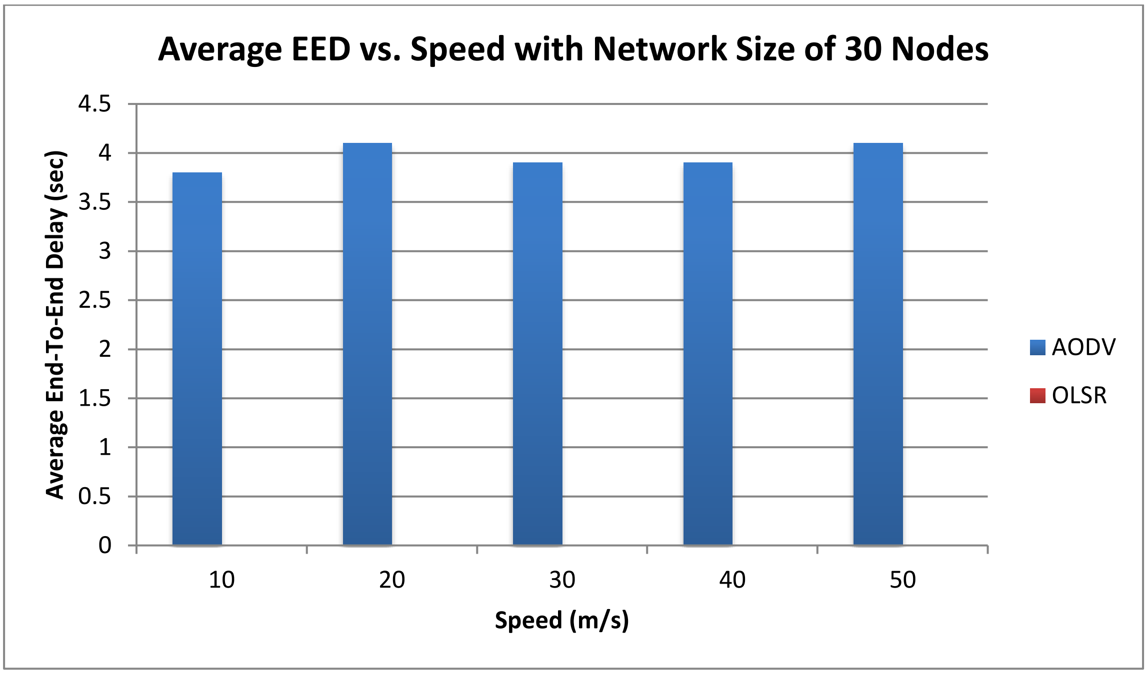


Figure 5.9: Average EED vs. Speed with Network Size of 30 Nodes

As illustrated in table 5.10, the average end-to-end delay of AODV climbs gradually when the network size extends, while OLSR continues performing with the minimum delay.

Average End-To-End Delay (sec) - 50 Nodes		
Speed (m/s)	**AODV**	**OLSR**
10	4.1	0.0002
20	5.2	0.0002
30	5.4	0.0002
40	5.6	0.0002
50	5.8	0.0002

Table 5.10: Average EED vs. Speed with Network Size of 50 Nodes

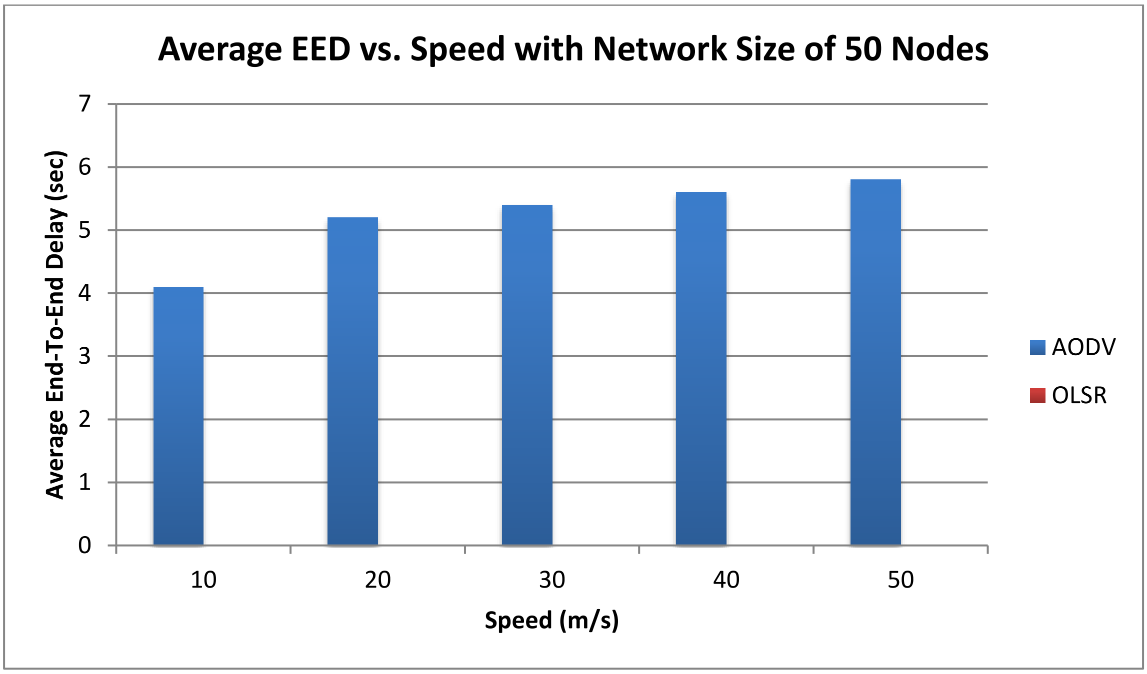


Figure 5.10: Average EED vs. Speed with Network Size of 50 Nodes

Furthermore, OLSR outperforms AODV by minor differences in terms of throughput in all cases. Table 5.11 illustrates throughput of both protocols with all selected speed varieties and 10 nodes.

Throughput (kbps) - 10 Nodes		
Speed (m/s)	**AODV**	**OLSR**
10	59	61
20	58	61
30	58	61
40	58	61
50	57	61

Table 5.11: Throughput vs. Speed with Network Size of 10 Nodes

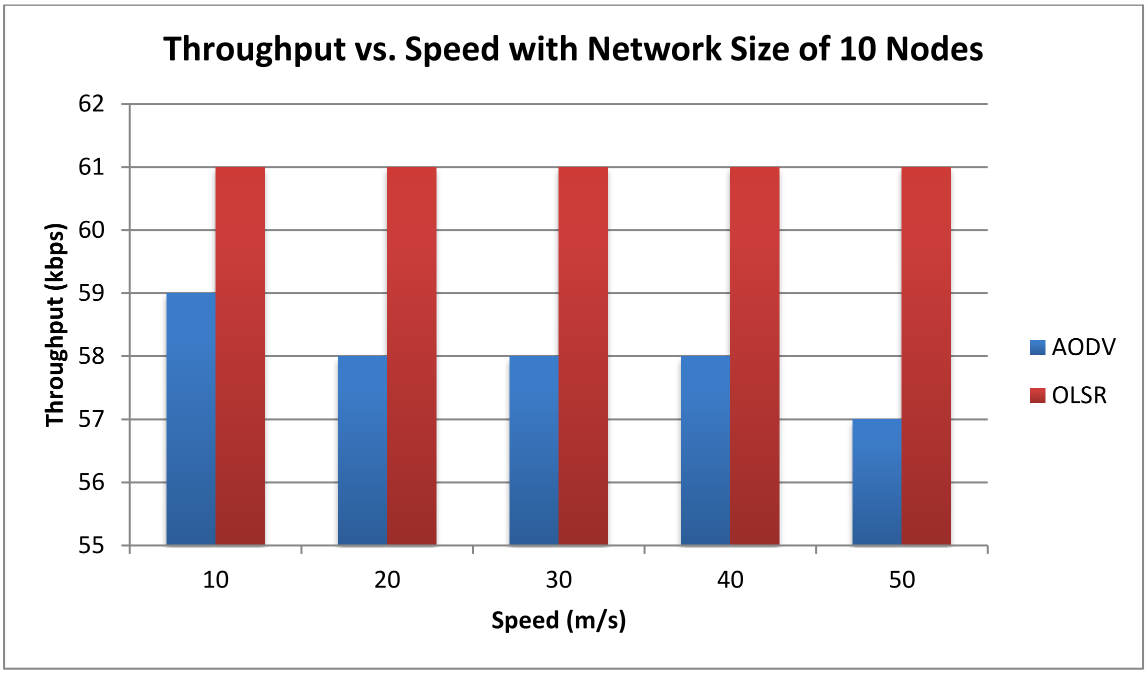


Figure 5.11: Throughput vs. Speed with Network Size of 10 Nodes

There can be observed significant increase in the throughput of both protocols as a result of varying the node density. AODV has throughput value above 100 Kbps, while OLSR reaches 200 kbps. As in the previous case, AODV is more influenced by the variance in the node speed.

Throughput (kbps) - 30 Nodes		
Speed (m/s)	**AODV**	**OLSR**
10	119	200
20	110	200
30	115	200
40	115	200
50	115	200

Table 5.12: Throughput vs. Speed with Network Size of 30 Nodes

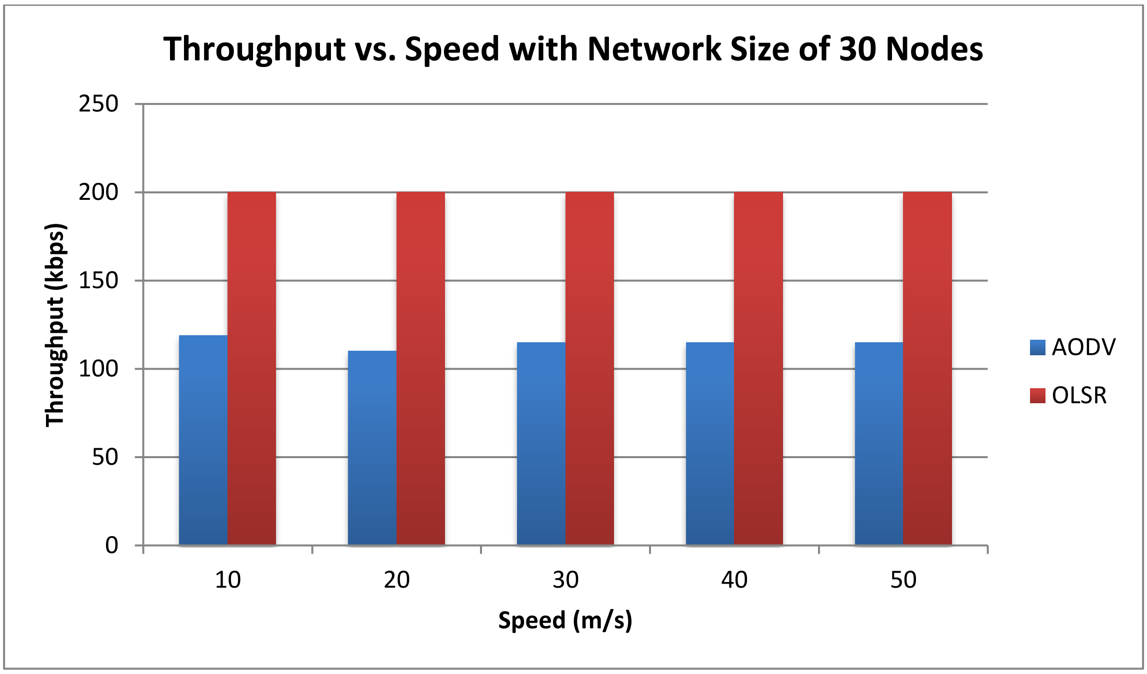


Figure 5.12: Throughput vs. Speed with Network Size of 30 Nodes

Surprisingly, throughput value of AODV decreases steadily when the network size expands to 50 nodes. However, the performance of OLSR boosts and the throughput appears to be above 300 Kbps.

Throughput (kbps) - 50 Nodes		
Speed (m/s)	**AODV**	**OLSR**
10	100	335
20	96	335
30	90	335
40	82	335
50	80	335

Table 5.13: Throughput vs. Speed with Network Size of 50 Nodes

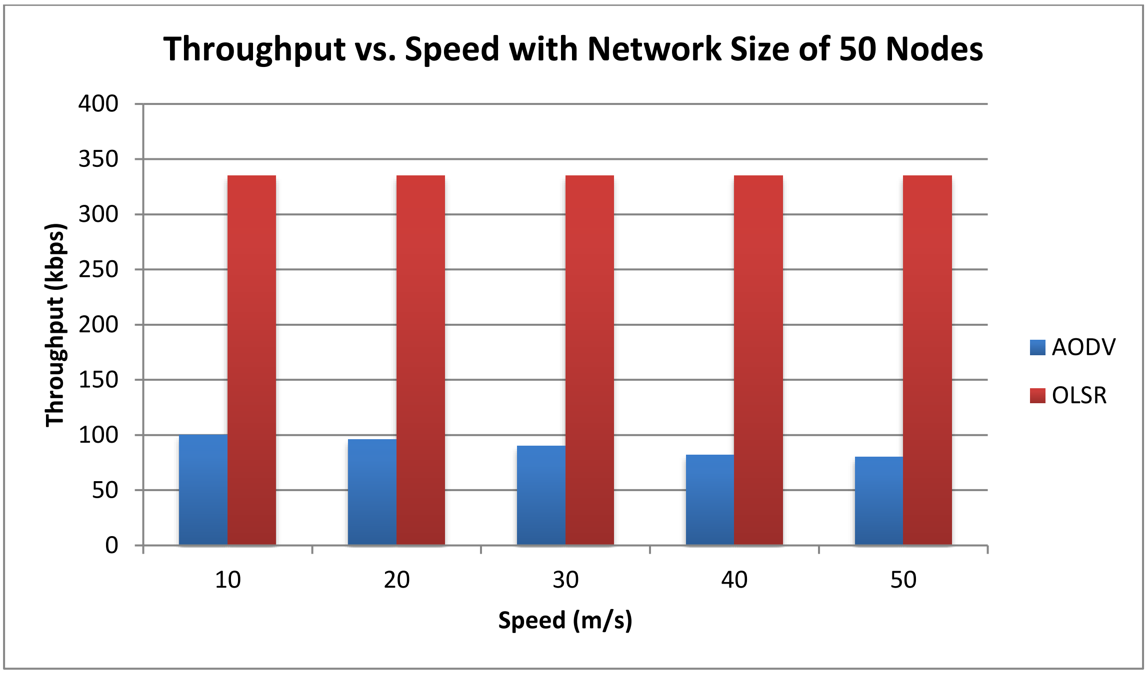


Figure 5.13: Throughput vs. Speed with Network Size of 50 Nodes

Total energy consumption is a significant factor that is considered in this scenario instead of routing overhead. As illustrated in tables 14-16, OLSR consumes less energy than AODV regardless the node density and mobility speed. Larger network size indicates that both protocols will consume more energy.

Total Energy Consumption (J) - 10 Nodes		
Speed (m/s)	**AODV**	**OLSR**
10	0.56	0.32
20	0.55	0.32
30	0.54	0.32
40	0.55	0.32
50	0.55	0.32

Table 5.14: Total Energy Consumption vs. Speed with Network Size of 10 Nodes

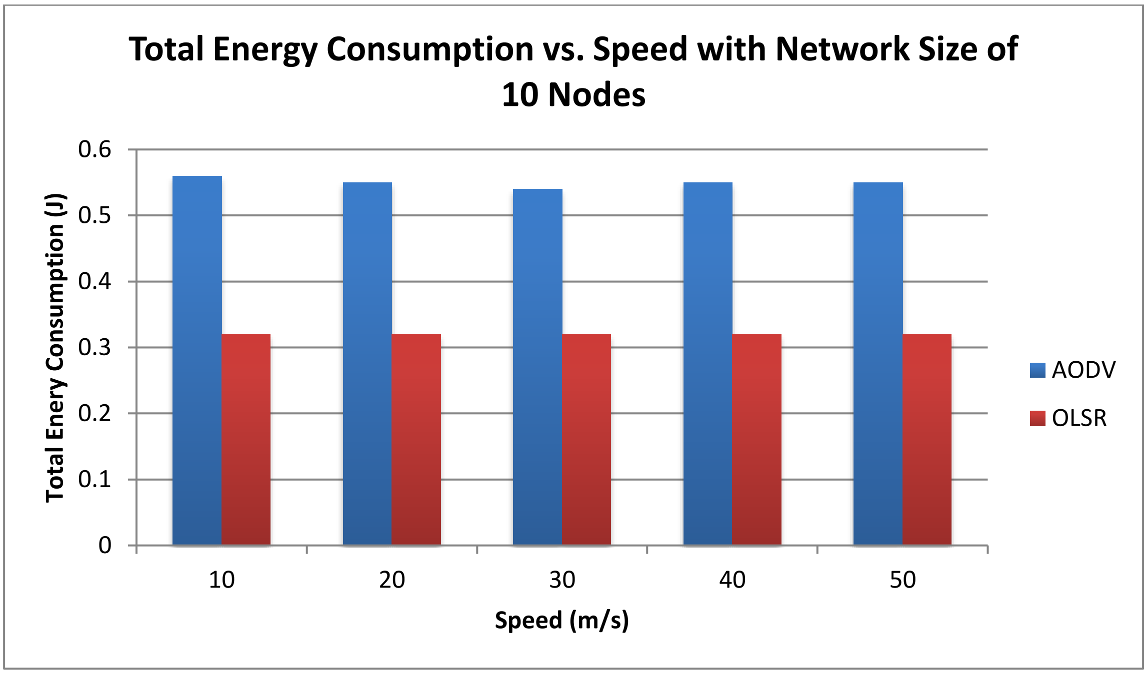


Figure 5.14: Total Energy Consumption vs. Speed with Network Size of 10 Nodes

Total Energy Consumption (J) - 30 Nodes		
Speed (m/s)	**AODV**	**OLSR**
10	2.05	0.5
20	2.03	0.5
30	2.01	0.5
40	2.03	0.5
50	2.09	0.5

Table 5.15: Total Energy Consumption vs. Speed with Network Size of 30 Nodes

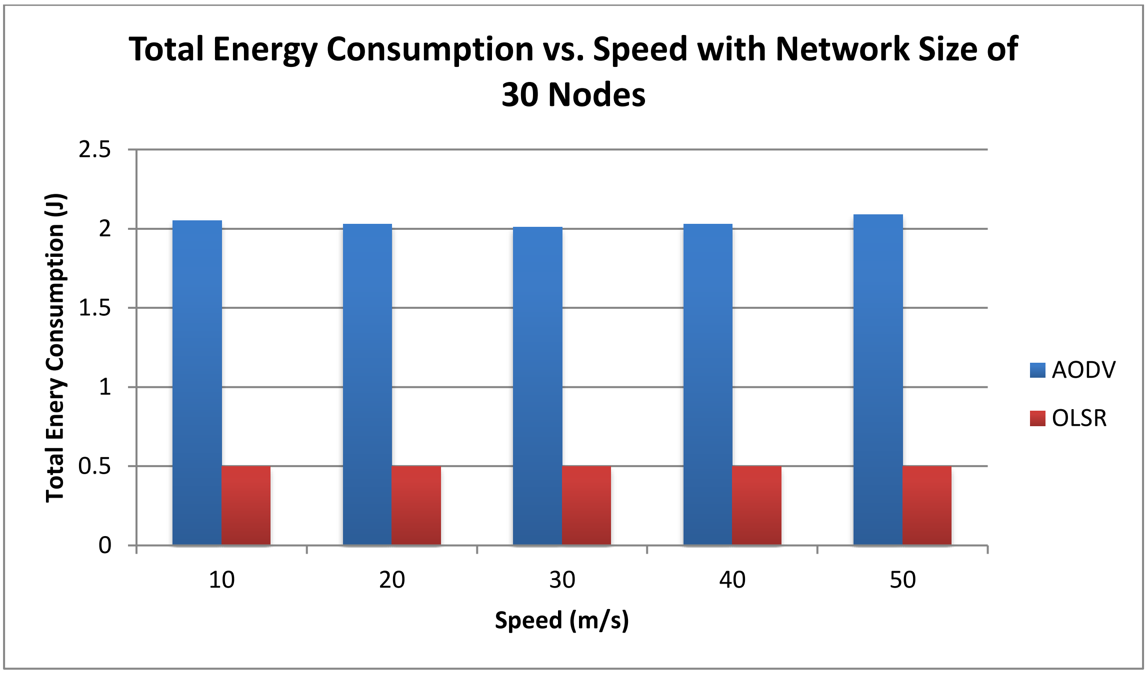


Figure 5.15: Total Energy Consumption vs. Speed with Network Size of 30 Nodes

Total Energy Consumption (J) - 50 Nodes		
Speed (m/s)	**AODV**	**OLSR**
10	2.11	0.8
20	2.2	0.8
30	2.19	0.8
40	2.23	0.8
50	2.2	0.8

Table 5.16: Total Energy Consumption vs. Speed with Network Size of 50 Nodes

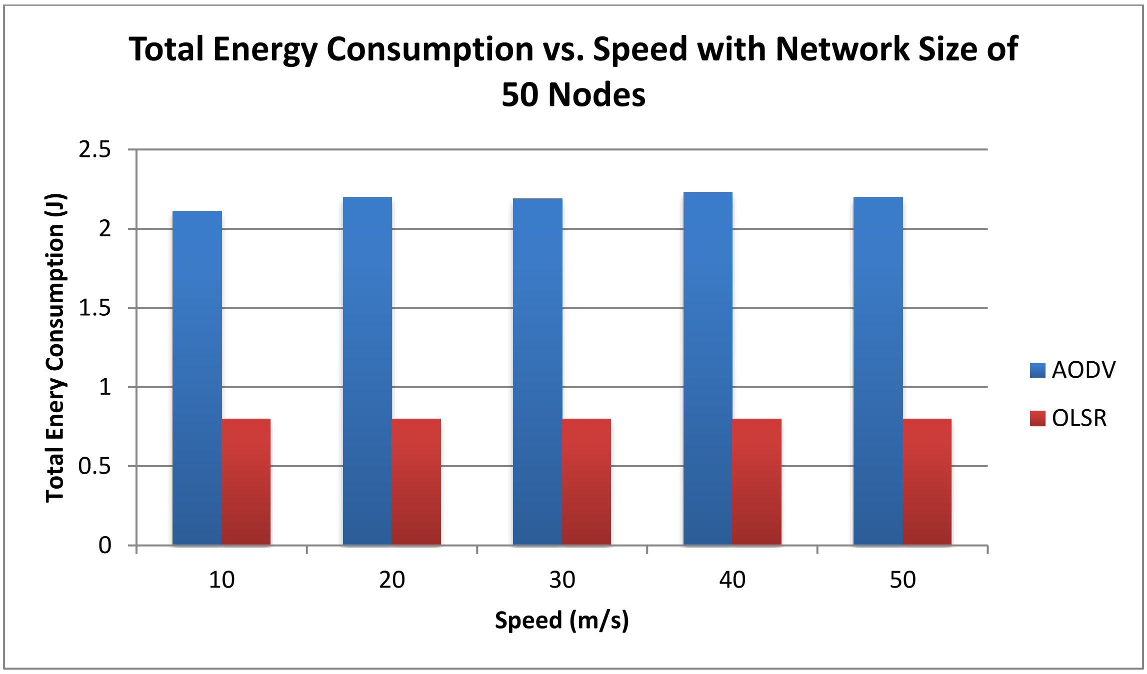


Figure 5.16: Total Energy Consumption vs. Speed with Network Size of 50 Nodes

Scenario 3 Results:

In the third scenario the performance of routing protocols was analyzed by altering node density (5, 15, 25) and the number of packets (100,200,300,400,500). Table 5.17-5.19 illustrate that AODV outperforms OLSR with respect to packet delivery ratio only with network size of 5 nodes at 100, 200 and 400 packets. Contradictorily, OLSR appears to perform better with the rest node and packet combinations. The PDR value of both AODV and OLSR fluctuates when the number of packets changes. Both AODV and OLSR show their best performance with the network size 5 nodes at 100 and 500 packets respectively by around 82% PDR. AODV performance degrades significantly at each time when the size of network becomes larger. The PDR value of OLSR decreases slightly with the extension in the network size when compared to AODV.

Packet Delivery Ratio (%) – 5 Nodes		
Number of Packets	**AODV**	**OLSR**
100	82	81
200	81	80

300	80	81
400	81	80
500	81	82

Table 5.17: PDR vs. Number of Packets with Network Size of 5 Nodes

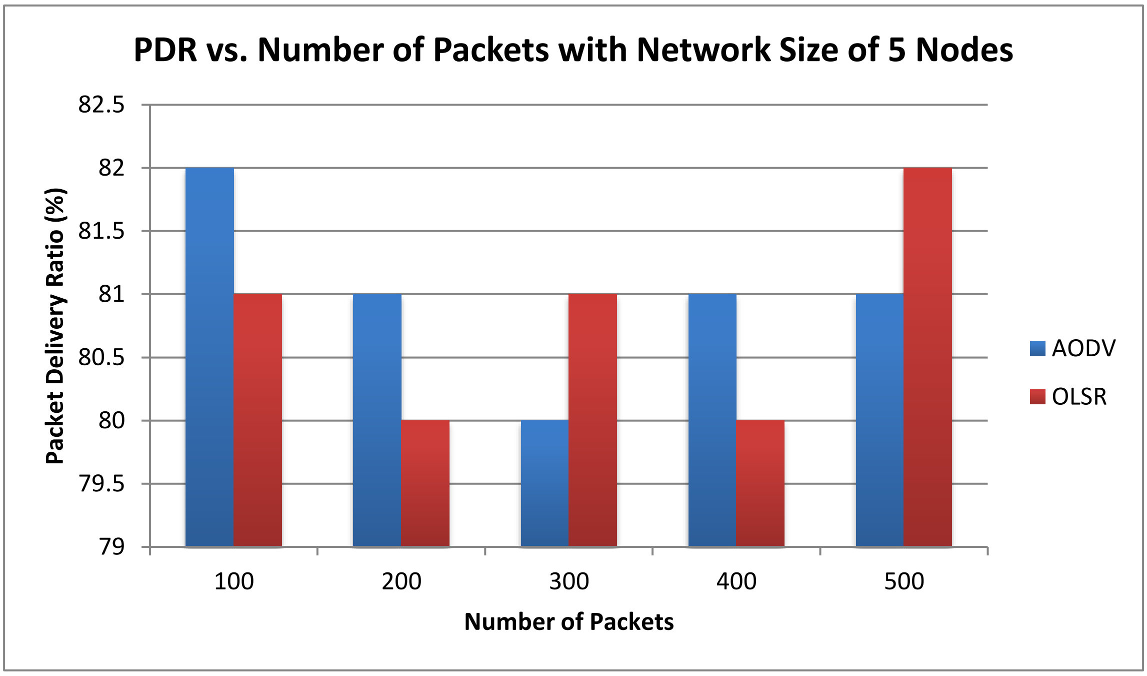


Figure 5.17: PDR vs. Number of Packets with Network Size of 5 Nodes

Packet Delivery Ratio (%) – 15 Nodes		
Number of Packets	**AODV**	**OLSR**
100	52	79
200	47	80
300	46	79
400	44	79
500	46	79

Table 5.18: PDR vs. Number of Packets with Network Size of 15 Nodes

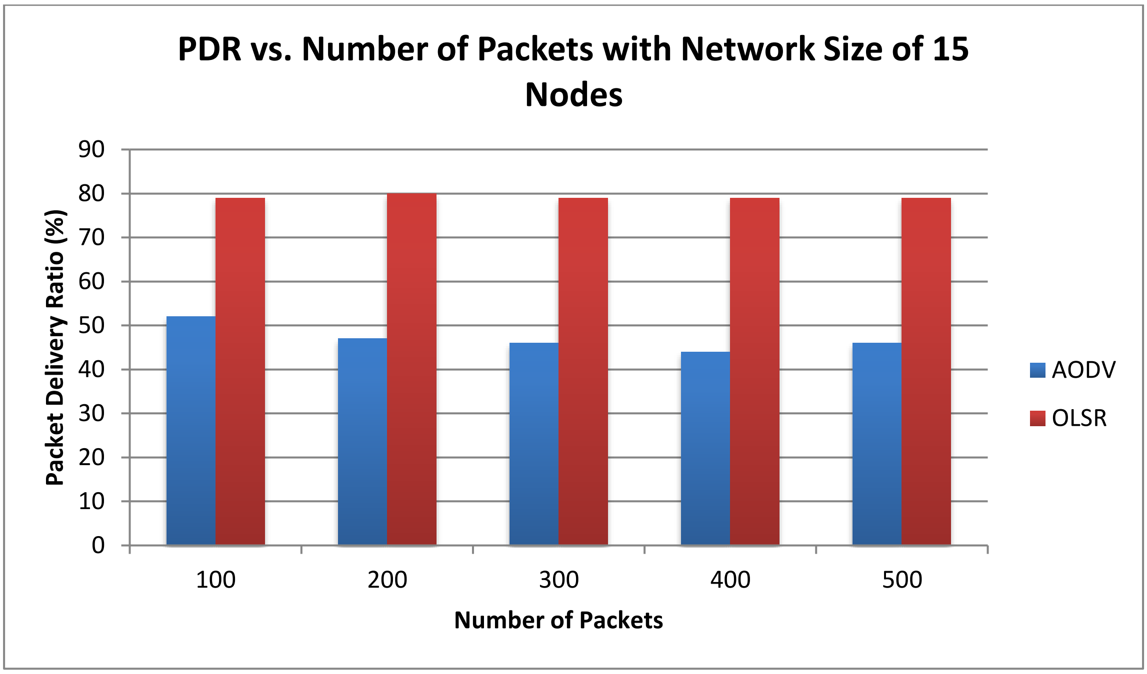


Figure 5.18: PDR vs. Number of Packets with Network Size of 15 Nodes

Packet Delivery Ratio (%) – 25 Nodes		
Number of Packets	**AODV**	**OLSR**
100	36	76
200	39	76
300	37	76
400	38	76
500	37	76

Table 5.19: PDR vs. Number of Packets with Network Size of 25 Nodes

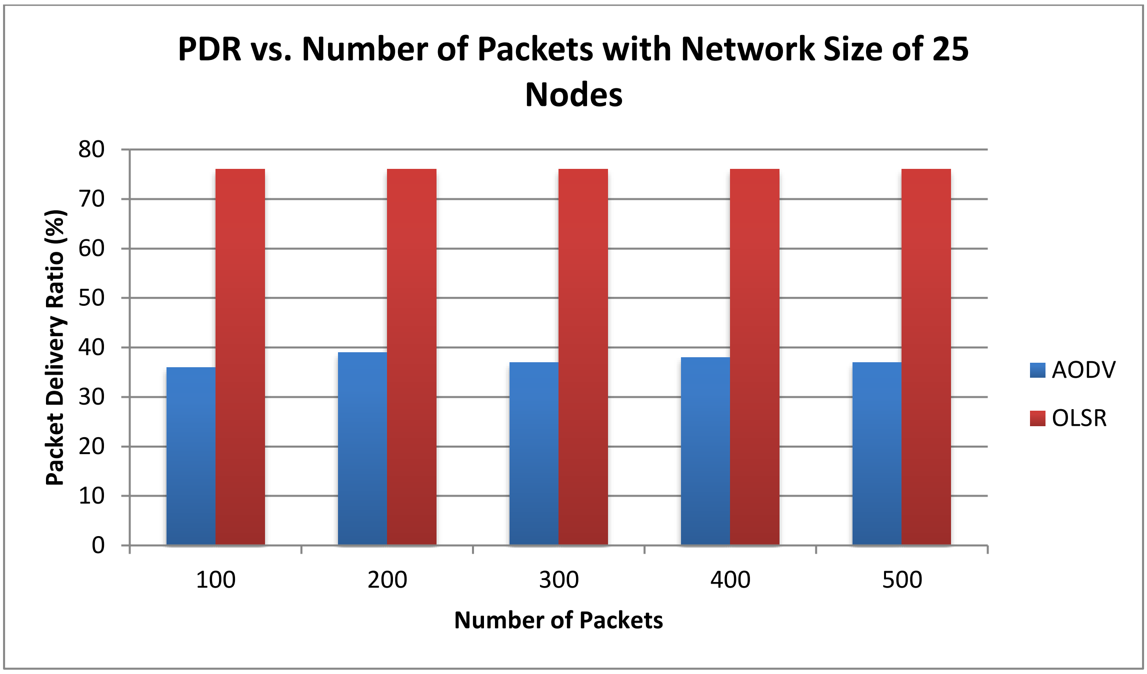


Figure 5.19: PDR vs. Number of Packets with Network Size of 25 Nodes

Tables 5.20-5.22 provide the differences between OLSR and AODV regarding average end-to-end delay. As expected, OLSR outperforms AODV in all variations due to its nature. Delay of OLSR decreases to almost minimum with the extension in the network size, yet AODV appears to perform with more delay when the number of nodes rises. It can be observed that AODV is positively affected by the growth in the traffic size at network size of 5 nodes, yet the increase in the number of packets results with rise in delay when the number of nodes is 15 and 25.

Average End-To-End Delay (sec) – 5 Nodes		
Number of Packets	**AODV**	**OLSR**
100	0.0044	0.0032
200	0.0038	0.0032
300	0.0036	0.0032
400	0.0035	0.0032
500	0.0034	0.0032

Table 5.20: Average EED vs. Number of Packets with Network Size of 5 Nodes

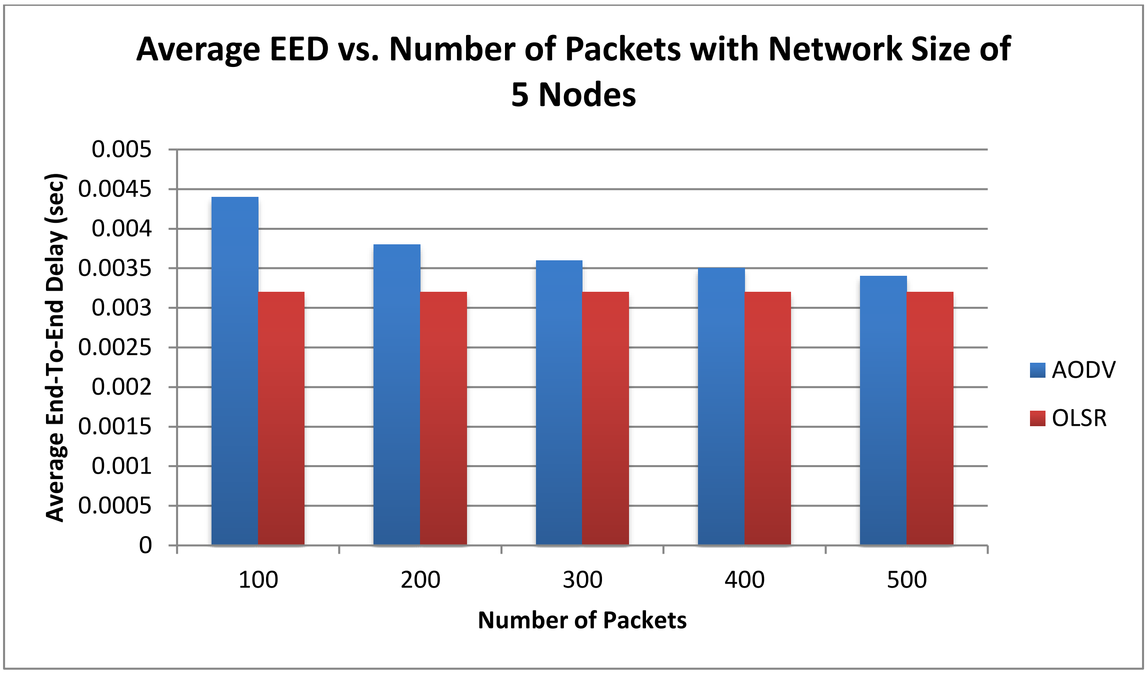


Figure 5.20: Average EED vs. Number of Packets with Network Size of 5 Nodes

Average End-To-End Delay (sec) – 15 Nodes		
Number of Packets	**AODV**	**OLSR**
100	0.24	0.002
200	0.32	0.002
300	0.4	0.002
400	0.42	0.002
500	0.52	0.002

Table 5.21: Average EED vs. Number of Packets with Network Size of 15 Nodes

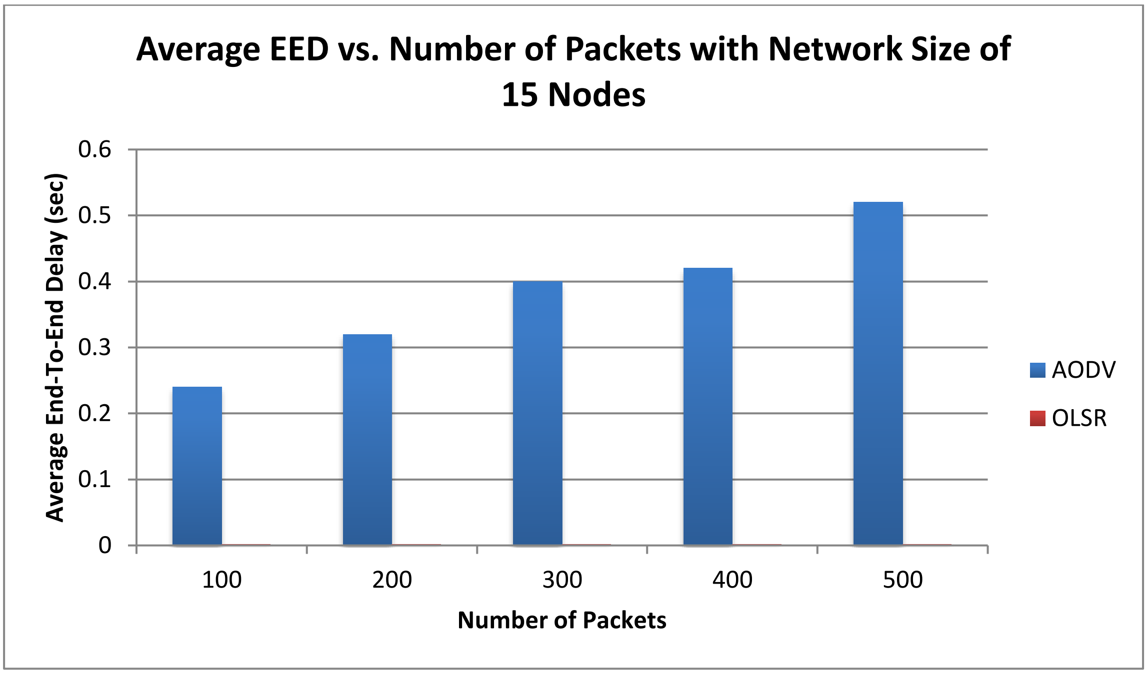


Figure 5.21: Average EED vs. Number of Packets with Network Size of 15 Nodes

Average End-To-End Delay (sec) – 25 Nodes		
Number of Packets	**AODV**	**OLSR**
100	0.28	0.0003
200	0.67	0.0003
300	0.88	0.0003
400	1.21	0.0003
500	1.36	0.0003

Table 5.22: Average EED vs. Number of Packets with Network Size of 25 Nodes

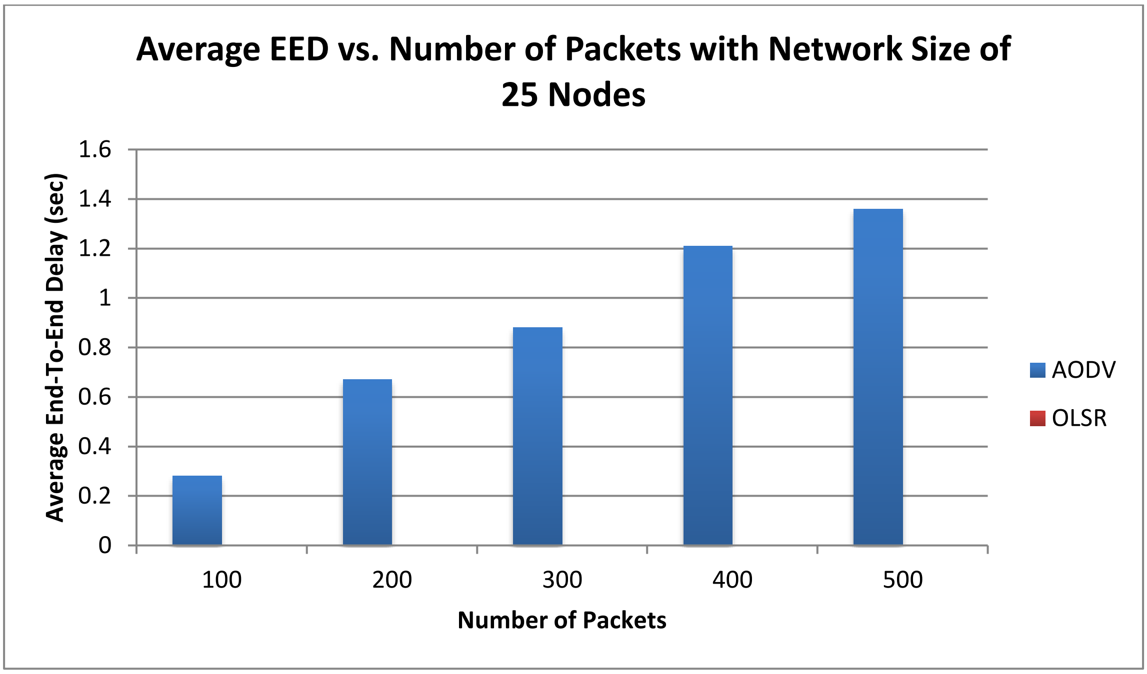


Figure 5.22: Average EED vs. Number of Packets with Network Size of 25 Nodes

Tables 5.23-5.25 reveals how AODV outperforms OLSR with higher throughput only with network size of 5 nodes at 100, 200, 300 and 400 packets, whereas OLSR shows greater performance in all other cases. Both protocols seem to increase their effectiveness dramatically in the variation of both the number of packets and nodes. More specifically, the large network and traffic size lead to high throughputs. The number of packets affects throughput of both protocols significantly, which can be observed easily by comparing the results with those achieved in the previous scenarios.

Throughput (Kbps) – 5 Nodes		
Number of Packets	**AODV**	**OLSR**
100	60	58
200	121	119
300	178	174
400	237	233
500	295	298

Table 5.23: Throughput vs. Number of Packets with Network Size of 5 Nodes

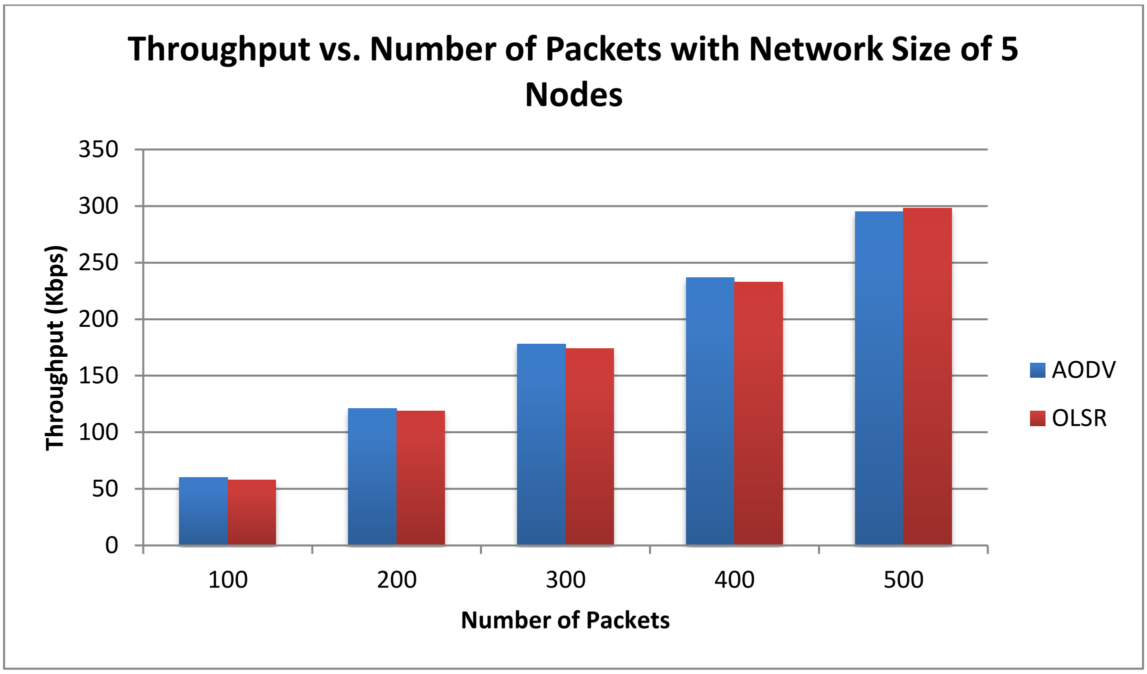


Figure 5.23: Throughput vs. Number of Packets with Network Size of 5 Nodes

Throughput (Kbps) – 15 Nodes		
Number of Packets	**AODV**	**OLSR**
100	123	197
200	241	399
300	351	597
400	456	803
500	583	1002

Table 5.24: Throughput vs. Number of Packets with Network Size of 15 Nodes

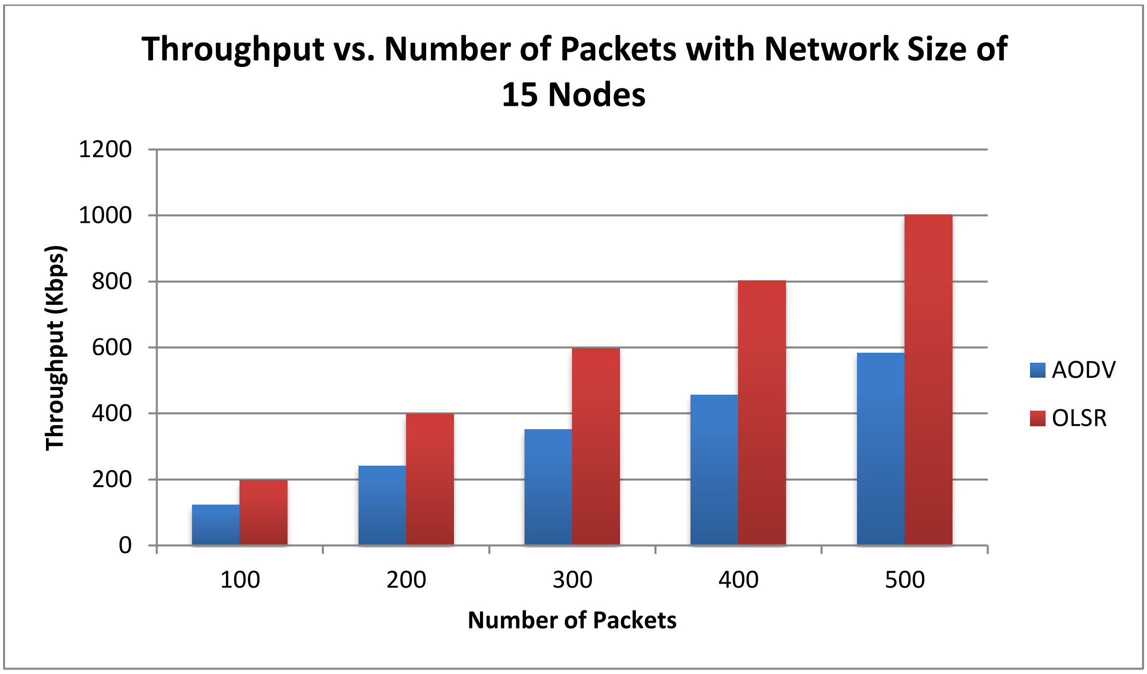


Figure 5.24: Throughput vs. Number of Packets with Network Size of 15 Nodes

Throughput (Kbps) – 25 Nodes		
Number of Packets	**AODV**	**OLSR**
100	168	335
200	329	654
300	484	992
400	689	1321
500	802	1683

Table 5.25: Throughput vs. Number of Packets with Network Size of 25 Nodes

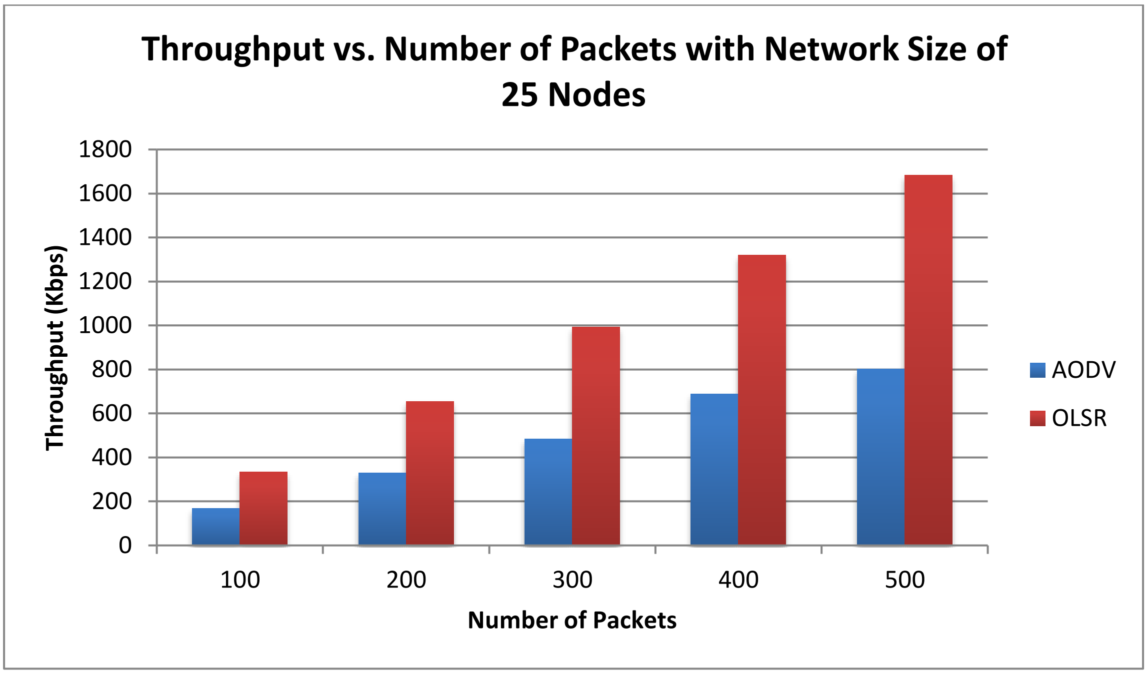


Figure 5.25: Throughput vs. Number of Packets with Network Size of 25 Nodes

Finally, OLSR operates with less total energy consumption with all variations of node density and traffic size. As can be seen from tables 5.26-28, both protocols are negatively influenced by the rise in the number of nodes and packets. The term "negatively" refers to the performance in our cases.

Total Energy Consumption (J) – 5 Nodes		
Number of Packets	**AODV**	**OLSR**
100	0.3	0.25
200	0.37	0.27
300	0.44	0.28
400	0.49	0.3
500	0.56	0.32

Table 5.26: Total Energy Consumption vs. Number of Packets with Network Size of 5 Nodes

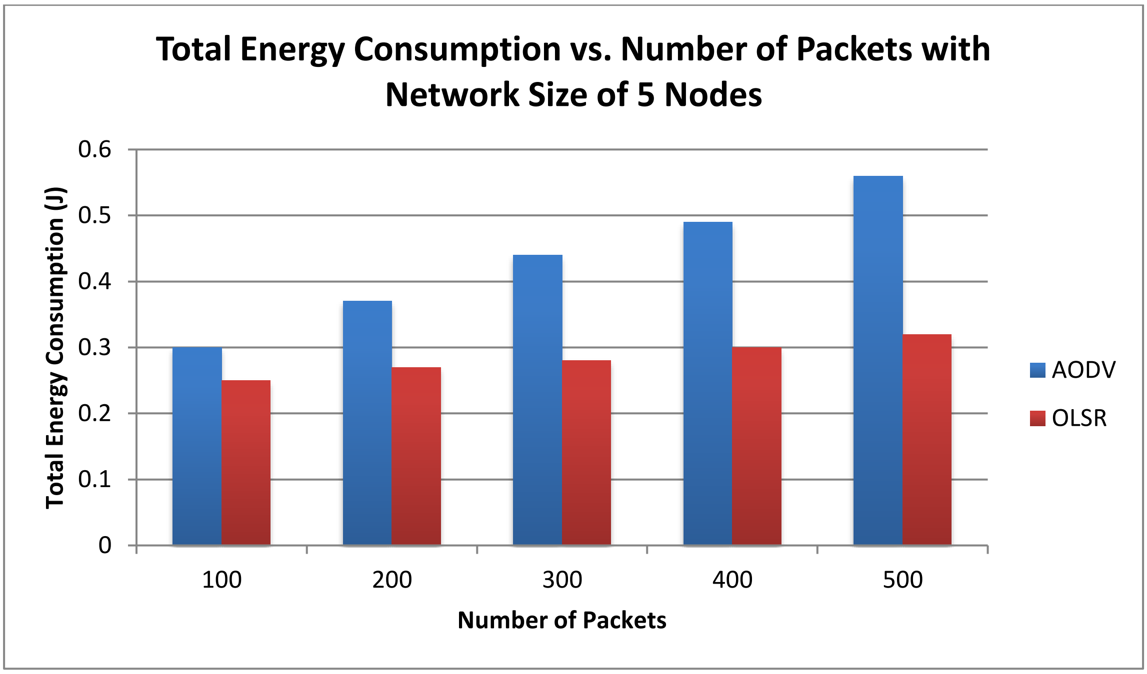


Figure 5.26: Total Energy Consumption vs. Number of Packets with Network Size of 5 Nodes

Total Energy Consumption (J) – 15 Nodes		
Number of Packets	**AODV**	**OLSR**
100	0.36	0.28
200	0.45	0.29
300	0.53	0.3
400	0.61	0.32
500	0.7	0.34

Table 5.27: Total Energy Consumption vs. Number of Packets with Network Size of 15 Nodes

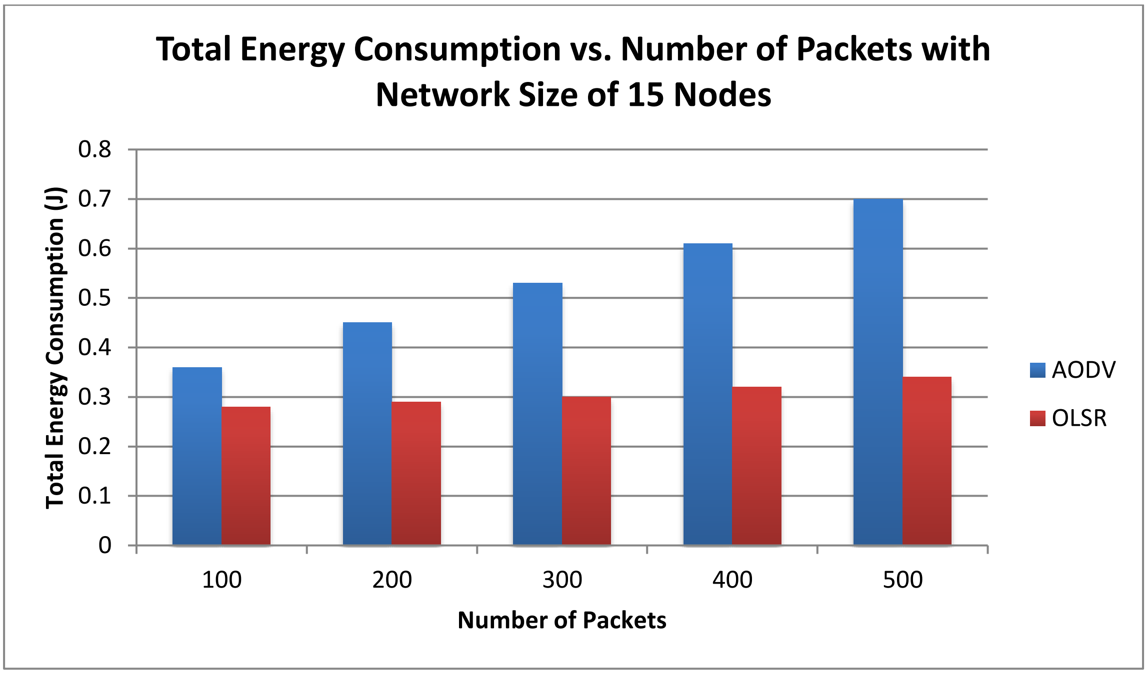


Figure 5.27: Total Energy Consumption vs. Number of Packets with Network Size of 15 Nodes

Total Energy Consumption (J) – 25 Nodes		
Number of Packets	**AODV**	**OLSR**
100	0.44	0.3
200	0.56	0.32
300	0.65	0.33
400	0.81	0.35
500	0.89	0.36

Table 5.28: Total Energy Consumption vs. Number of Packets with Network Size of 25 Nodes

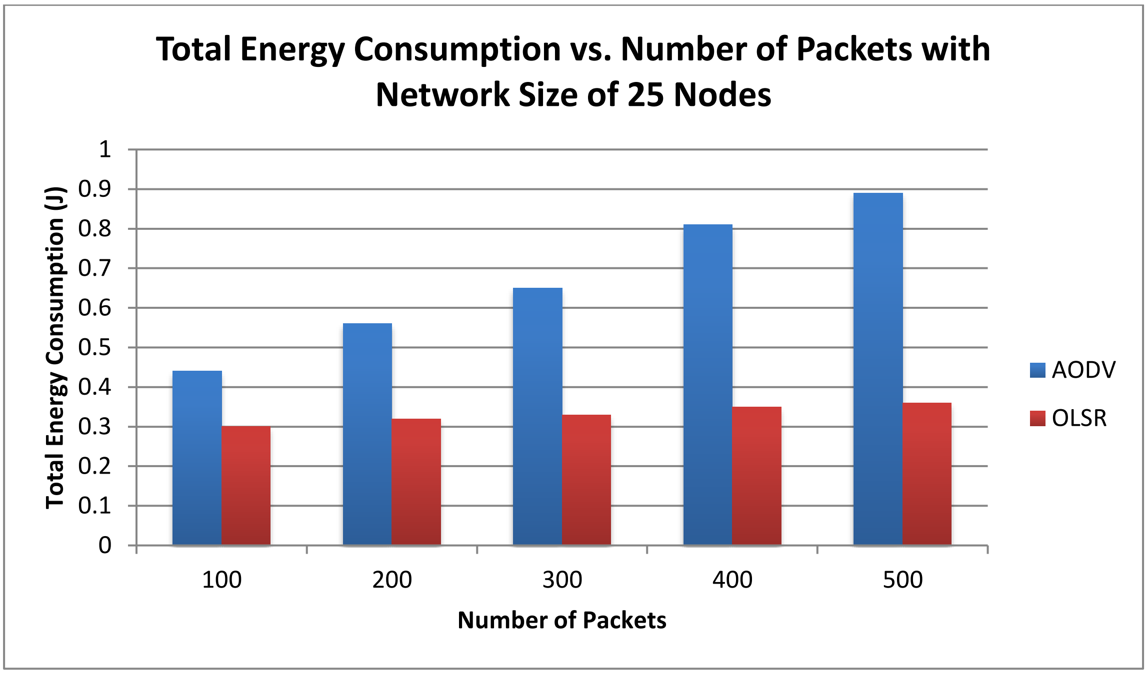


Figure 5.28: Total Energy Consumption vs. Number of Packets with Network Size of 25 Nodes

Chapter 6

Evaluation

Motivated by the significant developments in the communication industry, this project has addressed a full research of mobile ad hoc networks. The essential features, benefits and challenges of MANETs were evaluated in the background chapter. All types of routing protocol groups were discussed in details. The main focus of the experiment was to examine the performance of selected routing protocols from the reactive and proactive groups in order to state which of them has higher communication reliability. By using network simulator called NS-3 on the Linux operating system, the performance of AODV and OLSR were compared in diverse scenarios with respect to several performance metrics.

In the first scenario, where node density was varied, OLSR outperformed AODV only in terms of delay, which is on the strength of the fact that the routes are regularly maintained to all destinations in table driven protocols. However, such characteristic of proactive routing protocols causes them to be considered disadvantageous in comparison with reactive routing protocols when the routing overhead is analysed. Accordingly, AODV had less routing overhead than OLSR in our case regardless the network size. It should be pointed out that AODV outperformed OLSR with regard to throughput and packet delivery ratio as well in all cases of the first scenario. Despite the fact that PDR and throughput values of both protocols were positively affected by the extension in the node density, they seemed to operate with greater latency in larger networks. Finally, there were observed fluctuations in the routing overhead of both routing protocols when the number of nodes was varied.

In the second and third scenarios, the mobility speed and traffic size were varied along with the node density respectively. One of the selected performance metrics in the scenario one was modified as instead of routing overhead, the routing protocols were compared according to the total energy consumption. In the second scenario, OLSR performed much better with all combinations of node density and mobility speed in respect of each performance metric. OLSR was not affected by the changes in node speed, yet there were observed fluctuations in the AODV performance as a result of modifying the speed. OLSR operated with maximum performance in regard to packet delivery fraction in all node densities. However, the performance of AODV degraded at each time the network size enlarged. Similarly, the latency of AODV increased at each time the node density was varied; nevertheless, OLSR performed with less latency in larger networks. Both protocols consumed more energy when the simulation was implemented with a larger number of nodes. As in the first scenario, extension in the network size led to higher throughputs for OLSR, whereas this metric was fluctuated in AODV protocol as a result of varying node density.

Finally, in the third scenario, AODV outperformed OLSR with regard to throughput and packet delivery fraction only with network size of 5 nodes at specific packets. Yet, OLSR operated with much better performance in all other cases regarding any performance parameter. Expectedly, variations in the number of nodes increased throughput and energy consumption of both protocols. As in the previous scenario, average end-to-end delay of AODV enhanced with the extension in the network size, yet the opposite situation was observed for OLSR. PDR value of both protocols was negatively influenced by the change in the number of nodes. Changing the traffic size affected the results in different manners depending on the protocol, performance parameter and network size. Increasing the number of packets resulted with significant rise in the throughput of both AODV and OLSR. A linear relationship was also observed between the total energy consumption and number of packets in both protocols. Although average delay was gradually affected by the variations in the number of packets in AODV, it remained constant in OLSR. Finally, it should be pointed out that modifying the number of packets resulted with the fluctuations in the PDR values of both protocols.

Therefore, it can be concluded that a number of simulation parameters such as node density, traffic size or node speed considerably influence the performance of routing protocols in MANETs. Thus, it is wrong to generalize that any routing protocol is the most optimum. As in our project, the routing protocol performing well in one environment can be poor decision in other scenarios.

Chapter 7

Conclusion and Future Work

7.1 Conclusion

To sum up, this project focused on the analysis of ad hoc networks by discussing their characteristics, benefits and challenges. The demand towards MANETs has increased significantly over the last on the strength of the fact that they are adaptive, autonomous and self-configuring, which makes their use quite flexible in various emergency and military situations when an access point or base station cannot be established. However, it has been a challenge creating reliable and efficient routing protocols for ad hoc networks on the grounds that the topology is not fixed. This can lead to diverse problems such as loss of communication or security issues. Therefore, the current project analyzed the performance of two selected protocols in three difference scenarios. AODV and OLSR protocols were chosen for the project belonging to reactive and proactive groups respectively. In the proactive routing protocols routes are maintained to all destinations continuously, yet in reactive routing protocols they are created when data must be transmitted. One on hand, the above-mentioned characteristic of proactive routing protocols causes them to be considered advantageous when compared to reactive protocols due to less average end-to-end delay. Nevertheless, the periodic exchange of routing packets across the network in OLSR leads to higher routing overhead in comparison to AODV. Additionally, it should be noted that AODV outperformed OLSR in respect of packet delivery ratio and throughput in the first scenario where node density was varied. However, the opposite situation was detected and OLSR outperformed AODV with respect to all performance parameters in the second scenario, where the mobility speed was also varied respectively along with node density. In the third scenario, OLSR outperformed AODV with regard to total energy consumption and delay in all cases. AODV seemed to show better performance only in respect of throughput and packet delivery fraction with network size of 5 nodes at specific traffic sizes. It can be concluded that the simulation parameters such as node density, traffic size, node speed or simulation area have considerable impacts on results. Hence, it can be stated that none of the routing protocols in ad mobile ad hoc networks can be considered as the most optimum alternative in general. To be more specific, the protocol that is the best option in one scenario because of its high performance could be wrong decision in other environments, which was also proven in the current project.

Therefore, a number of factors should be taken into consideration before choosing the best routing protocol for a specific scenario. For instance, as in the first scenario of our experiment, AODV could be better option while the number of packets is fixed to a small number and packet size is not large. Yet, as in our second scenario, OLSR could be much more optimum alternative with higher number of packets and larger packet size. In the last scenario, OLSR totally outperformed AODV where the packet size was increased to 4096 bytes and the number of packets was varied significantly. Despite the fact that most proactive protocols are not useful for large-size networks, OLSR generally increased its performance with the extension in the network size, which can be explained by the fact that optimization is implemented through the MPR technique, which decreases the size of control packets and overhead from flooding of control traffic significantly. A number of other parameters such as mobility model, data rate or simulation area can also have impact on the routing in mobile ad hoc networks. It can be concluded that AODV is more efficient in the networks with low density and traffic. On the other hand, OLSR would probably operate with higher performance in dense networks with large traffic. The differences can be observed much easily particularly when the network size is large. Furthermore, any performance parameter could be much preferred affecting the decision considerably. More precisely, OLSR is always better option if lower latency is required as routing information is regularly updated on every node and becomes available immediately when packet transmission is required. However, this characteristic can significantly increase the traffic in OLSR; hence AODV is mostly preferable when low overhead is necessary.

7.2 Future Work

Although this thesis provides a comprehensive study in terms of performance investigation of OLSR and AODV, ad hoc networking is broad and hot topic in the communication industry nowadays and there are several issues to be solved. Further studies can be conducted on the cost comparison of sending few large packets versus many large control messages. Furthermore, simulation-based studies can be conducted where unidirectional links are taken into consideration or multicast routing is implemented. As has been mentioned before, ad hoc networks are vulnerable to attacks because of the absence of infrastructure, which must be solved to some extent with future investigations to increase the reliability of MANETs. Meanwhile, researches should focus on proposing energy-efficient protocols. Moreover, the performance investigation of OLSR routing protocol by varying TC and HELLO message could be a significant study. Future studies can focus on the performance analysis of routing protocols in ad hoc networks by altering the bandwidth of nodes and transmission range. Finally, the performance of new versions of the protocols used in our experiment, AODVv2 and OLSRv2, can be evaluated with the use of other network simulators such as GLOMOSIM or OPNET.

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