Performance Analysis and Comparison of Ad Hoc Routing Protocols AODV and OLSR on Video Conferencing using OPNET Simulator

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ABSTRACT

The use of devices with wireless technologies such as Laptops and mobile phones are very popular. These devices influence the use of wireless networks such as ad hoc networks. Mobile ad hoc network (MANET) is a group of devices that are connected to each other by wireless links without any centralized controlling or infrastructure. Nodes (devices) of this network are changing their locations, and also the number of nodes may change during the time. Therefore, the topology type of this network is known as dynamic. Nodes in a dynamic topology communicate with each other using routing protocols. Routing protocols are responsible for finding a path between nodes. These protocols have a significant role for the total performance of the ad hoc networks. Routing protocols of ad hoc networks are divided into the following; proactive, reactive and hybrid routing protocols. Different types of routing protocols for ad hoc networks were improved by network designers and researchers to enhance the performance of ad hoc networks by finding the shortest and efficient route establishment between two nodes for message delivery. To evaluate and compare the performance of routing protocols, a number of performance metrics are used. Each of these methods has its own properties and is suitable for a specific application type.

In this study, two well-known ad hoc routing protocols, Ad hoc On-demand Distance Vector (AODV) and Optimized Link State Routing (OLSR), were analysed and compared according to their performance using a video conference application. Interactive video conferencing was chosen as an application in this study because of the increasing popularity of multimedia and real time applications by the users of ad hoc networks recently. Routing protocols are analysed with respect to the following metrics; number of hops per route, route discovery time, routing traffic sent and routing traffic received. For comparison among the mentioned protocols, metrics were used that are important for video conference applications, namely which are packet delay variation, packet end-to-end delay and normalized routing load. OPNET simulator version 17.1 is used to model and simulate ad hoc networks.

The results of experimental simulations show that OLSR has better performance in packet delay variation. With OLSR protocol, the time that is required to transfer a packet from source to destination is less than the time taken by AODV. AODV has less (better) normalized routing load than OLSR in high density networks. In low density network, AODV is again better when a few nodes are communicating. On the other hand, Normalized routing load of OLSR is getting down compared with AODV when the number of communicating nodes are increasing.

Keywords: Ad hoc networks, routing protocols, AODV, OLSR, simulation, performance metrics, OPNET simulator.

ÖZ

Kablosuz teknolojilerin kullanıldığı laptop ve cep telefonu gibi cihazlar gününüzde popüler hale gelmiştir. Bu tür cihazlar özel amaca yönelik (ad hoc) ağlar gibi kablosuz ağların kullanımını da etkilemektedir. Mobil özel amaca yönelik ağ (MANET), herhengi bir merkezi kontrol ve altyapı almaksızın birbirine bağlı bir grup cihazdan oluşur. Bu ağın düğümleri (cihazlar) konumları değiştirebileceği gibi, düğün sayısı da zamanla değişebilir. Bu nedenle, bu ağın dinamik bir topolojisi vardır. Bu dinamik topolojideki düğümler, yönlendirme protokollerini kullanarak birbirleriyle iletişim kurarlar. Yönlendirme protokolleri düğümler arasında yol bulmada kullanılır ve özel amaca yönelik ağların performansında önemli bir role sahiptirler. Özel amanca yönelik ağlarda kullanılan yönlerdirme protokolleri, proaktif, reaktif ve karma olmak üzere üç katagoriye ayrılır. Mesaj iletiminde, ad hoc network performansını artırmak amacıyla, iki düğüm arasınde en kısa ve etkili yolun kurulmasında kullanılan farklı tipteki yönlendirme protokolleri, ağ tasarımcıları ve araştırmacılar tarafından iyileştirilmiştir. Yönlendirme protokollerinin performanslarını değerlendirme ve karşılaştırmada kullanılan performans ölçümlerinin her birinin kendi özellikleri ve kullanıldığı belirli uygulama alanları vardır.

Bu tezde, iki iyi bilinen yönlendirme prototolü, Ad hoc On-demand Distance Vektör (AODV) ve Optimized Link State Routing (OLSR), video konferans uygulaması ile kullanılmış ve performans karşılaştırması yapılmıştır. Son zamanlarda, ad hoc ağ kullanıcıları tarafından multimedya ve gerçek zamanlı uygulamaların

kullanımının artması nedeniyle, bu tezde interaktif video konferansı uygulaması seçilmiştir. Seçilen protokoller her yoldaki sekme sayısı (number of hops per route), yol keşif zamanı (route discovery time), gönderilen yönlendirme trafiği (routing traffic sent) ve alınan yönlendirme trafiği (routing traffic received) performas ölçütleri kullanılarak analiz edilmiştir. Protokoller arasında karşılaştırma yapmak için, video konferans uygulamasında önemli olan, paket gecikme değişimi (packet delay variation), paketlerin uçtan uca gecikmesi (packet end to end delay) ve normalize edilmiş yönlendirme yükü (normalized routing load) ölçütleri kullanılmıştır. OPNET simulator versiyon 17.1 ad hoc ağlarının modellenmesi ve simulasyonu için kullanılmıştır.

Deneysel simulasyon sonuçları, OLSR protokolünün paket gecikmesi değişimi performansının daha iyi olduğunu göstermiştir. OLSR protokolünün, kaynaktan hedefe olan paket iletim süresinin AODV protokolünden daha az olduğu tespit edilmiştir. Diğer yandan, yüksek yoğunluklu ağlarda, AODV'nin normalize edilmiş yönlendirme yükü, yüksek ve düşük yoğunluktaki ağlarda OLSR'a göre daha iyidir. Ayni zamanda, OLSR kullanılırken iletişim kuran düğüm sayısı arttığı zaman, normalize yönlendirme yükünde, AODV ile karşılaştırıldığında, azalma görülmektedir.

Anahtar kelimeler: Özel amaca yönelik ağlar, yönlendirme protokolleri, AODV, OLSR, simulasyon, performans ölçütleri, OPNET simulatörü.

To the loving memory of my father, the first to teach me

To my beloved Mother, for her prayers to me

To my brothers and sisters, for care and support all the time

To all my friends

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LIST OF ABBREVIATIONS

PRNET	Packet Radio Network
SURAN	Survivable Adaptive Radio Networks
MANETs	Mobile Ad hoc Networks
AODV	Ad hoc on demand Distance Vector Routing
OLSR	Optimized Link State Routing
TORA	Temporally Ordered Routing Algorithm
GRP	Geographic Routing Protocol
DSR	Dynamic Source Routing
NS2	Network Simulation 2
OPNET	Optimized Network Engineering Tool
SANET	Static Ad hoc Network
ACOR	Admission Control enabled on demand Routing
ABR	Associatively Based Routing
DSDV	Destination Sequenced Distance Vector
AWDS	Ad hoc Wireless Distribution Service
CGSR	Cluster head Gateway Switch Routing
MPEG	Moving Picture Experts Group
DCT	Discrete Cosine Transform
LC	Layered Coding
MDC	Multiple Descriptions Coding

VoIP	Voice over Internet Protocol
RERR	Route Error Message
RREP	Route Replay Packet
RREQ	Route Request Packet
TC	Topology Control
MPR	Multi Point Relay

Chapter 1

INTRODUCTION

Wireless networking is a widely used technology which enables users to access information and other services on the network within geographically coverage area of the network. Ad hoc network is an infrastructureless mode of the wireless network. It consists of a group of devices communicating with each other without a central access point. Nodes (devices) in this network are self-configurable in the network. They are the transmitter, receiver and antenna. The ability of self-configuration of these nodes makes them require immediate connection to connect with the network, when they become active nodes. Nodes in this network can be fixed or mobile, and new nodes can join or leave from the network in time. Therefore, topology of an ad hoc network may change in time. The Figure 1.1 shows an example of an ad hoc network.

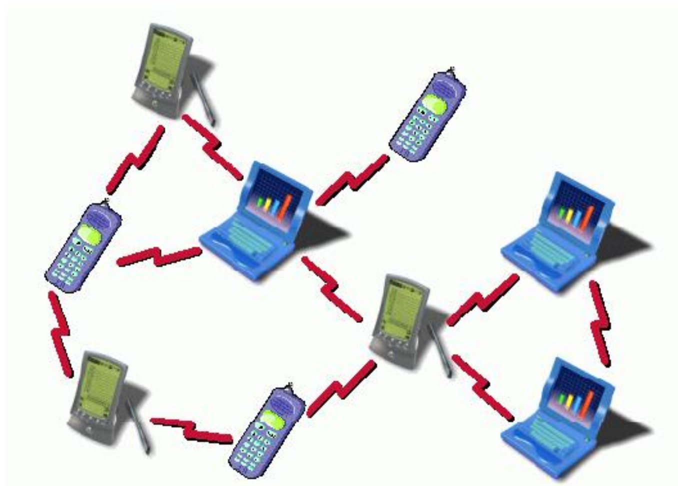

Figure 1.1. An Example of Ad hoc Network [1]

In order for the communication to be possible between different nodes, routing protocols are used to find paths that are used by transmitted packets from the sender to receiver node. Routing protocols have some standards or rules that control on how two nodes are agreed in the communication way. Routing Protocols are used to find and establish the route that is the shortest and most efficient between communicating nodes. However, protocols that are developed may not perform well for a certain topology, hence factors that are affecting performance of protocols require accurate investigation. These factors are mobility speed of nodes, network load and size, signal strength, type of application and bandwidth. The type of application that was used in this study for analysing and comparing the performance of routing protocols is video conferencing.

Real time multimedia services require high reliability with low time delay and high transmission rate. However, wireless channels are error prone, offer limited bandwidth and are time varying. Transmission of real-time traffic is one of the greatest challenges of infrastructureless mode wireless networks. The main issue of routing protocols of wireless ad hoc networks is to discover an efficient route from source node to destination node. The route should be reliable and deliver data within time boundary. Thus, in an ad hoc network, routing protocols on video conferencing have a significant role on performance of network for real-time traffic. Multimedia applications over ad hoc network have started in the last few years, although the ad hoc network has a long history.

Ad hoc network history dates back to Packet Radio Network (PRNET) in 1970, and Survivable Adaptive Radio Networks (SURAN) in 1980 [2]. The purpose of PRNET and SURAN programs was to make a packet switching network movable in an infrastructureless environment in the battleground (aircraft, soldiers, tanks, etc., representing nodes on the network). In 1990s, new developments in an ad hoc network appeared. Notebook computers became widely used with open-source software and communications equipment using infrared and radio frequency (RF). The IEEE's 802.11g subcommittee adopted the "ad hoc networks" term for the first time and for the non-military (commercial) purposes. After long research and work on ad hoc networks by researchers, this network still does not have a real form of Internet base standards. Request for calls (RFCs) of ad hoc network routing protocols has been in use since 2003, and the proposed algorithms of these protocols are considered as trial technology. There is a chance that they will be developed into standards [3]. Interactive video conferencing over mobile ad hoc network routing protocols are also in testing and developing step and still there is no real software supporting them.

There is more than one routing protocol developed for ad hoc networks, each one having different features. Ad hoc network protocols have different properties making them each perform better in a specific situation. The choice of best and correct routing protocol for a specific network is not easy and requires testing and evaluating under the target application. Some evaluations and comparisons between these protocols were done before, which are mentioned in the next paragraph. By using some information from these experiences, two of the best protocols were chosen as AODV and OLSR. These two protocols were analyzed and compared to choose the best one for video conferencing over an ad hoc network. Through this process it was attempted to answer two questions, "what is the difference between these two routing protocols?", and "which of these two routing protocols can perform better and can be used for video conferencing applications on ad hoc networks?", respectively.

In [1] a performance comparison of protocols AODV, OLSR and TORA on real-time video traffic using OPNET simulation was performed. In that study, the results of simulation show that OLSR outperforms AODV and TORA routing protocols in terms of higher network load and minimal delay. End-to-end delay of AODV was 35% greater in comparison with protocol OLSR. The main disadvantage of that study is the form of network structure in the simulation model. They used server in the middle of the network and all other nodes where in the coverage area of the server. That structure is not really representing the idea of an ad hoc network. In [3], another study on comparing ad hoc protocols on video streaming was done. In that study, the authors conclude that OLSR and GRP perform better than AODV and DSR in network size and number of nodes in the network. In that study, the authors made a comparison based only on metric throughput. Other metrics that are important for real time applications such as end-to-end delay and packet delay variation were not used. In paper [4], the performance of routing protocols AODV and DSR was studied on video conferencing using NS2 simulator. The results obtained from the simulation study show that AODV has better performance than DSR in packet loss and end-to-end delay, and also the area that was covered by AODV is greater than DSR area. In [5], the performance of routing protocols AODV, DSR and OLSR were compared using NS2 simulator. In this study, CBR traffic was used that includes services such as video conferencing and voice services [5]. The simulation results conclude that OLSR shows the best performance in terms of data delivery ratio and end-to-end delay. In [6], the authors compare performance of routing protocols AODV, DSDV and OLSR on constant bit rate (CBR) traffic using NS2 simulator. The simulation results show that in low load scenarios, all three protocols react in a similar way in terms of end-to-end delay, while with load increasing DSDV outperforms AODV and DSR routing protocols. In [7], the author evaluated performance of routing protocols AODV, OLSR and DSR on multimedia transmission using NS2 Simulator. The data traffic used in this study is CBR traffic. Authors used vehicle speed in this study The simulation results of this study show that DSR outperform AODV and OLSR in terms of end-to-end delay and packet delay variation. In [8], the authors studied the effect of different ad hoc network conditions and parameters on quality of video that will be used in video conferencing applications. This study exposes that the video rate, bandwidth and level of congestion significantly affect the quality of video in video conferencing sessions on ad hoc networks. Some of the simulation parameters of this works are shown in Table 1.1.

Table 1. 1 Summary of Related Works

Ref. No.	**Simulation Setup**						
	Simulator	**Application Type**	**Routing Protocols**	**Number of Nodes**	**Mobility**	**Environment (m x m)**	**Performance metric**
[1]	OPNET	Video Conferencing	AODV, OLSR and TORA	24 clients and one server	Mobile	500x500	Throughput End-to-end delay Network Load
[5]	OPNET	Continuous Bit Rate (CBR) traffic	DSR, AODV and OLSR	25, 50, 75, 100	Mobile	1000x1000	Routing load End-to-end delay Packet delivery ratio
[6]	NS2	CBR traffic with 20 kbps	AODV, DSDV and DSR	50	20 m/s	500x500	Packet delivery ratio end-to-end delay Normalized routing load
[7]	NS2	CBR traffic with Packet size 512 bytes and 64 packets/sec	DSR, AODV and OLSR	50	0m/s - 20m/sec	500x500	Packet delivery ratio End-to-end delay Packet delay variation Routing overhead

Ad hoc network routing protocols are classified into three categories, which are reactive, proactive and hybrid. In this study, the algorithms of selected protocols (AODV and OLSR) are explained. Moreover, we studied the performance of mentioned protocols according to the designed simulation model. Video conferencing application in this sdudy, is considered for three cases of conferencing; one to one node, one to three nodes and one to five nodes scenarios. The scalability of network is considered with 25 and 80 nodes with two cases of mobility non-mobile and mobile nodes. The network structure of this study is designed to represent and work according to the properties of ad hoc networks. All nodes are not in the coverage area of each other. Intermediate nodes are used to reach far nodes. Furthermore, the performance metrics were chosen for comparing protocols that are important for real time applications which are packet delay variation and end-to-end delay. Additionally, a Normalized routing load was used that is not supported by OPNET simulator.

The present dissertation is divided into four main chapters; Chapter 1 introduces the topic. Chapter 2 provides the background and basic information about MANET, video conferencing over MANET, routing protocols of this network. Chapter 3 describes and explains the used routing protocols and simulation program (OPNET). Chapter 4 contains MANET model representation on OPNET simulator, simulation setup, simulation results and analysis and comparison of routing protocols. Chapter 5 presents the conclusion and the appendices section include confidence intervals for simulation results.

Chapter 2

BACKGROUND AND BASIC INFORMATION

2.1 Wireless Networks

Wireless networking is a widely used technology, which enables users to access network services within a geographically coverage area of the network. Instead of using cables for communication these networks use some type of radio frequencies across air in order to transmit and receive data. The most interesting facts regarding wireless networks is that there is no need to lay out cables and no maintenance cost.

Advantages of Wireless Networks:

- They provide mobile users with access to information even when users are far from their office or at home.
- A wireless network system is easy and fast to set up, and it does not need any cables for computers through ceilings and walls.
- The area that can be covered by wireless network cannot be wired.
- Wireless networks provide more flexibility and adjust easily changes made to the network configuration.

Disadvantages of Wireless Networks:

- They are susceptible to interference from weather influence, radio frequency of another device and obstructions such as walls.

- The total amount of throughput is influenced when there is more than one connection.

Problems in Wireless Communications

Some problems relative to wireless communications are: limited frequency spectrum, path loss, interference, and multi-path propagation. Limited frequency spectrum occurs when the band of frequency is shared by more than one wireless technology. Path loss can be defined as an enervation of the strength of the transmitted signal when it is propagating away from the sender device. Path loss is determined as the proportion transmitted signal power to the signal that it receives. It depends on factors like area nature and frequency of radio. Sometimes it is important to estimate path loss in communications of wireless. Because area nature and radio frequency is not the same everywhere, path loss estimation during communication is hard. A number of signals during communication in atmosphere possibly interfere with each other causing destruction of the original signal. Multi-path propagation is a state which occurs when the transmitted signal from source to destination suffers from some obstacles in its way. This causes the signal to propagate in paths instead of in a direct line because of the following mechanisms:

- Reflection: propagation wave hits on an object that is larger than a wavelength, such as buildings, walls, the surface of earth, etc.…
- Diffraction: surfaces that have sharp edges obstruct the radio path from sender to receiver. Signals bend over the obstacle, even if line of sight does not exist.
- Scattering: small objects which are smaller than the wavelength of the propagation wave, such as lamp posts, street signs, etc.…

Figure 2.1 shows the effect of objects that are obstructing the propagation of the signal through air.

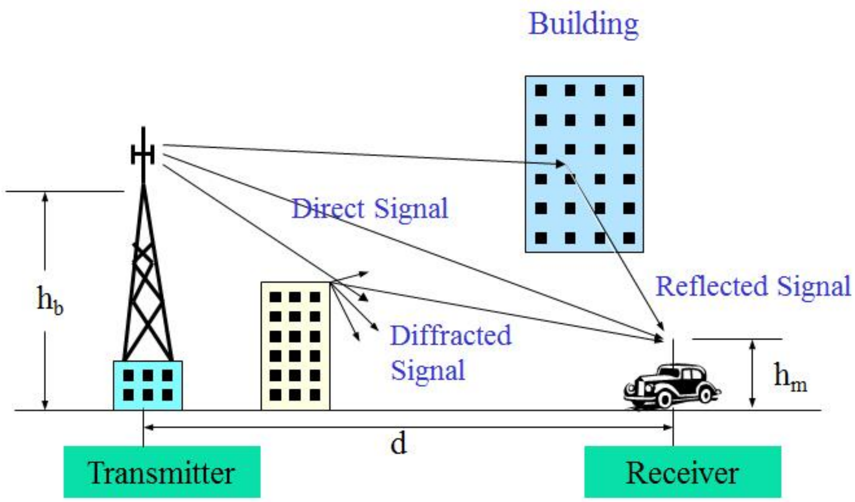

Figure 2.1. Radio Signals Propagation [9]

2.2 Types of Wireless Networks

There are two main groups of wireless networks; infrastructure and infrastructureless wireless networks.

2.2.1 Infrastructured Wireless Networks

The network topology deployed in this type of network is fixed. Infrastructured network has an access point or base station that is used by devices of this network to communicate through it. The access point or base station of the network is connected to main network by wired link (backbone), or it can also be a wireless link. The wired link that is connecting wireless networks together can be a coaxial cable, a twisted pair type cable or a fibre optic cable. The access point or base station device is one of the most important units in this network. All communications between nodes of this network have to go through the base station. A node of these wireless networks can connect to any of base stations that are in its transmission range.

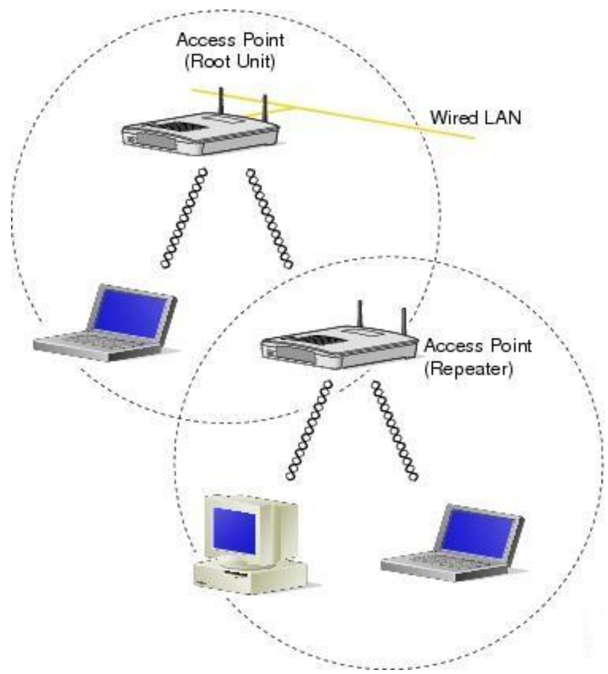

Figure 2.2. Infrastructured Wireless Networks [10]

2.2.2 Infrastructureless Networks (Ad hoc)

The devices in this network are connecting through wireless links. In this type of network, there is no access point or base station, nodes communicating with each other directly. Nodes in an infrastructureless network request data from other nodes and also act like routers by forwarding received data to another node. Joining or leaving of nodes in the network is free and there are no restrictions for that. Due to that, the topology of ad hoc network is changeable during the time. There are two forms of ad hoc networks; the first type is called static ad hoc network (SANET), and the other is called mobile ad hoc network (MANET). In SANET, nodes are fixed and are not moving in the network area. In MANET, however, nodes are moving in random directions in the whole area of the network. It became possible to implement the ad hoc network after new technology way developed such as 802.11[11]. The main cause for deployment a network like ad hoc is the easiness, flexibility of deployment and the applications that can be used in it.

MANET is a suitable network and can be used for emergency issues. However, having all these qualities in an ad hoc network, its operation becomes difficult to handle. Node's operation, maintaining a routing table and forwarding packets to neighbours are the responsibilities of each node. Due to changeable topology of MANET, it needs reliable and efficient routing protocols [12]. Figure 2.3 shows an example of infrastructureless wireless network.

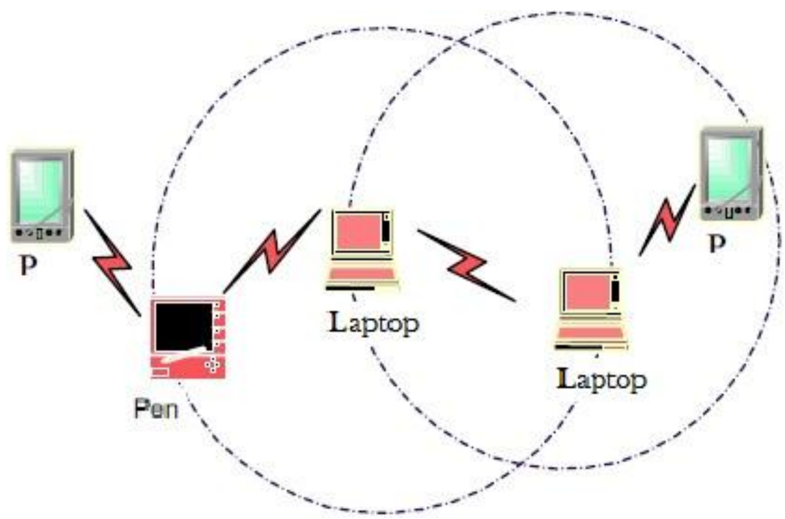

Figure 2.3. Infrastructureless Wireless Networks [12]

In MANET, mobile nodes can connect to all other nodes in the coverage area of wireless network because they are self-configuration devices. MANETs were designed in the beginning to be used for military purposes, but now it has many areas of use such as:

- Collecting data, which is used for this purpose in some regions.
- Disaster hit areas
- Virtual class and conferences

By growing the size of MANET, it contains nodes that are moving in the network area and the challenges of nodes for self-configuration in the network become more complex.

Nodes in MANET waste a lot of energy when joining in and getting out with the network communication. Connecting and reconnecting after getting out from the communication area make the limitation on energy of nodes. The efficiency of routing protocols can be specified by the power consumption of the node's battery. The energy of nodes is consumed in routing traffic and when they are participating in network services. There are many routing protocols that are used in MANET such as AODV, OLSD, DSR, TORA, GRP, etc. The routing in MANET is discussed in detail in Section 2.3 of this chapter.

Restrictions on MANETs

- Dynamic topology: because of the join/leave of nodes and mobility in the network in a dynamic manner, it makes establishment and removal of links in a dynamic way. Therefore, communication links are susceptible for loss during a node's movements.
- Bandwidth constrained: due to the errors that affect wireless link (interference, environmental condition, fading, etc.), the capacity of a wireless connection is significantly lower than wired links. This results in degradation of received signal and makes bit error rate high.
- Energy constrained: in this type of networks, the performance of communication is not only required but other factors like consumed energy by nodes must also be considered.
- Limitation of physical security: the devices of this network are susceptible to be stolen more than fixed nodes. The wireless link is relatively easy to steal and use to access network services.

- Self-operation and infrastructureless: due to no access points in this network, complex system management is required to get efficiently running system operation.

2.3 Routing Protocols in Ad Hoc Networks

Routing is the process of choosing a communication path between two nodes. The term "routing" is used for various types of networks like the Internet, electronic data networks and in telephony technology. The routing process is controlled by routing protocols. A network protocol is an object that has been characterized with types and format of messages that are exchanged with other peers and the actions that will take place after receiving a message. The routing protocols in mobile ad hoc networks are responsible for searching and finding a route or communication path from one node to all other nodes and for sharing data packets in the network. In ad hoc network, routing is done with use of routing tables. These tables are stored in the cache of nodes. Some routing mechanisms are unicast, multicast and broadcast. In unicast mode, the source node sends the packets directly to one destination. In multicast mode, the source node sends packets to a number of destinations in the network. In broadcast mode, the source node sends packets to all nodes in the network. Ad hoc routing protocols have some standards which control choosing routes that will be used to transmit data packets from source to destination. When a new node wants to enter the network, it will try to discover the topology by using an announcement about its presence and listening to broadcasts from other nodes of the network. The discovery of route is realized in different ways depending upon the type of routing protocol algorithm. There are many routing protocols working in the ad hoc network. These protocols are classified according to routing strategy into three categories; reactive, proactive and hybrid [13].

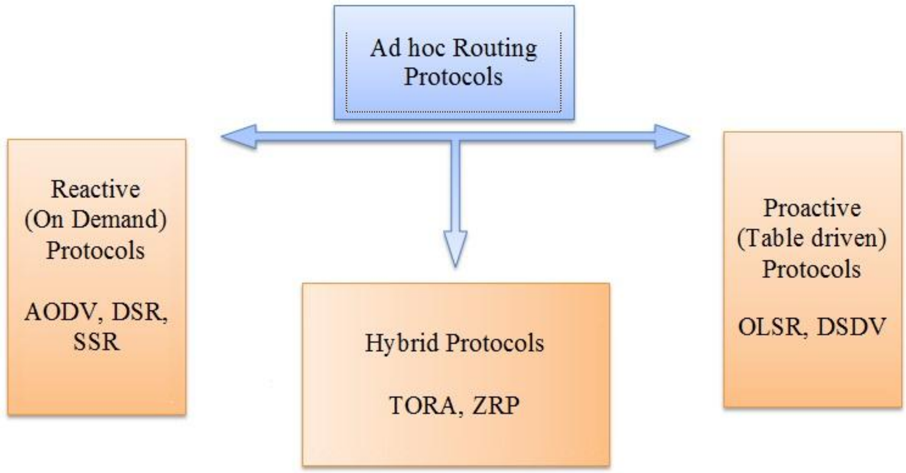

Figure 2.4. Ad hoc Routing Protocols Categories

2.3.1 Reactive Routing Protocols (On Demand)

These protocols are called on demand as a result of not maintaining information of routing table on nodes when there is no communication. When a node wants to send a data packet to another node, firstly, this node will search for a route to the destination in an on-demand way and then transmit the data packet on the discovered route to destination. The process of discovering a route commonly occurs by use of flooding packets of routing request through the network. These types of protocols do not cause a high routing packet traffic on the network. The main disadvantage of these protocols is that they have latency on searching to find a route. There are many routing protocols working in ad hoc networks that belong to this category such as ad hoc on demand distance vector (AODV), dynamic source routing (DSR), admission control enabled on demand routing (ACOR), associatively based routing (ABR) protocols.

2.3.2 Proactive Routing Protocols (Table driven)

Routing protocols of this category are called table driven because they update information of routing table even if the path is not needed or there is no data transmission. Routing table on nodes is periodically updated when changes on the network topology occur [14]. Proactive protocol on each node needs to maintain the entries of its routing table about all nodes in the network. Therefore, this type of protocols is not suitable for large-size networks. Periodically, the control messages are transmitted, even when there is no flow of data to be sent. Collecting information by routing packets between nodes makes consumption of more network bandwidth. On the other hand, the advantage of these protocols is that the node can get up-to-date routing information easily to start transmitting data flow. The protocols that belong to this category are Optimized Link State Routing (OLSR), Destination Sequenced Distance Vector (DSDV), Ad hoc Wireless Distribution Service (AWDS) and Cluster head Gateway Switch Routing (CGSR).

2.3.3 Hybrid Routing Protocols

Based on combination of both table and demand driven routing protocols, some hybrid routing protocols are proposed to combine the advantage of both proactive and reactive protocols. The most typical hybrid one is zone routing protocol (ZRP).

2.4 Problems of Routing in Ad Hoc Networks

- Asymmetric links: The communications in the wired networks mostly rely on symmetric links. However, this may not be possible on ad hoc networks. Due to the node's mobility, the positions of nodes are changing. For example, in MANET when node A sends some video conferencing packets to node B, A may not receive packets with the same quantity or may receive them with delay [15].
- Routing overhead: in MANET, as a result of changing locations of nodes within the network some route entries will be created in the routing table without being used. These routed packets make a useless overhead to the network.
- Interference: This is the major problem with mobile ad-hoc networks as links come and go depending on the transmission characteristics, transmissions might interfere with each other and node might overhear transmissions of other nodes and can corrupt the total transmission.
- Dynamic topology: due to the dynamic topology of ad hoc network, the routing has many problems. During nodes communicating, the characteristics of a medium may change or nodes may move. When the changes occur in the topology, routing tables must somehow reflect these changes in topology and routing algorithms have to be adapted.

2.5 Video Conferencing Mechanisms on Ad Hoc Networks

For several years, video streaming over the Internet has become a well-established service and has many successful applications including video conferencing. Recent developments of wireless network and mobile devices, supply the technical platform to extend applications and services of video streaming to increase the number of mobile users [16]. In the case of MANET, wireless links introduce additional challenges that must be addressed to provide streaming services with sufficient quality to the end users. The problems that are subjected to video streaming over ad hoc networks are a result of resources with low abilities (bandwidth, power of CPU, energy, and capacity of storage), high rate of errors (connection loss, bit errors and changes of route) and changeable environment (availability and amount of resources).

Techniques that are proposed for video streaming over MANET in general, try either to add redundancy or to enhance efficiency. The improvement of efficiency, for example, includes:

- Video coding optimization in order to match bit-rate with the network; also match decoded video quality with the receivers.
- Optimize paths for suitable quality, frequently across several paths that duplicate to the number of sub-streams from the coder of the video.
- Enabling prioritization of packets at MAC layer, also making the MAC layer re-transmission limit optimally to match the required end-to-end delay.

2.5.1 Video Coding Techniques

One of the main challenges in realizing streaming over MANETs stems from the limited amount of resources. A key ingredient in meeting these challenges is the efficiency of the involved codec, i.e., its ability to reduce the bitrate of streams while at the same time preserving an acceptable quality [16]. As shown in Figure 2.5, at the sender side there is an encoder and at the receiver side there is a decoder. MANETs are heterogeneous and highly dynamic networks. The codec technique must be acceptably flexible in order to be capable of adjusting the suitable video streams for the characteristics of the network during the transmission. Additionally, in MANET, video streams may suffer from high rates of unexpected loss of packets.

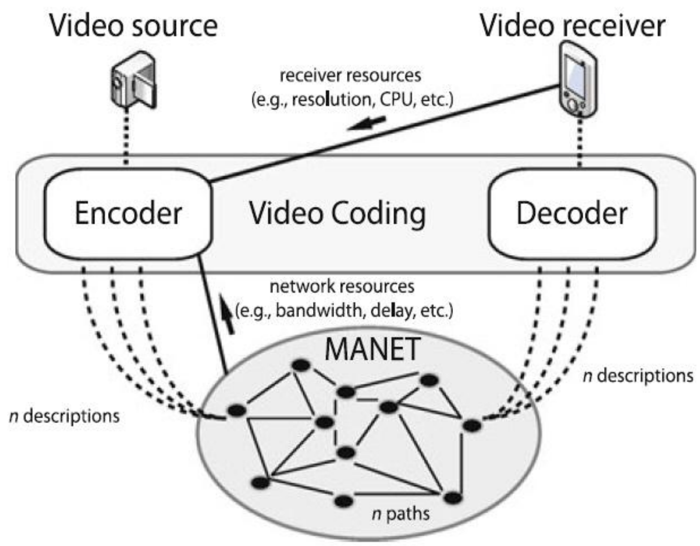

Figure 2.5. Video Coding [16]

Video coding has some standards that had been defined by MPEG and ITU-T organizations, like MPEG-2, MPEG-4, and H26X. Video coding standards use redundancy within both individual frames (pictures) and between frames to perform coding with high efficiency. These techniques are based on the notion of macro blocks. They partition individual frames into logical blocks of pixels. Correlations of pixel values both between and within these blocks are utilized in order to achieve coding with high efficiency. Analogously, redundancy that is between pictures within a group, known as a group of pictures, is discovered via estimation of the movement of the blocks. To achieve that, H26X and MPEG split frames into two main types: frames that can be individually coded (called I-frames) and others that are predicted from previous frames (named as B and P-frames). Techniques of estimating motion at the encoder side make estimation to the movement of blocks in I-frames and transmit this through the network to the decoder side. According to the estimated motion vectors, P-frames are decoded based on prior P and I-frames, and B-frames based on both previous and followed P and I-frames. Thus, frames in order I, P, B, are lessening importance in dependency on surrounding frames.

Motion estimation and the pixels in I-frames in prediction process for frames P and B are subjected to three steps in the process of compression; de-correlation, quantization and entropy coding. De-correlation is done by using special transforms (like integer transformations and DCT [16]). This indicates correlation value among the original values. Values that are small can be left out with minimal loss from the quality. In the process of quantization, the remaining coefficient's values are changed to a group of intervals. Before packets transmission and as a last step, entropy techniques (like Huffman coding) are applied in order to decrease any remaining redundancy.

2.5.2 Multi-stream Coding for Video Streaming over MANETs

Multi-stream coding is a technology allowing a stream to be split into several sub-streams, such that each sub-stream contributes to the overall quality of the video. Therefore, it is not important by decoding side to receive all sub-streams to be capable of decoding video in passable quality. This brings the benefit of down scaling a stream at any point in a network simply by selectively dropping packets. In ad hoc networks, clients may be different in decoding ability and presenting a large amount of video, because of computational characteristic (e.g., CPU) or presentational limit (e.g., Screen resolution). Using multi-stream coding, the problem of heterogeneous nodes will be solved. It can relieve the source and intermediate nodes from computationally intensive tasks of re-encoding and transcoding a stream to fit the client, by instead simply allowing them to drop selected packets. Since a certain amount of packet drops can be tolerated by the client, multi-stream coding is attractive in scenarios where retransmissions are not feasible or impossible. This happens in scenarios when the delay values that were taken by video packets are not tolerated as well as in real-time video streaming (video conferencing). Multi-stream coding has two approaches as outlined below:

- **Layered Coding (LC)**: Both MPEG-2 and MPEG-4 part 2 support layering. It is however the scalable video coding extension to H.264/AVC (H.264/SVC), which has gained the most attention in the last years. Enabling scalability in the three dimensions, time, space and quality, the current set of available H.264/SVC profiles allow splitting a stream into up to 47 layers [16]. Decoding layer (n) is related to (n-1). Layer (n) can only be decoded if all inferior layers are first decoded. Layer (0) is called base layer, and it holds the base quality while decoding. Other layers are called enhancement layers. The overall quality of video will be improved by decoding each of these layers after layer 0.
- **Multiple Descriptions Coding (MDC)**: In MDC, the different sub-streams, called descriptions, and they are of equal importance. Decoding any one sub-stream yields a base quality, while each additional decoded description improves

quality [17]. Hence, every received sub-stream is useful without taking into account the unavailability of the others.

The two approaches were compared in [18-21]. The authors conclude in general that LC performs better than MDC when there is low packet loss rate or in the situations where there is a possibility to protect layer (0) by retransmission. When delay through the network prevents such a retransmission and large amount of packets are dropped, MDC is better. Therefore, MDC is better for scenarios when delay is sensitive during streaming on very dynamic MANET systems.

Chapter 3

DESCRIPTION OF USED ROUTING PROTOCOLS AND THE SIMULATOR ENVIRONMENT (OPNET)

3.1 Selected Routing Protocols

As discussed in Chapter 2, ad hoc routing protocols are classified under three categories: reactive, proactive and hybrid routing protocols. Reactive protocols supported by OPNET simulator are AODV and DSR, while the proactive protocol is OLSR. Other protocols supported by OPNET are TORA and GRP which are hybrid protocols. In this study, we tried to use protocols that perform better according to previous studies and research done on evaluating the performance of these protocols. It is concluded in [4] that AODV has a better performance than DSR, especially in cases where all nodes participate in video conferencing and the area covered by AODV is larger than DSR with less end-to-end delay. Furthermore, it is stated in [22] that DSR has the poorest performance compared with other protocols using VoIP application. As a result, the AODV protocol is chosen from the reactive category and the OLSR from the proactive category. The description and strategy of working for the chosen protocols are described in the following sections.

3.1.1 AODV Routing Protocol

AODV stands for Ad Hoc On-demand Distance Vector Routing which belongs to the reactive routing protocol category. This protocol works in a distributed manner where it is not required for the source node to keep a full sequence path of intermediate objects on the network in order to arrive at the destination [23]. On each node, this protocol uses a routing table, and it keeps one or two recent updated routes. It uses periodic beacon messaging, routing in hop by hop manner and sequence numbering. Periodic beacon messages from AODV are for determining the identity of neighbouring nodes. Sequence numbering is used to guarantee routing of a loop free, and also of a fresh route to the destination node. One of the advantages of AODV over this category of protocols is that it minimizes the size of the routing table and process of broadcast when routes are created [23].

The two important mechanisms of routing are route discovery and route maintenance. These mechanisms are described below:

- **Route Discovery**: when a node has data packets for transmission, it firstly initiates a route request (RREQ) message through a network. This message contains: address of source node, source sequence number, address of destination node, broadcast ID and hop count. The combination of source address and source broadcast ID is to describe a message to request a route. Two pointers during route discovery are set at intermediate nodes between sender and receiver. Forward pointers are set for requesting a route and also for packets in order to be transmitted from sender to receiver node, whereas back pointers send away a message for reply in the reverse direction.

- **Route Maintenance**: this mechanism is achieved by using messages: HELLO, route error (RERR) and route timeout. A HELLO message is used periodically to prevent forward and backward pointers from dying. The message route timeout is used when the route has no activity for a period of time so that it will expire and be deleted from the routing tables. Whenever one of the links along the route fails, a route error message (REER) is initiated, and as a result an error packet is broadcast. As is illustrated in Figure 3.1, when the link between nodes number 3 and 4 breakup up, nodes directly broadcast updating messages in order to remove the route affected by the link failure. When a link failure occurs, the route repair is executed using local and global route repair. A local route repair is where the intermediate nodes try to repair the route at first; however, if there are no available routes in the intermediate nodes, a message is sent to the source, and the source initiates a global route repair.

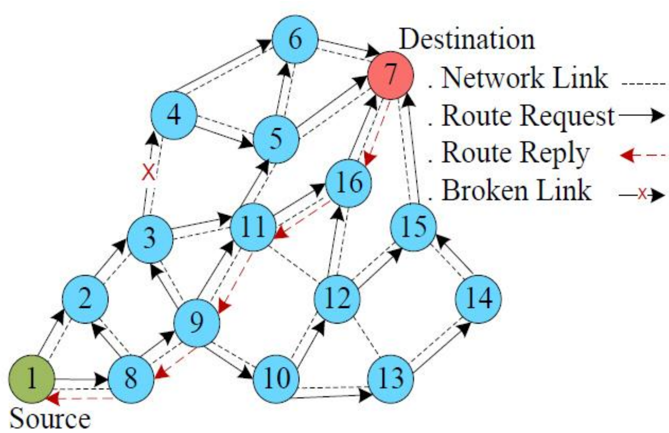

Figure 3.1. Routing Mechanism of AODV [13]

AODV suffers from large delays from constructing routes. When the link fails it will initiate another route discovery, as a result, an extra delay will occur with more bandwidth consumption. Figure 3.2 illustrates the routing algorithm of AODV protocol.

The flow chart explains the process of transferring packets from source node to destination node and describes the action taken by nodes when an error occurs. As is shown in the algorithm, if the route to a destination is available then the connection will be established and it will proceed to the transmission process. In case a route to the destination is not available, global route repair will be activated by using broadcast messages from the sender to find a new route to the destination, and the algorithm will start from the beginning.

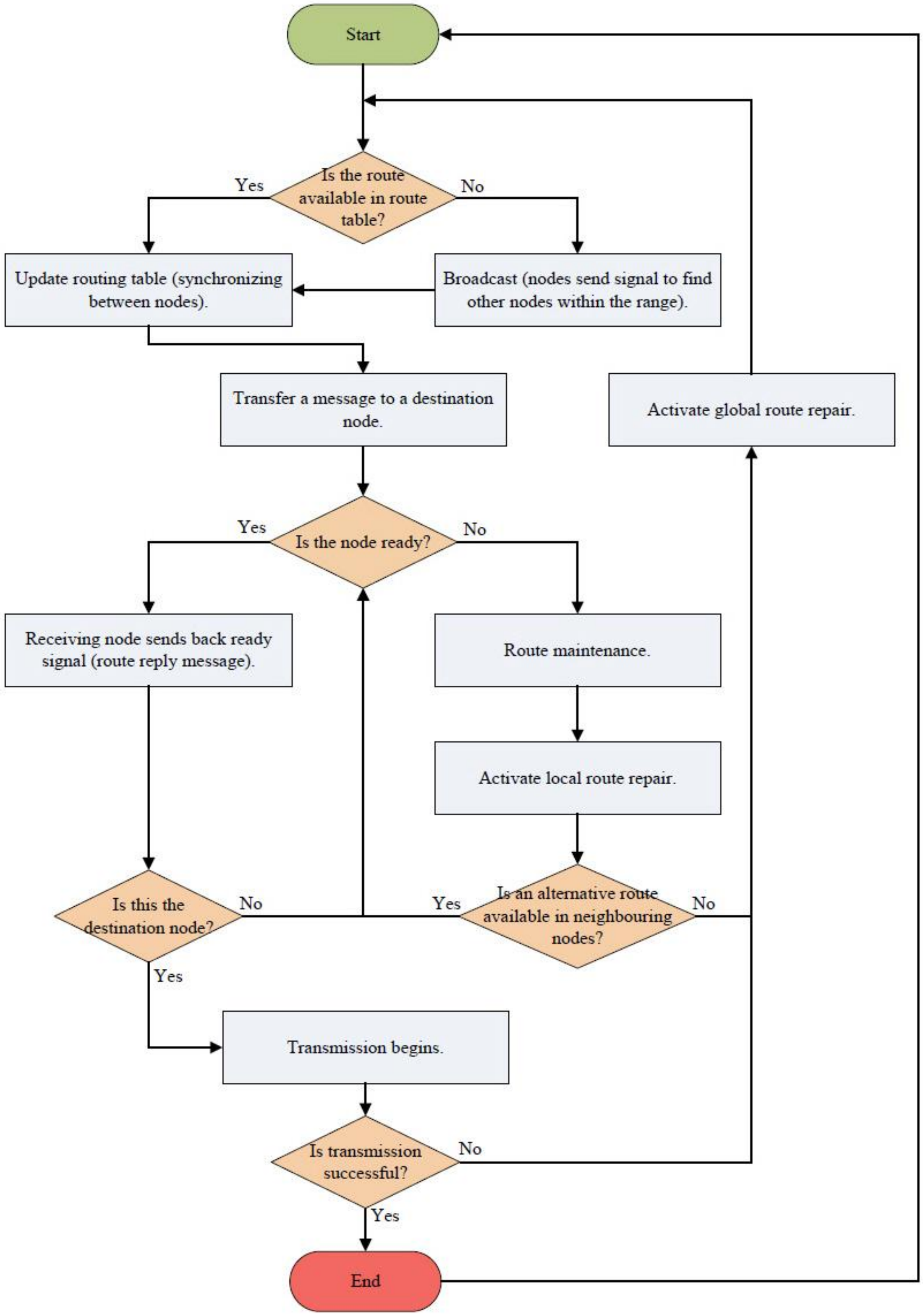

Figure 3.2. Routing Algorithm of AODV Protocol [24]

3.1.2 OLSR Routing Protocol

Optimized Link State Routing (OLSR) protocol belongs to the proactive routing category. OLSR always has available routes in its routing table. This protocol is designed to decrease the amount of retransmission duplicates. OLSR uses a mechanism of hop by hop for forwarding packets [24]. In order to make this possible, topological information is exchanged between nodes periodically by using multi point relay (MPR) nodes. MPR is a useful feature other protocols don't have. Additionally, OLSR has: neighbour sensing, HELLO and topology control messages as features. In OLSR protocol strategy, MPR nodes are selected to be used for forwarding control messages (TC). Since other nodes are unable to send these. Selecting MPR in the topology has the benefit of reducing the amount of control messages in the network, where the overhead of the network is minimized. Figure 3.3 shows MPR nodes and the way they forwarding messages. MPR nodes (G, I, B and S) as they shown in Figure 3.3, they periodically use TC messages to advertise the information about a link state to network nodes.

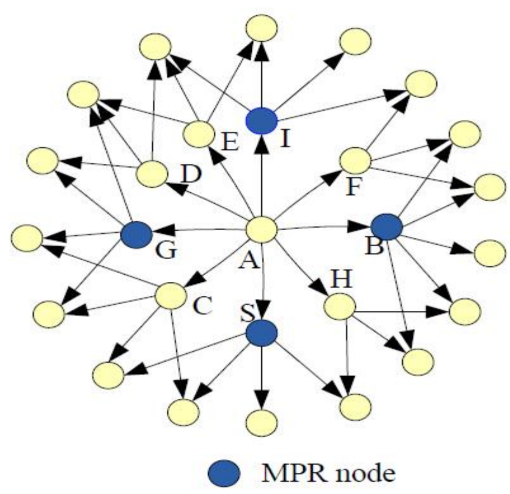

Figure 3.3. OLSR Multipoint Relays [24]

A HELLO message is periodically broadcast by each node for link sensing, neighbor detection and MPR selection process. A neighbor detection is a process where two nodes link, sense, and would consider each other as neighbors only if a link is established symmetrically. A HELLO message sent by a node contains its address and all the addresses of its neighbors. Each node can obtain topological information up to two hops from a HELLO message. The process of MPR selection uses information of one by one hop symmetric to make the calculation for MPR set again, i.e. MPR recalculation. This is occurs when a change in the 1st or 2nd hop neighborhood's topology has been detected. When it receives the update information, each node recalculates and updates the route to each known destination [24]. A TC message is used to broadcast topological information through the network, however, only MPR nodes are used to forward the TC messages to nodes in its routing table.

Figure 3.4 illustrates the OLSR routing protocol algorithm. It shows the process of transferring packets from a source to a destination. Firstly, the algorithm checks if the route to the destination is available in the routing table. If the route does not exist, the sender prepares a broadcast message to all possible routes. According to proactive behaviour of OLSR, the route must be available in the routing table, and it will be established by using a HELLO message to inform the receiver that the sender is ready to send a packet. Once the sender receives a route reply message (ready signal), it begins the data packet transmission process. If failure occurs a TC message is sent to update the topological changes in the MPR nodes.

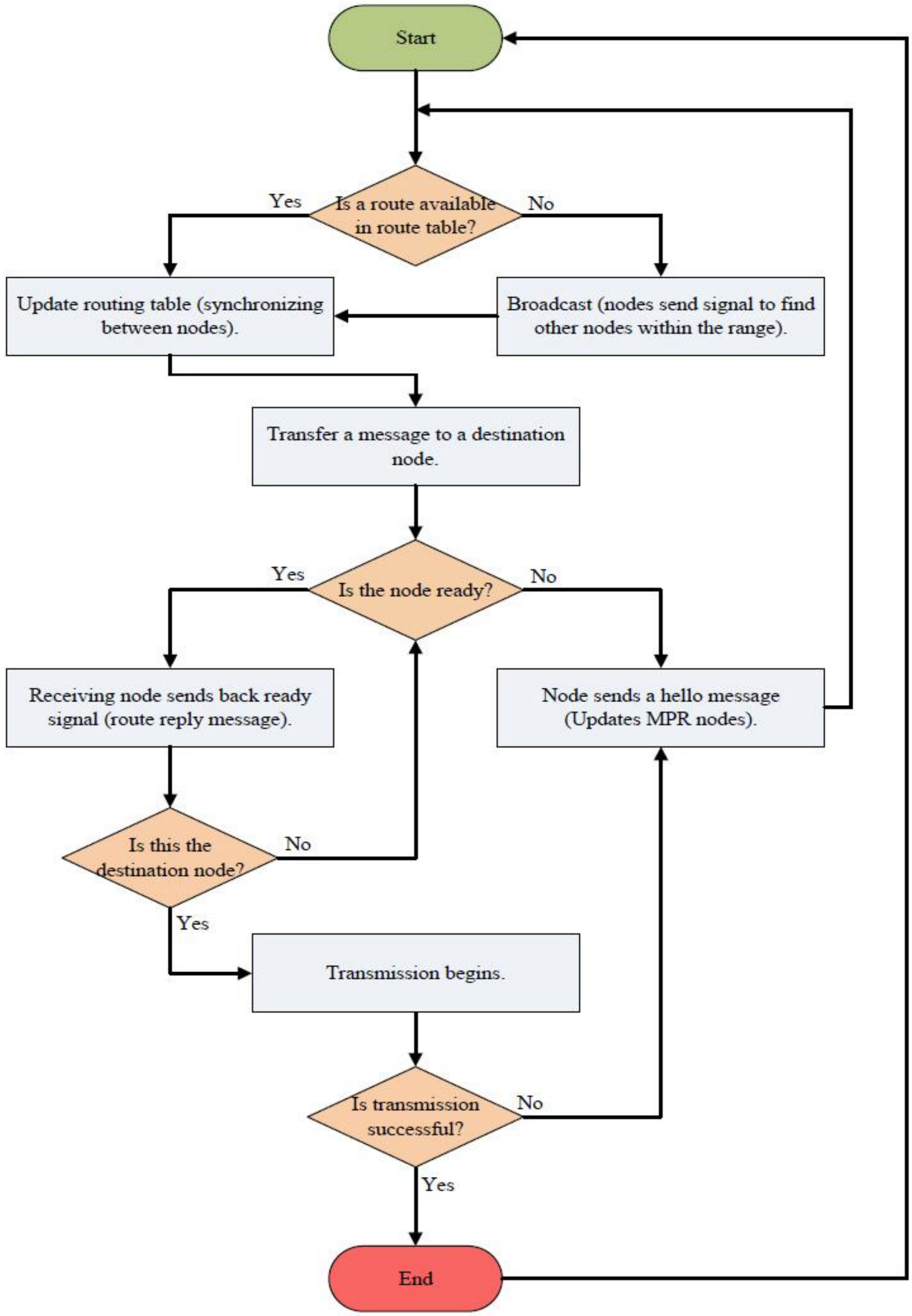

Figure 3.4. Routing Algorithm of OLSR Protocol [24]

3.2 OPNET Simulator

There are many simulators that can be used as tools to simulate networks and analyse the performance of routing protocols. A popular set of network simulators are: NS2, GloMoSim, QualNet and OPNET.

OPNET stands for Optimized Network Engineering Tool. It was first introduced in 1986 by MIT graduate [25]. OPNET simulator can be used for general purpose of network simulations. It is a discrete event and an object oriented simulator [26]. In this thesis, OPNET simulator was chosen because it contains the desired properties of a good network simulator. OPNET is one of the most measurable and efficient simulation tools due to its powerful characteristics such as comprehensive graphical user interface and animation. It also contains hundreds of protocol and builtin devices model with flexibility for examination and analysis.OPNET modules and embedded tools include: OPNET modeler, library of models, planner and tools for analysing. This simulator is extensively used for designing network models, evaluating, and analysing the performance of networks. Additionally, OPNET could be used to model ad hoc networks and evaluate the performance of their protocols.

OPNET simulator has both advantages and disadvantages. Main advantages are its user friendly graphical interface environment, and its customisable outputs of results. Also, OPNET consists of inclusive library, tools for network models, configurable protocols and source coding for models [27]. Main disadvantages are that OPNET is a commercial tool and an expensive simulator. Additionally, OPNET is complex for modelling networks, in that many details are required when configuring settings of a network. Furthermore, large amounts of CPU are consumed by OPNET processes, therefore, it requires high computational power.

3.2.1 Architecture of OPNET Modeler

OPNET modeller supports an inclusive advanced environment to make models for systems and evaluate their communication performance. OPNET contains a number of tools that are used for specific composing of modelling tasks. These tools are categorized into three types that represent three stages of a simulation project:

- Model specification
- Data collection and simulation
- Analysis

These stages must be performed in a sequence. The cycle of these stages starts with specification and ends with analysis, in return, in some cases specification is run again. Specification, in fact, is separated into two parts, initial specification and re-specification as is shown in Figure 3.5.

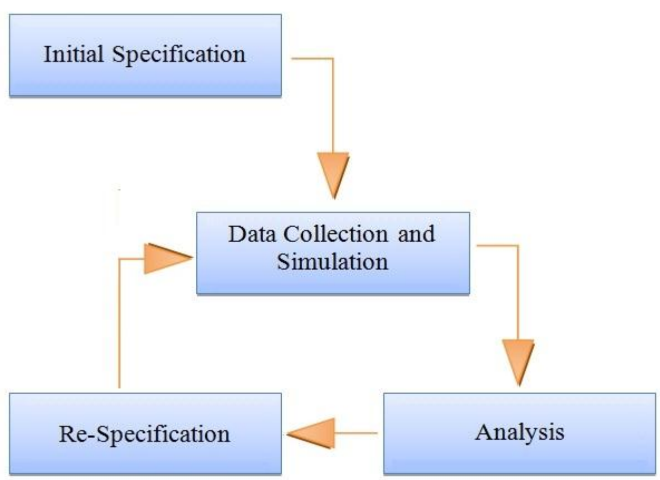

Figure 3.5. Simulation Flowchart of OPNET

3.2.2 OPNET Models of MANETs

There are different node models for MANETs which are supported by OPNET. All these nodes are included in the object palette of MANETs as shown in Figure 3.6. To evaluate the performance of ad hoc routing protocols, ad hoc network must be created using ad hoc object models. The models that are used mostly in MANET are:

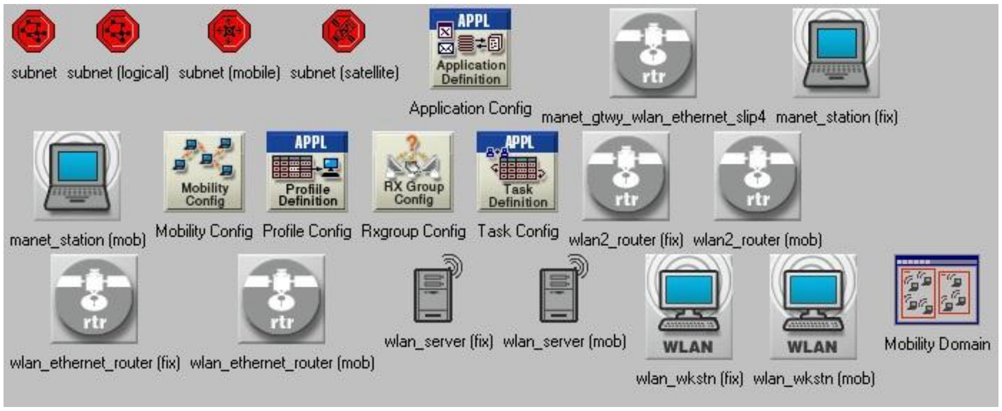

Figure 3.6. MANET Models of OPNET

- **Application Configuration**: this is used for configuring an application in the network. More than one application can be configured in one object model for a group of users. Multiple applications are organized by profile configuration object.
- **Profile Configuration**: this object is an intermediate between users and applications in the network. It is used to configure a profile for users. A user profile may consist of different types of applications (e.g., HTTP, FTP, Video conferencing, etc.) which can operate serially or concurrently.
- **Mobility Configuration**: using this object, nodes in the network can be configured as mobile nodes in the entire network. Different properties can be

configured for mobile nodes like: speed of movement, mobility domain, start time, stop time, etc.

- **Rx Group Configuration**: This object can be used to compute the set of receivers a source node can communicate with. For example using distance threshold as a condition criteria, nodes that are further away than the used distance will not be able to receive data from source node.
- **Wireless LAN Workstations and Servers**: These nodes can be used to utilize the configured applications. The server node is used to configure an application in the entire network to provide a specific service (HTTP, FTP, Video conferencing, etc.). Workstations are used as destinations of this data traffic.

3.2.3 Routing Protocol Configurations

Ad hoc routing protocol configurations means specifying how the target protocol is going to work. There are many parameters in each routing protocol that can be used to change the properties of a used protocol. Figure 3.9 shows parameters of AODV routing protocol.

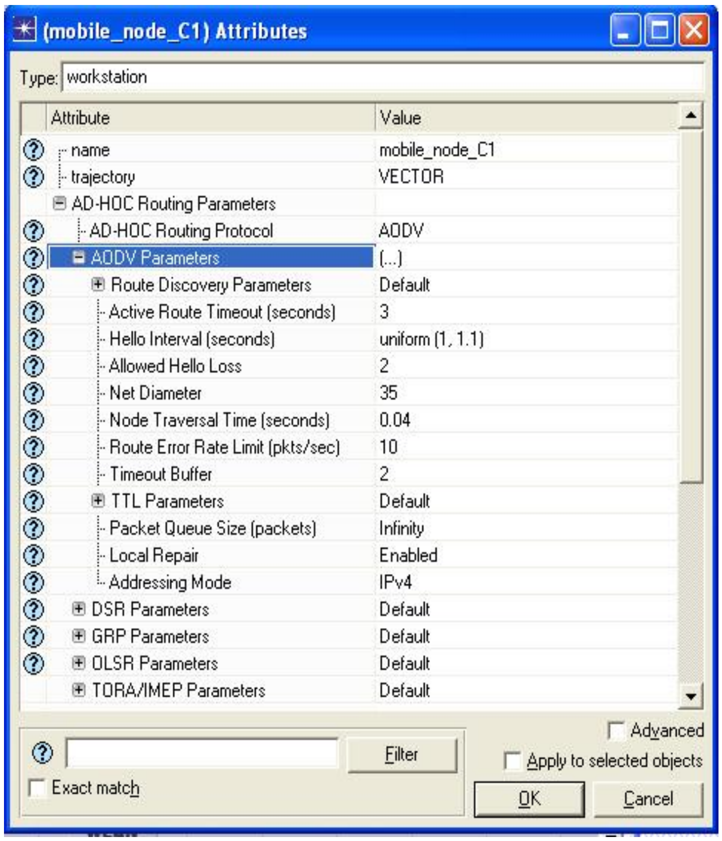

Figure 3.7. AODV Routing Protocol Configurations

3.2.4 Simulation Run and Results

Before running simulation on OPNET, the simulation statistics must be selected in order to be able to see and analyse the simulation results. Choosing statistics depends on the type of application. Each application has some statistics that are related and important for this application, for example, jitter (sec) used for audio application and page response time (sec) used for HTTP. Additionally, each routing protocol has its own statistics to show the performance of the used protocol. Figure 3.8 illustrates the dialog box of choosing statistics in OPNET module.

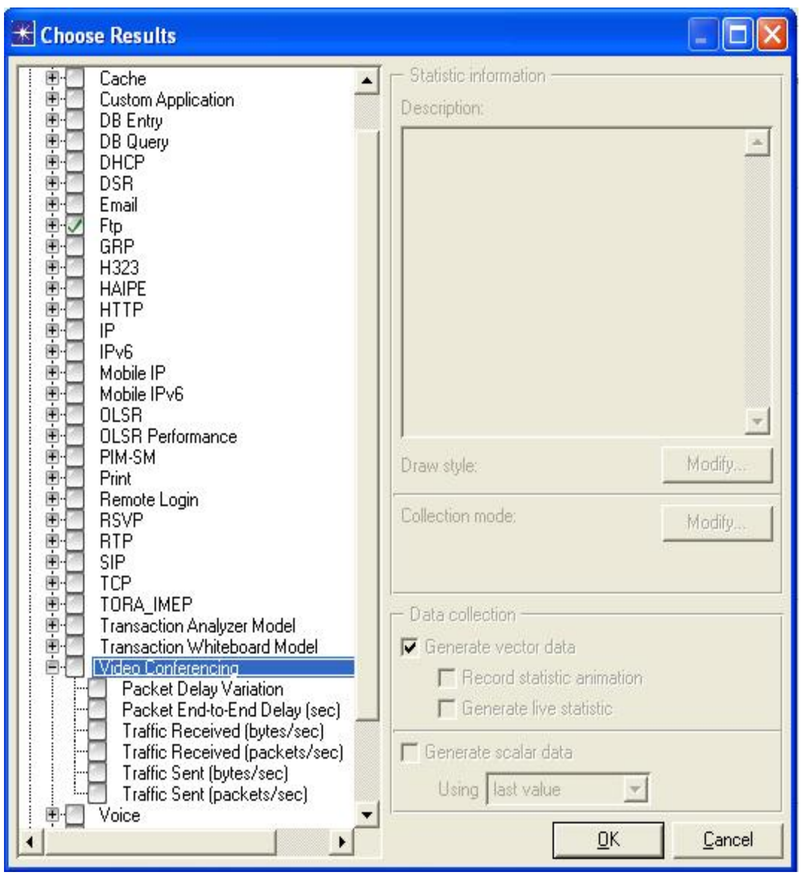

Figure 3.8. Simulation Statistics in OPNET

Chapter 4

MODELING AD HOC NETWORKS IN OPNET, SIMULATION SETUP AND RESULTS

4.1 Performance Metrics

In order to analyse and evaluate the performance of routing protocols, some performance metrics must be used to show the behavior of each routing protocol. To analyse the performance of protocols, we used number of hops per route, route discovery time, routing traffic received and routing traffic sent. For comparing the performances of protocols, we used packet delay variation, packet end-to-end delay and normalized routing load. Here is the description of the used performance metrics:

Number of hops per route: This statistic represents the number of hops (nodes) in every route to every destination in the route table of all nodes in the network. This calculation is done by taking values of hops in all routes that are used for all packets to arrive at all destinations in the network and gives the result as an average.

Route discovery time (sec): The time to discover a route to a specific destination is the time from which a route request was sent out to discover a route to that destination until the time a route reply is received with a route to that destination. This metric is calculated for all nodes in the network (in second), and gives a mean for the time elapsed in discovering routes for all nodes.

Routing traffic received (Pkts/sec): It represents the total amount of routing traffic packets received by all nodes in the network per second.

Routing traffic sent (Pkts/sec): It represents the total amount of routing traffic packets sent by all nodes in the network per second.

Packet delay variation (sec): It is a variation between end-to-end delays for video packets. For a video packet, end-to-end delay is measured from the time it is created to the time it is received. This is a very important metric for real time applications like video conferencing.

Packet end-to-end delay (sec): It measures the time spent for sending a packet from the application layer of sender to application layer of the destination node. This statistic records data from all nodes in the network.

Normalized routing load (NRL): This metric is used to determine the amount of routing traffic done by the protocol in order to receive data packets. It is calculated as the ratio of the total number of routing packets sent by all nodes over the number of data packets received by destinations [6].

$$\text{NRL} = \frac{\text{Number of routing traffic sent.}}{\text{Number of data packet received}}$$

4.2 Modelling of Ad Hoc Network in OPNET and Simulation Setup Parameters

OPNET simulator version 17.1 is used for creating an ad hoc network environment. OPNET provides the required objects to create and configure ad hoc network with desirable properties that will run almost a real ad hoc network. The objects used in this network simulation are mobile nodes (computers). Application configuration object is used to configure video conference application and creating data traffic; profile configuration object is used to configure a profile for users, and Rxgroup configuration is used to configure the receiver group. Simulation setup and important parameters are described in the following sections.

4.2.1 Network Configurations

The simulation environment area is set to 500mx500m [1], [6]. Nodes are distributed randomly in the entire network with two network density cases: low density with 25 nodes and high density with 80 nodes [1], [3]. Figure 4.1 shows the network environment of 25 nodes.

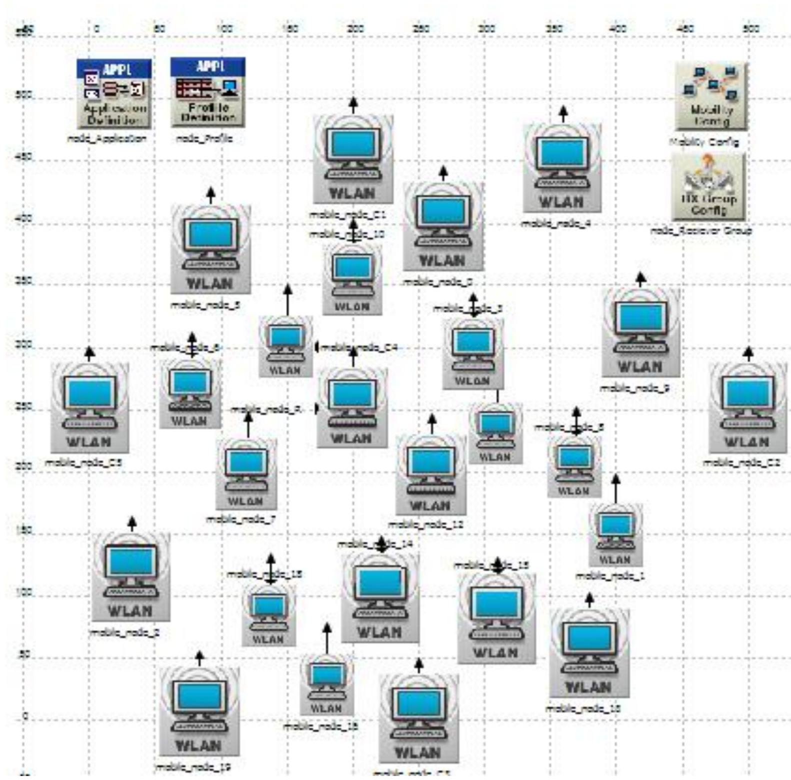

Figure 4.1. Network Environment of 25 Nodes

Nodes in this network are configured with two cases of mobility. In the first case, nodes are configured as fixed (implying that no mobility profile was configured during the whole simulation time). In the second case, nodes are configured with mobility profile (Random Waypoint) with the mobility parameters shown in Table 4.1. Nodes in the network will move with a speed changing from 0 to 1m/s. Nodes will start to move after 5 seconds from starting of the simulation time, and they will continue moving to the end of the simulation time.

Table 4.1. Configurations of Node Mobility

Parameter	**Value**
Area of mobility	500m x 500m
Speed (meters/seconds)	Uniform(0,1)
Start time	Constant(5)
End time	End of Simulation

4.2.2 Distribution of Nodes

Nodes that will communicate with the server are initially assigned to positions where they are made to use one or more intermediate nodes to arrive at the destination node. For example, the distance between the caller node (node_C1), which wants to make a video call to called node (node_R) is 200 meters. Therefore, it will use an intermediate node to arrive at the destination because the coverage area of receiving is set to 150 meters in the RXgroup configuration object. Figure 4.2 shows the initial positions of nodes in case of five clients communicating with the server node (node_R). Figure 4.2 shows (X, Y) positions of nodes in the network area.

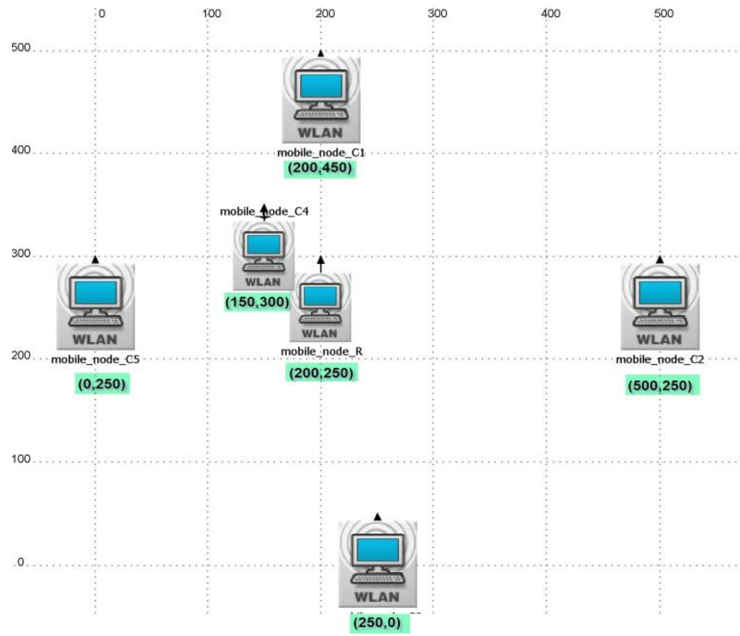

Figure 4.2. Initial Positions of Communicating Nodes

As is shown in Figure 4.2, the server node (node_R) is in position (200,250). X,Y position of all clients (node_Ci) are shown in Table 4.2.

Table 4.2. Distance in Meters Between Server and Clients

Node	**Position X , Y (meters)**	**Distance to node_R (meters)**
Node_C1	200 , 450	200
Node_C2	500 , 250	300
Node_C3	250, 0	200
Node_C4	150 , 300	70.7
Node_C5	0 , 250	200

These are only initial positions, and they will change during the simulation running. The remaining nodes are distributed randomly in the simulation network area in both 25 and 80 nodes' cases.

4.2.3 Application Configuration

The application used in this study is interactive video conferencing. It lets users communicate and transfer video streaming frames across the network in both directions. Video conferencing is modeled in OPNET as is shown in Figure 4.3.

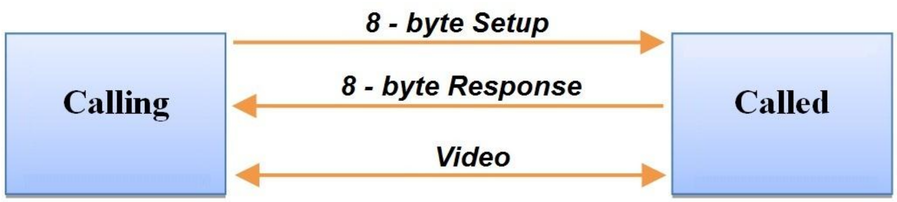

Figure 4.3. Modeling of Video Conferencing in OPNET

The calling node which wants to make a video conferencing sends a message of 8-byte size as a request to the called node, after which the called node will likewise respond with on 8-byte size message to the calling node. Then the video conferencing will begin with transmitting video frames in both directions. The frame size for a configured video conferencing is 17280 bytes and has the interval time 0.1 or 10 frames per second which will be sent from communicating nodes with video conferencing application. The parameters of application are shown in Table 4.3.

Table 4.3. Video Conference Application Parameters

Parameters	**Value**
Application Name	Video Conference
Video Type	Low Resolution
Incoming Frame Size	17280 bytes
Outgoing Frame Size	17280 bytes
Frame Interracial Time	10 frame/second

Thus, the amount of transferred data for interactive video conferencing is calculated as:

Amount of data transferred /second = frame size * 10*2

Amount of video data transferred /second= 17280 *10*2= 345600 bytes/second

Not all nodes are communicating with video conference during simulation, the number of nodes that do this changes from one scenario to another. Three different scenarios are used with different number of clients 1, 3 and 5. Figure 4.4 illustrates the transmission of video packets between nodes in a situation where five clients communicate with the server.

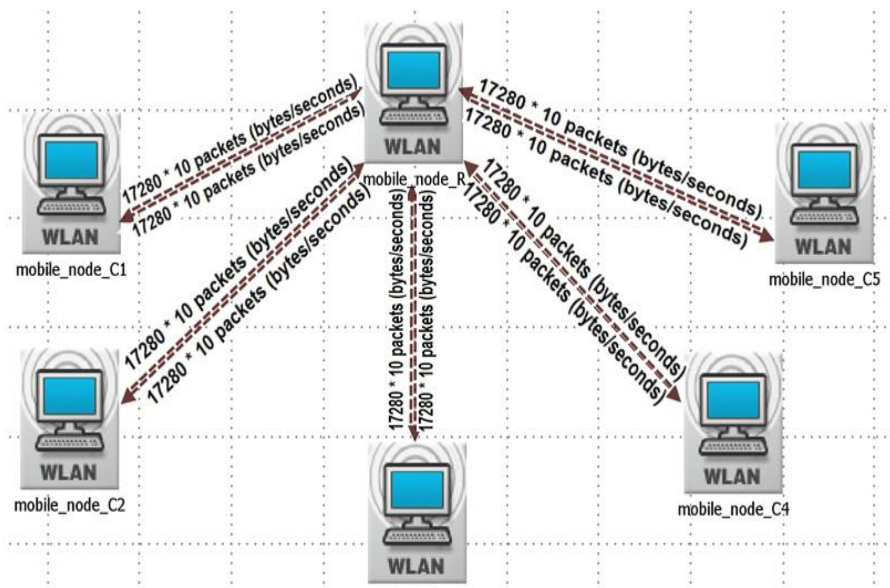

Figure 4.4. Video Frames between Nodes

4.2.4 Profile Configurations

In all simulations, simulation time is set to 1000 seconds and a user profile is configured to start after 60 seconds of starting the simulation. After 30 seconds of running profile the application will start as is shown in Figure 4.5. The application's duration is set to the end of the last task of video conferencing, and the application repetition is set to unlimited so it will be repeated during the whole simulation time.

Table 4.4. Profile and Application Simulation Parameters

Configuration	Parameter	Value
Profile	Start Time (Second)	Constant (60)
	Duration	End of Simulation
	Repeatability	Once at start Simulation
Application	Start Time (Second)	Constant (30)
	Duration	End of Last Task
	Inter Repetition Time	Exponential (0.5)
	No. of repetitions	Unlimited

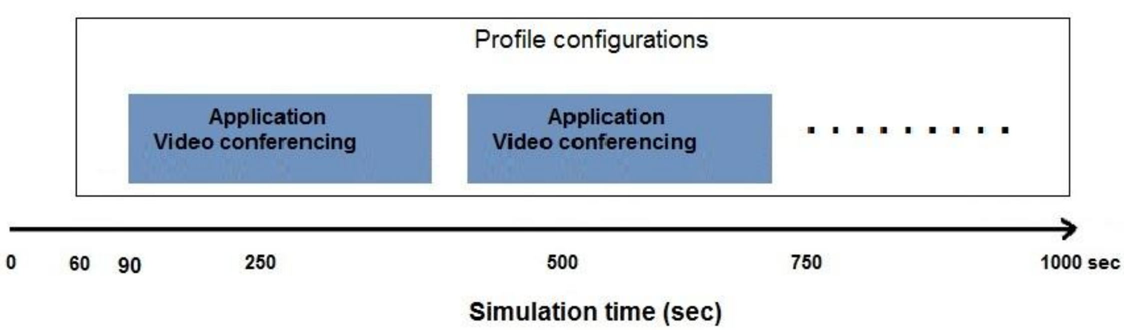

Figure 4.5. Simulation Time Graph

4.2.5 Nodes Configuration

According to the type of work, nodes in the simulation are divided into three categories: clients, server and intermediate. These nodes are configured as follows:

- **Caller Node (Clients)**: In this node, application settings will be configured in section application supported profile; the name of profile is set to be (Vdo_pro). Furthermore, in this section, application destination preference and actual name of server must be set.
- **Called Nodes (Server)**: For this node only application supported service parameter will be configured with the name of the video application.
- **Intermediate Nodes:** These nodes will only act as intermediate between communicating nodes and video conferencing. No application settings will be configured to them

The wireless network for all nodes is set to wireless standard IEEE 802. 11g with the data rate of 54 Megabits per second. The buffer size is set to 1024000, used to store video frames before they arrive to the application layer. Simulation parameters are shown in Table 4.5.

Table 4.5. Wireless Parameters of Nodes

Parameters	**Value**
Physical Characteristic	Direct Sequence
Data Rate(bps)	54Mbps
Buffer Size	1024000 bits
Transmit Power	0.005W

The transmission power is set to 0.005W. Using this power as described in [25], the range of transmission will arrive at about 1000 meters. Therefore all nodes will be in the coverage area of each other. Due to that, the intermediate nodes will not be used, and the network will not be represented as a truly ad hoc network. To solve this problem, a restriction on transmission distance was used. Nodes further away than 150 meters will not receive video frames from the sender. In the network structure, we choose initial positions of communicating nodes with video conferencing to make the distance between themes more than 150 meters as shown in Figure 4.2. This is to make it possibility to use intermediate nodes when nodes are communicating.

The range of receiving packets is restricted by using a configurable object in OPNET named Receivers Group configurations. The duration of applying these configurations is set to start at the beginning of the simulation and at the end of the simulation. Refresh Interval is set to never, because these settings are fixed during the whole simulation time. A channel match criterion is set to all channels in the network. The distance threshold is set to 150 meters for the reasons mentioned in above section. Receivers Group object parameters are in Table 4.6.

Table 4.6. Receiver Group Object Parameters

Parameters	**Value**
Begin Time (Second)	Start of simulation
End Time (Second)	End of simulation
Refresh Interval (Second)	Never
Channel Match Criteria	All Channels
Distance Threshold (meters)	150

4.3 Analysis of Protocols for Different Scenarios and Simulation Results

In order to analyse and evaluate the performance of routing protocols different scenarios are created by changing node density, number of clients and mobility for AODV and OLSR protocols. For each protocol, we set the number of nodes to 25 and 80 with a different number of clients 1, 3 and 5 in both cases of fixed and mobile nodes. Totally, 24 scenarios were created, 12 for each protocol. Table 4.7 shows the scenarios of each protocol.

Table 4.7. Scenarios of Each Protocol

Network density	25 Nodes						80 Nodes					
Mobility	Fixed			Mobile			Fixed			Mobile		
Number of clients	1	3	5	1	3	5	1	3	5	1	3	5

Results for performance metrics of these scenarios are collected by taking the mean value of four runs for each scenario.

Tables 4.8- 4.11 presents simulation results of AODV protocol for mobile and non-mobile nodes with 25 and 80 nodes in the network.

Table 4.8. Simulation Results of AODV Protocol with 25 (fixed) Nodes in The Network

Performance metrics	**Number of clients**		
	1	**3**	**5**
Number of hops per route	1.5690	2.5616	2.7895
Route Discovery Time (sec)	0.0371	0.0585	0.1054
Routing Traffic Received(pkts/sec)	50.10	305.27	397.14
Routing Traffic Sent(pkts/sec)	10.37	81.34	109.65
Packet Delay Variation (sec)	0.0004	0.0867	0.2456
Packet End-to-end delay (sec)	0.0250	0.0525	0.1163
Normalized routing traffic	0.5744	1.6827	2.0383

Table 4.9. Simulation Results of AODV Protocol with 80 (Fixed) Nodes in the Network

Performance metrics	**Number of clients**		
	1	**3**	**5**
Number of hops per route	1.2670	1.6093	2.2737
Route Discovery Time (sec)	0.1407	0.1442	0.1882
Routing Traffic Received (pkts/sec)	385.51	1618.02	5629.85
Routing Traffic Sent (pkts/sec)	25.80	128.45	498.49
Packet Delay Variation (sec)	0.0264	0.0650	0.3631
Packet End-to-end delay (sec)	0.0236	0.0426	0.1891
Normalized routing traffic	1.4295	2.6345	9.2700

Table 4.10. Simulation Results of AODV Protocol with 25 (Mobile) Nodes in the Network

Performance metrics	**Number of clients**		
	1	**3**	**5**
Number of hops per route	1.6561	2.6206	3.0715
Route Discovery Time (sec)	0.1715	0.2206	0.2161
Routing Traffic Received (pkts/sec)	53.78	224.71	507.55
Routing Traffic Sent (pkts/sec)	11.82	62.91	150.02
Packet Delay Variation (sec)	0.0192	0.1265	0.3591
Packet End-to-end Delay (sec)	0.0444	0.1042	0.1971
Normalized routing load	0.6975	1.5517	3.2134

Table 4.11. Simulation Results of AODV Protocol with 80 (Mobile) Nodes in the Network

Performance metrics	**Number of clients**		
	1	**3**	**5**
Number of hops per route	1.2827	1.7252	2.3650
Route Discovery Time (sec)	0.2355	0.2355	0.2355
Routing Traffic Received (pkts/sec)	392.16	2131.09	6450.02
Routing Traffic Sent (pkts/sec)	27.33	181.08	592.18
Packet Delay Variation (sec)	0.0169	0.5067	0.9312
Packet End-to-end delay (sec)	0.0374	0.0750	0.2220
Normalized routing load	1.5979	4.0886	11.9944

AODV routing protocol is analysed using number of hops per route, route discovery time, routing traffic sent and routing traffic received metrics.

Figures 4.6 and 4.7 present number of hops per route with respect to number of clients with other parameters.

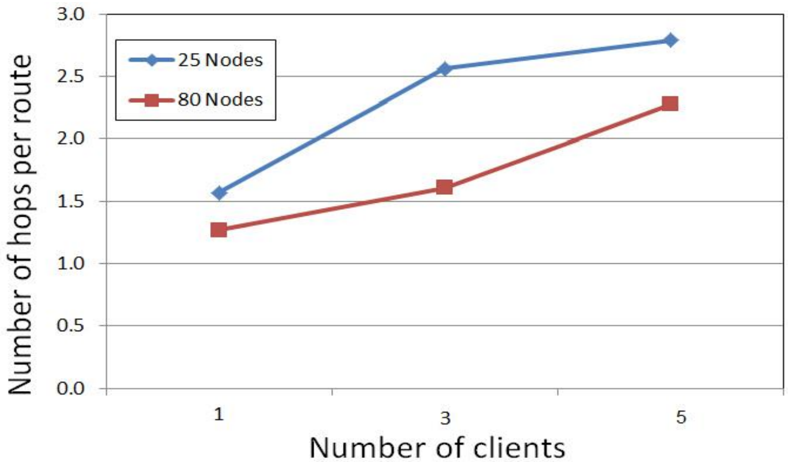

Figure 4.6. Number of Hops Per Route for AODV with 25 and 80 Fixed Nodes

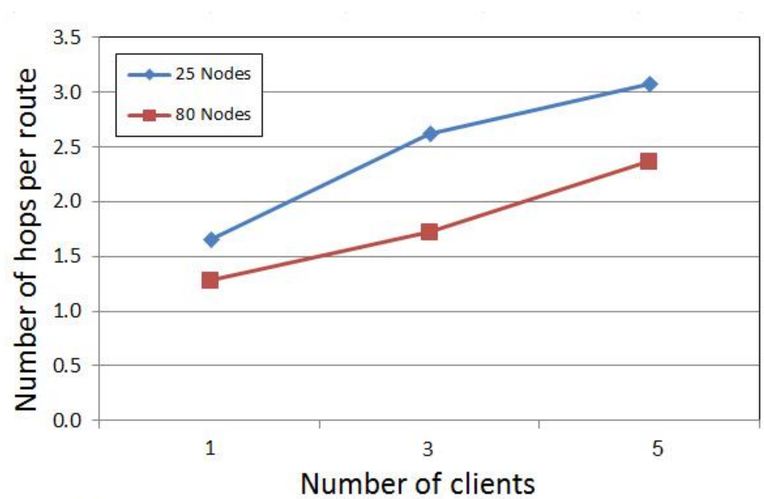

Figure 4.7. Number of Hops Per Route for AODV with 25 and 80 Mobile Nodes

As shown in Figure 4.6, the number of hops measured with 80 nodes network is less than with 25 nodes network. This is due to the fact that the numbers of one hop per route is greater in case of 80 nodes than 25 nodes, and this metric uses the average of the number of hops per route used during simulation running. The hops per route between client and server in 25 and 80 may not be too different because AODV is a reactive protocol and the routing packets are only used when the client wants to communicate with the server. There is a difference between fixed and mobile nodes. In mobile nodes the peak value is greater than the fixed. If we compare Figure 4.6 with Figure 4.7, this difference is due to the fact that when nodes are moving, the distance between clients and server becomes greater than when they were in initial positions.

Figures 4.8 and 4.9 present route discovery time with respect to number of clients with other parameters.

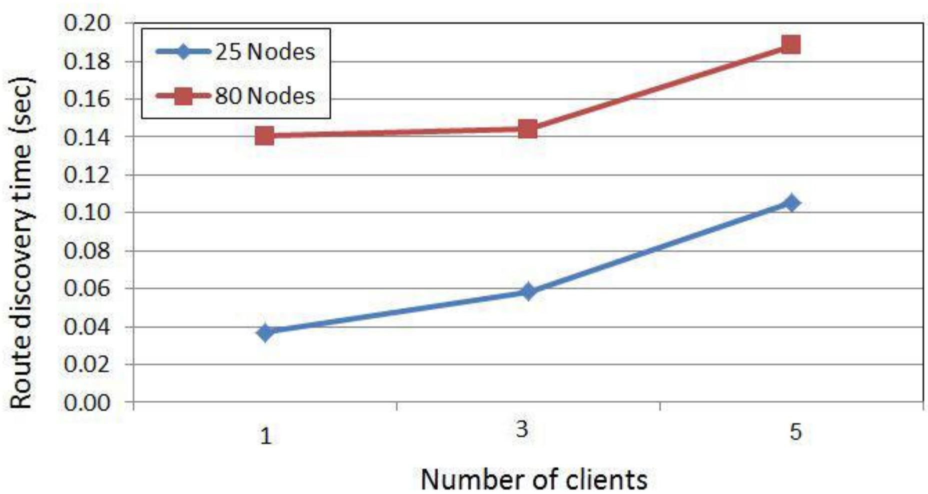

Figure 4.8. Route Discovery Time for AODV with 25 and 80 Fixed Nodes

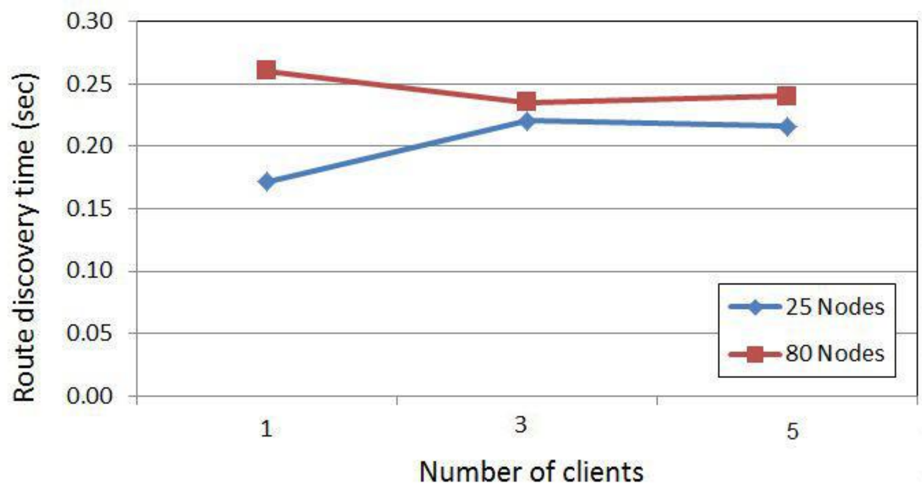

Figure 4.9. Route Discovery Time for AODV with 25 and 80 Mobile Nodes

The time required to discover a route in a 80 nodes' scenario is greater than in a 25 nodes' network, as shown in Figure 4.9. This difference is due to more intermediate nodes being required before arriving at the destination. In mobile cases, the values are generally increased in 1, 3 and 5 clients, due to the changes occurring in the nodes' positions. Furthermore, the difference between 25 and 80 nodes' scenarios in Figure 4.8 is greater than the difference in Figure 4.9 because of nodes mobility.

Figures 4.10 and 4.11 present route discovery time with respect to number of clients with other parameters.

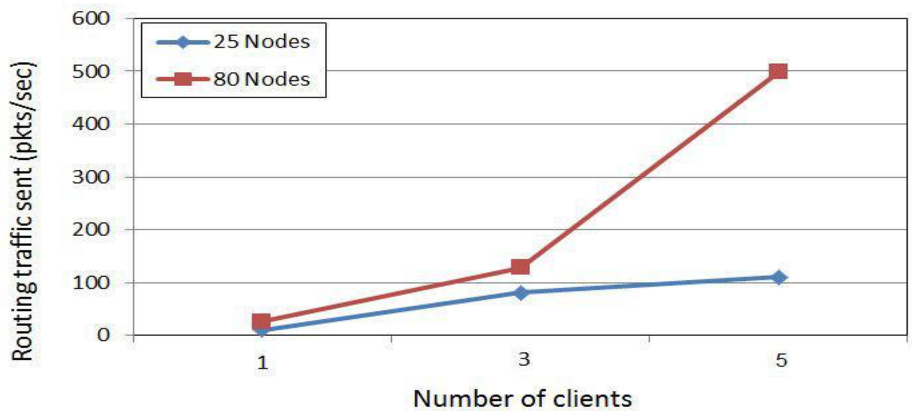

Figure 4.10. Routing Traffic Sent for AODV with 25 and 80 Fixed Nodes

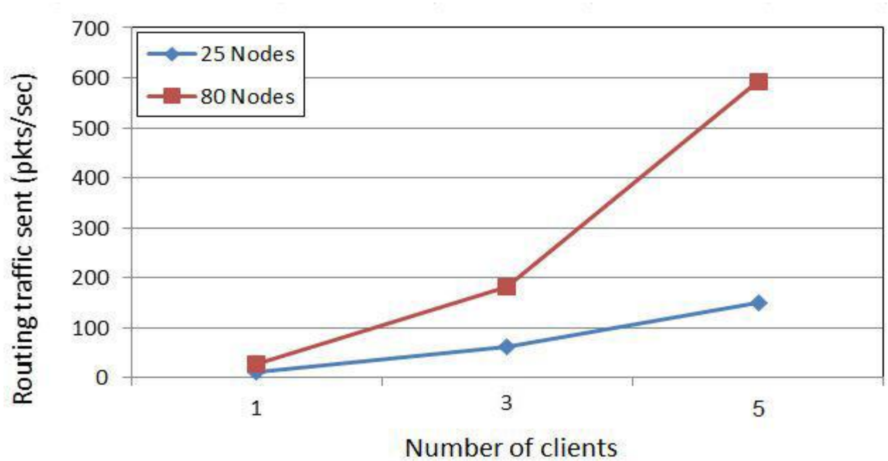

Figure 4.11. Routing Traffic Sent for AODV with 25 and 80 Mobile Nodes

As shown in Figure 4.10, the number of sent routing packets increases where there is an increasing number of clients 1, 3 and 5, because there will be an increasing number of requests. The difference between 25 and 80 nodes is increased by increasing the number of clients because of the behaviour of the reactive protocol. In mobile cases, the number of sent routing packets increases due to nodes' mobility leading to the loss of some packets. Therefore, more routing packets are required to be sent in order to discover the path.

Figures 4.12 and 4.13 present routing traffic received time with respect to number of clients with other parameters.

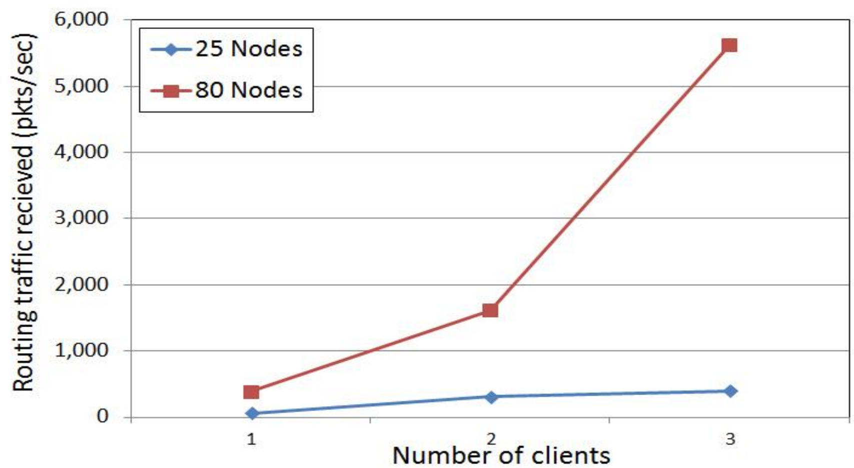

Figure 4.12. Routing Traffic Received for AODV with 25 and 80 Fixed Nodes

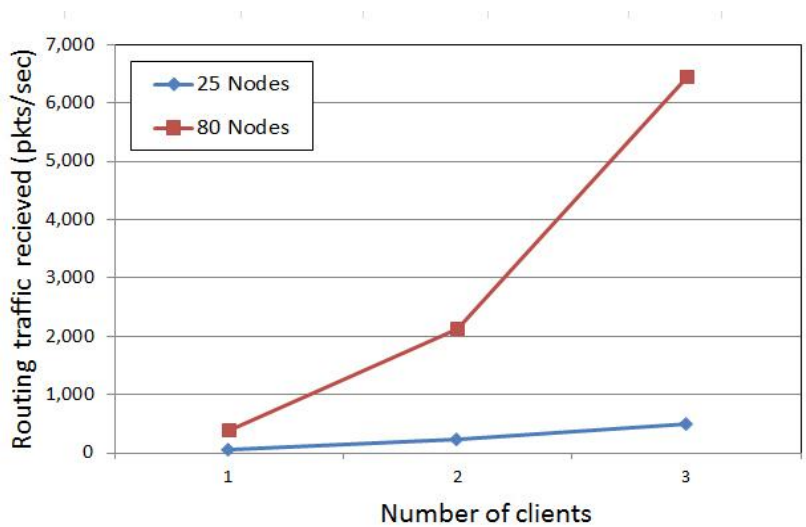

Figure 4.13. Routing Traffic Received for AODV with 25 and 80 Mobile Nodes

As shown in Figure 4.12, there is a large difference in the amount of routing traffic received between 25 and 80 nodes' networks. This difference is because of the reactive behaviour of AODV, by increasing number of clients requesting to communicate. Comparing routing traffic received figures in both cases fixed and mobile with routing traffic sent graphs in Figure 4.10 and Figure

4.11, we will see that routing traffic received have greater values, this is because of flooding process when nodes are searching for the destination node.

Tables 4.12- 4.15 presents simulation results of OLSR protocol for mobile and non-mobile nodes with 25 and 80 nodes in the network.

Table 4.12. Simulation Results of OLSR Protocol with 25 (Fixed) Nodes in the Network

Performance metrics	**Number of clients**		
	1	**3**	**5**
Routing Traffic Received(pkts/sec)	407	392	393
Routing Traffic Sent(pkts/sec)	67.55	72.26	77.96
Packet Delay Variation (sec)	0.0001	0.0016	0.0090
Packet End-to-end delay (sec)	0.0213	0.0399	0.0879
Normalized routing traffic	3.7291	1.4265	1.1232

Table 4.13. Simulation Results of OLSR Protocol with 80 (Fixed) Nodes in the Network

Performance metrics	**Number of clients**		
	1	**3**	**5**
Routing Traffic Received (pkts/sec)	9398	9682	10363
Routing Traffic Sent (pkts/sec)	524.55	587.13	677.77
Packet Delay Variation (sec)	0.0001	0.0004	0.0293
Packet End-to-end delay (sec)	0.0228	0.0228	0.1398
Normalized routing traffic	29.0469	11.8611	11.4680

Table 4.14. Simulation results of OLSR Protocol with 25(Mobile) Nodes in the Network

Performance metrics	**Number of clients**		
	1	**3**	**5**
Routing Traffic Received (pkts/sec)	397	381	391
Routing Traffic Sent (pkts/sec)	70.0	73.6	79.6
Packet Delay Variation (sec)	0.0012	0.0138	0.0405
Packet End-to-end delay (sec)	0.0431	0.0606	0.1139
Normalized routing load	4.6977	1.8870	1.5111

Table 4.15. Simulation Results of OLSR Protocol with 80 (Mobile) Nodes in the Network

Performance metrics	**Number of clients**		
	1	**3**	**5**
Routing Traffic Received (pkts/sec)	9091	9535	9866
Routing Traffic Sent (pkts/sec)	519.7	591.2	652.9
Packet Delay Variation (sec)	0.0004	0.0106	0.0461
Packet End-to-end delay (sec)	0.0270	0.0684	0.1322
Normalized routing load	17.2403	43.6420	53.5068

OLSR routing protocol is analysed using traffic sent and routing traffic received metrics.

Figures 4.14 and 4.15 present routing traffic sent with respect to number of clients with other parameters.

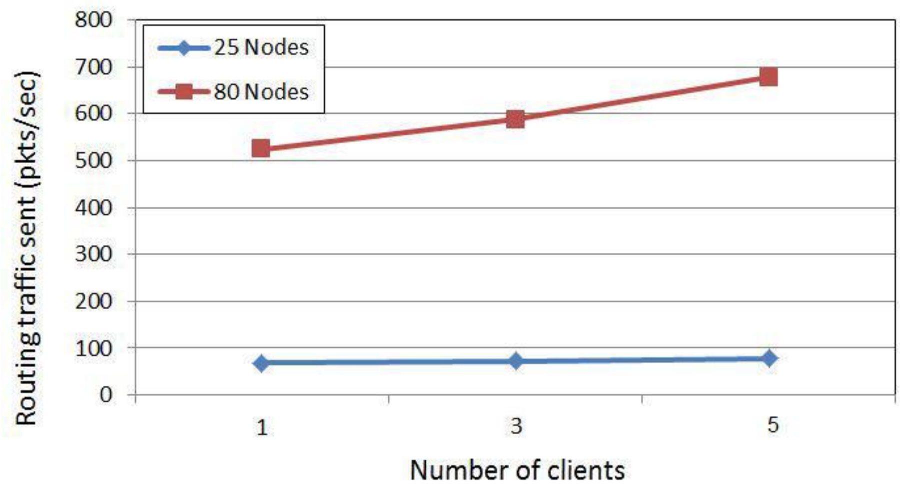

Figure 4.14. Routing Traffic Sent for OLSR with 25 and 80 Fixed Nodes

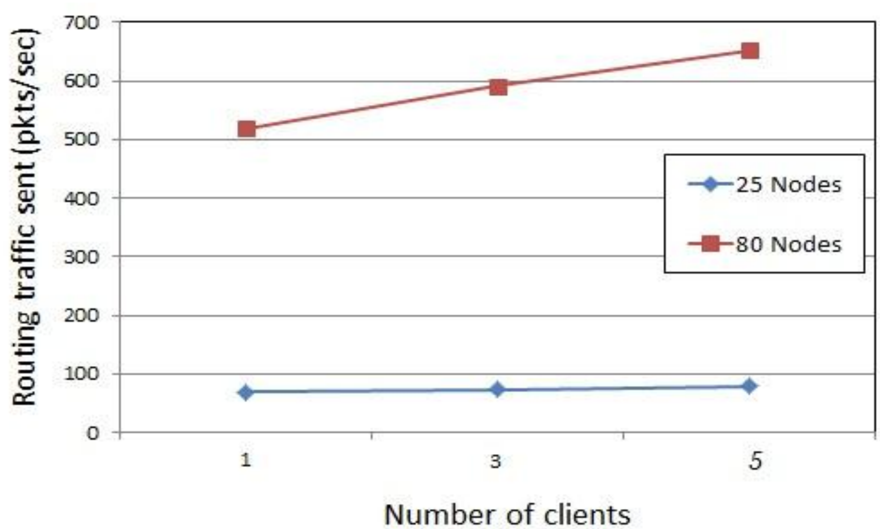

Figure 4.15. Routing Traffic Sent for OLSR with 25 and 80 Mobile Nodes

Even when only one client communicates with the server, the amount of routing sent is high due to the proactive protocol type. Nodes in this network are continuously sending routing packets to reachable nodes to update the routing table when changes occur to network topology. The amount of routing traffic sent in mobile case is as shown in Figure 4.14. It is more than in the fixed case because of the change in topology and the need to update the routing table.

Figures 4.16 and 4.17 present routing traffic received with respect to number of clients with other parameters.

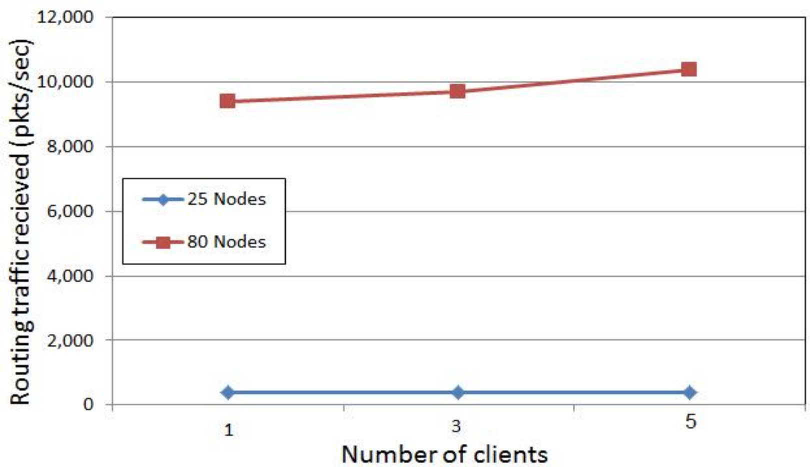

Figure 4.16. Routing Traffic Received for OLSR with 25 and 80 Fixed Nodes

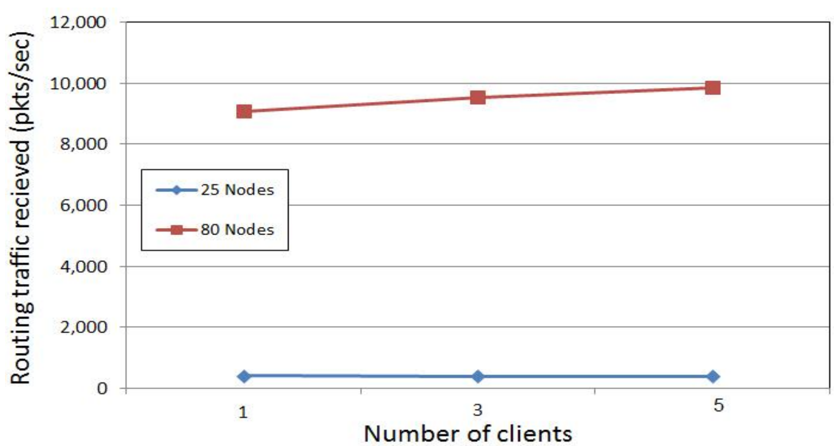

Figure 4.17. Routing Traffic Received for OLSR with 25 and 80 Mobile Nodes

Comparing Figure 4.14 and Figure 4.15 with routing received graphs, the amount of received packets is greater than in the situation of AODV because of the flooding process when nodes are discovering routes to the destination.

4.4 Performance Comparison of Protocols AODV and OLSR

To make a comparison between these protocols based on video conferencing, we used a number of performance metrics. We used packet delay variation which is very useful for real time applications like video conferencing, because packets that do not arrive in transmission order are useless and may be discarded. Also, packet end-to-end delay is used, which is especially important for applications like video conferencing having less end-to-end delay, where the number of discarded packets will be small and the quality of video will be good. Additionally, normalized routing load is used (this metric does not exist in OPNET). This is calculated from the routing traffic packets sent and data packets received to see the scalability of these protocols.

Investigation of protocols based on packet delay variation: The results of packet delay variation are calculated under nodes' mobility and network density.

1. **Comparison of Protocols in Fixed Nodes Network**

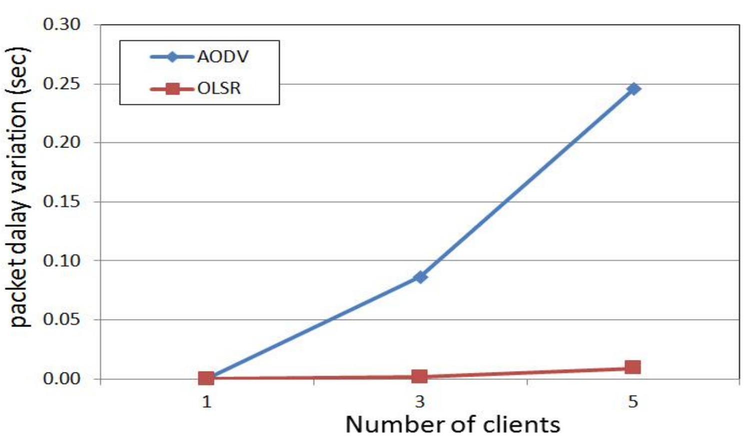

Figure 4.18. Packet Delay Variation of AODV, OLSR for 25 Fixed Nodes

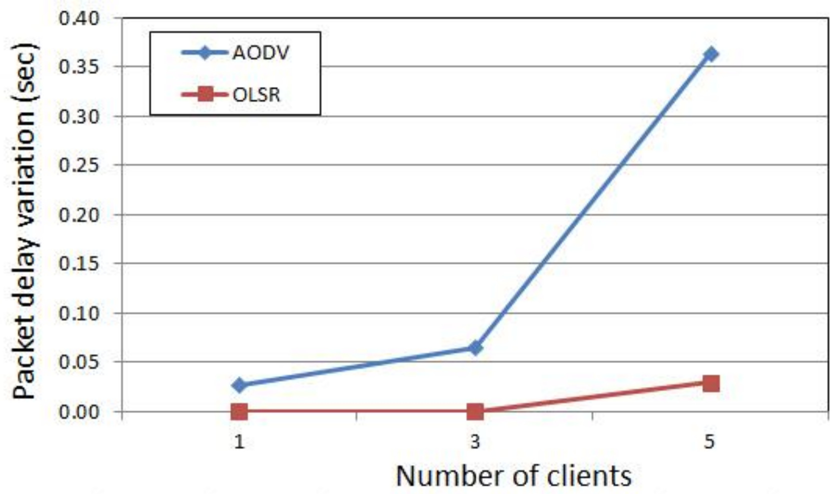

Figure 4.19. Packet Delay Variation of AODV, OLSR for 80 Fixed Nodes

The variation between delivering packets in OLSR is small compared with AODV. This is good behaviour from OLSR, especially for video conferencing. According to the packet delay variation, it can be said that OLSR performs better than AODV in both 25 and 80 nodes' cases as shown on Figure 4.18 and 4.19.

2. Comparison of Protocols in Mobile Nodes Network

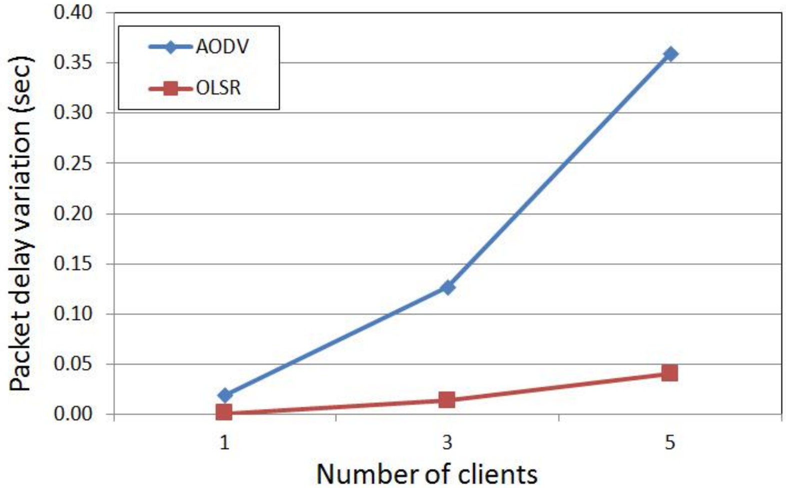

Figure 4.20. Packet Delay Variation of AODV, OLSR for 25 Mobile Nodes

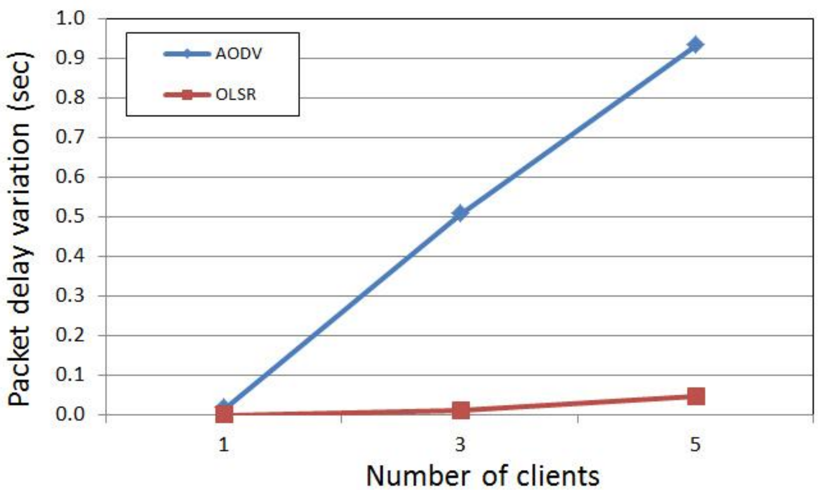

Figure 4.21. Packet Delay Variation for AODV, OLSR of 80 Mobile Nodes

Packet delay variation in mobile nodes' mode increased if we compare Figures 4.20 and 4.21 with fixed mode graphs. This is because of the changing nodes' positions during the simulation run. OLSR still performs better than AODV in both 25 and 80 nodes' cases.

Investigation of protocols based on packet end-to-end delay: The results of the packet end-to-end delay are calculated under nodes' mobility and network density.

1. **Comparison of Protocols in Fixed Nodes Network**

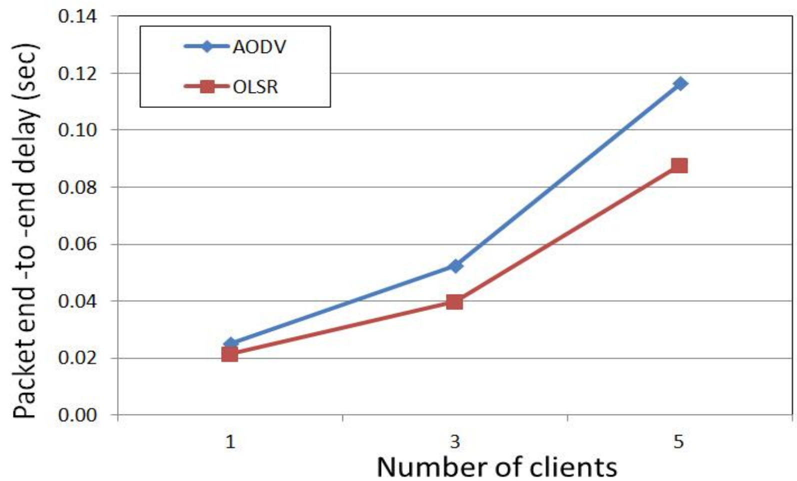

Figure 4.22. Packet End-to-End Delay of AODV, OLSR with 25 Fixed Nodes

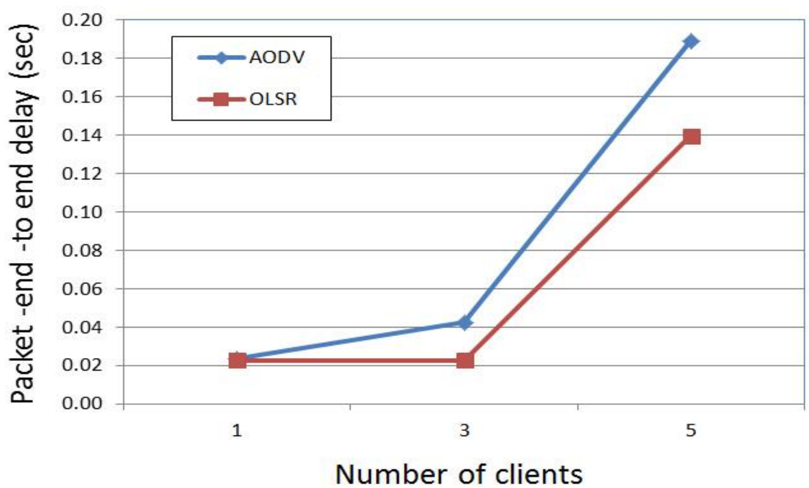

Figure 4.23. Packet End-to-End Delay for AODV, OLSR with 80 Fixed Nodes

The time that is required to transfer packets from the application layer of clients to the server in OLSR is less than in AODV. The peak value of OLSR in 5 clients' case is about 0.09 second but in AODV it is about 0.12 seconds. OLSR has better performance in both cases of network size in 25 nodes and 80 nodes as illustrated in Figures 4.22 and 4.23.

2. Comparison of Protocols in Mobile Nodes Network

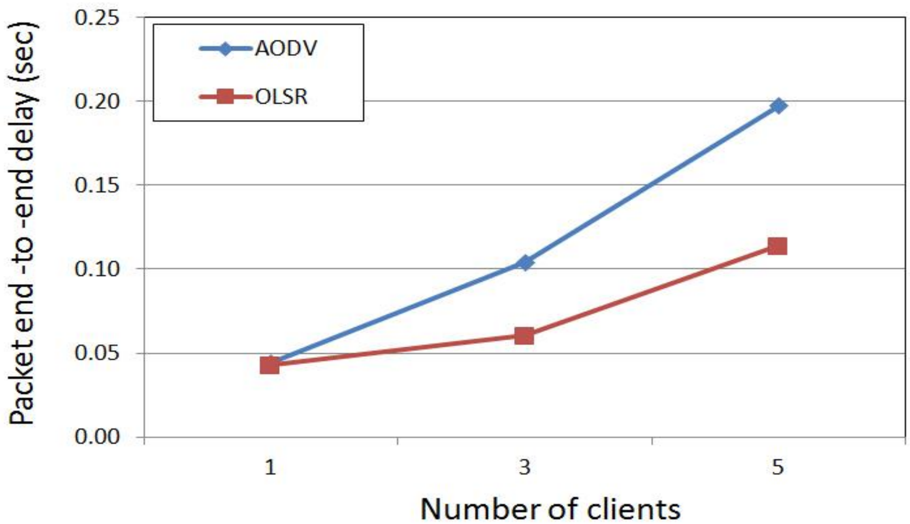

Figure 4.24. Packet End-to-End Delay of AODV, OLSR for 25 Mobile Nodes

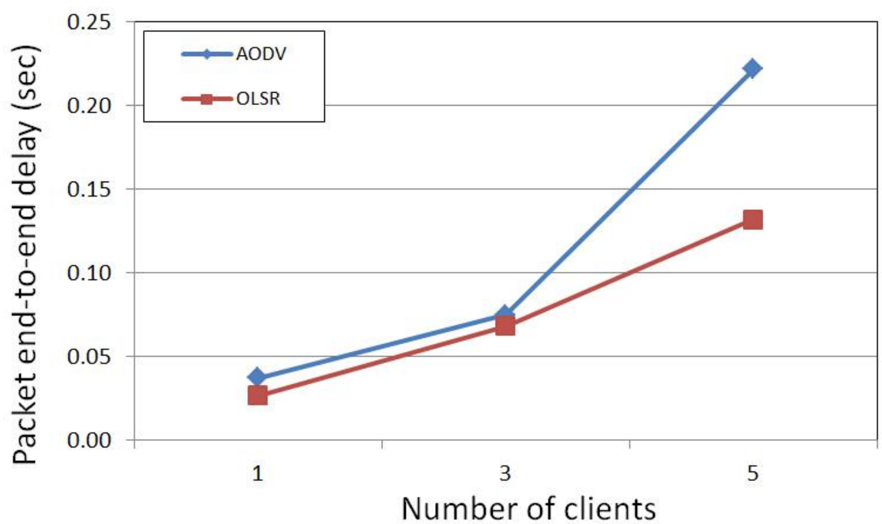

Figure 4.25. Packet End-to-End Delay of AODV, OLSR for 80 Mobile Nodes

In mobile nodes' end-to-end delay in both network size 25 and 80 nodes increased because of changes in the nodes' positions and increased distance between communicating nodes and video conferencing. In mobile cases, transferred video packets suffer from longer delays compared with fixed nodes before they arrive at the destination. This can be seen in Figure 4.24 and 4.25.

Investigation of protocols based on normalized routing load: The results of normalized routing load are calculated nodes' mobility and network scalability.

1. **Comparison of Protocols in Fixed Nodes Network**

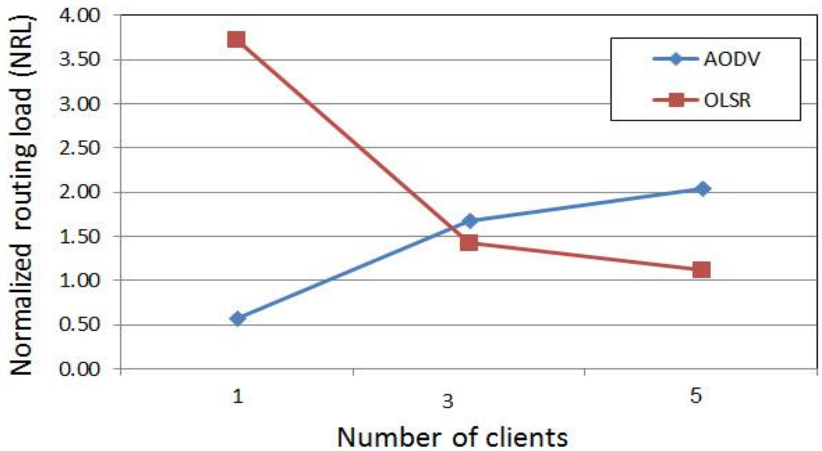

Figure 4.26. Normalized Routing load of AODV, OLSR for 25 Fixed Nodes

This metric is used to see the ratio of routing load with data packets. It is useful to see the scalability of the network base of the used protocol. In Figure 4.26, OLSR has greater normalized routing load for one client because of the high routing traffic packets in the network. However, in AODV the normalized routing load packets' is less because of less routing traffic packet's load. By increasing the number of clients that participate in video conferencing, OLSR's normalized routing load becomes less with 3 and 5 clients because of the substantial amount of video packets transmitted between server and clients.

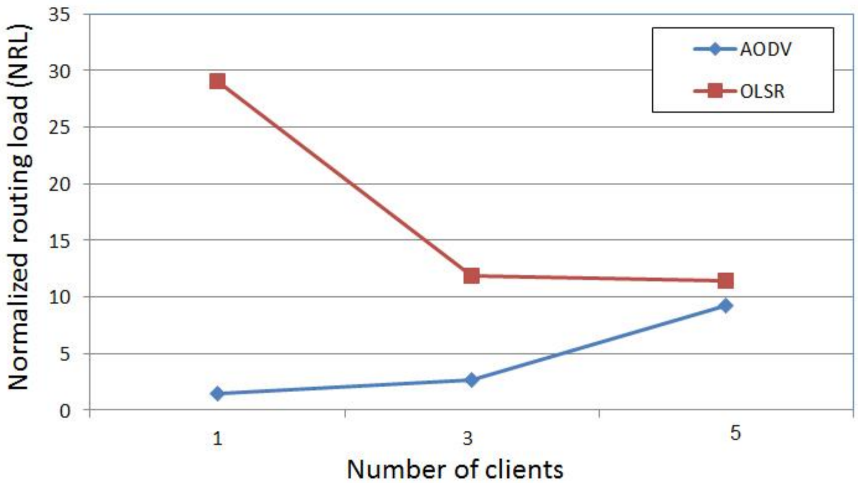

Figure 4.27. Normalized Routing Load for AODV, OLSR of 80 Fixed Nodes

In the case of 80 nodes, as shown in Figure 4.27, OLSR has greater value in all cases of clients 1, 3 and 5 because of the high routing traffic done by 80 nodes in the network.

2. Comparison of Protocols in Mobile Nodes Network

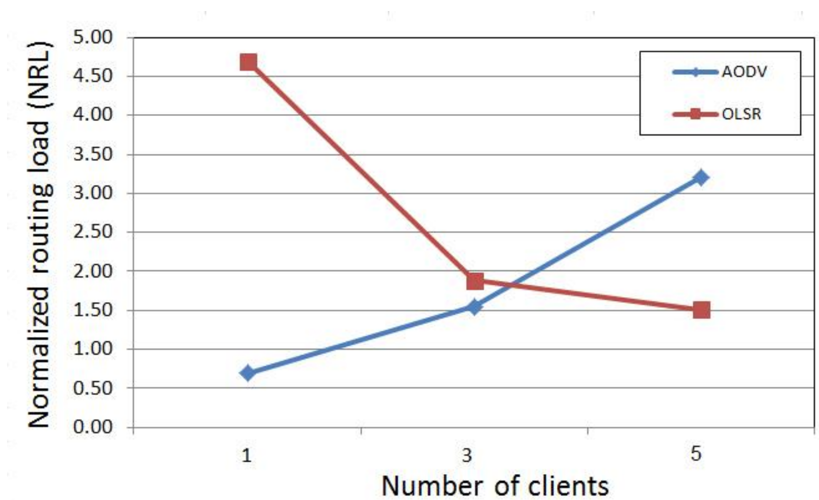

Figure 4.28. Normalized Routing Load of AODV, OLSR for 25 Mobile Nodes

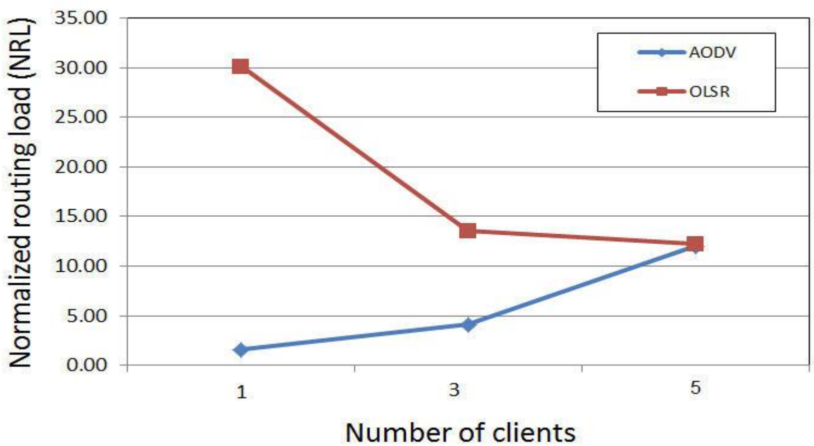

Figure 4.29. Packet Delay Variation for AODV, OLSR of 80 Mobile Nodes

In mobile nodes' case, OLSR has greater value in 1 and 3 clients in Figure 4.28, due to the fact that OLSR protocol is required to update its routing table. In the 5 clients' scenario, the value of normalized routing load for OLSR becomes less than AODV. In case of 80 nodes the value of OLSR is greater than AODV in all clients' cases 1, 3 and 5, because of higher routing traffic by OLSR in 80 nodes' network compared with the fixed nodes' case.

Tables 4.16 and 4.17 present a summary of all simulation results for 25 and 80 nodes in the network respective.

Table 4. 16. Preferred Protocol for Each Scenarios with 25 Nodes in the Network

Mobility status	**Number of clients that are participating with video conferencing**	**Routing protocol that performs best accordıng to each performance metrics**		
		End-to-end delay	**Packet delay variation**	**Normalized routing load**
Fixed	1	OLSR	OLSR	AODV
	3	OLSR	OLSR	OLSR
	5	OLSR	OLSR	OLSR
Mobile	1	OLSR	OLSR	AODV
	3	OLSR	OLSR	AODV
	5	OLSR	OLSR	OLSR

Table 4. 17. Preferred Protocol for Each Scenario with 80 Nodes in the Network

Mobility status	**Number of clients that are participating with video conferencing**	**Routing protocol that performs best accordıng to each performance metrics**		
		End-to-end delay	**Packet delay variation**	**Normalized routing load**
Fixed	1	OLSR	OLSR	AODV
	3	OLSR	OLSR	AODV
	5	OLSR	OLSR	AODV
Mobile	1	OLSR	OLSR	AODV
	3	OLSR	OLSR	AODV
	5	OLSR	OLSR	AODV

Chapter 5

CONCLUSION

In this thesis, two ad hoc routing protocols Ad hoc On-demand Distance Vector (AODV) from the reactive routing category and Optimized Link State Routing (OLSR) from the proactive category had been chosen based on their performance in existing studies. These protocols are evaluated and compared under interactive video conferencing application. 24 different scenarios had been created by changing the density of nodes, mobility and number of clients participating with video conferencing. The performance metrics used are; number of hops per route, routing discovery time, routing traffic sent, routing traffic received, end-to-end delay, packet delay variation, and normalized routing load. The experiments are performed using simulator OPNET 17.1.

This study makes clear that investing ad hoc networks with different routing protocols is necessary to define their main roles and what effect they have on the performance of these networks. There is no single protocol that performs better under all conditions; some protocols may perform better than others in some specific metrics with different network parameters. Therefore, choosing a routing protocol for a network depends on the network’s conditions and type of application.

According to results obtained from simulations of video conferencing, one can come to the following conclusions: OLSR performs better in packet delay variation for 25 and 80 nodes in the network. The performance of both AODV and OLSR protocols is better in fixed cases because of changes occurring in the topology during simulation time for mobile cases. The OLSR protocol takes less time to transfer a packet from source to the destination, than does the AODV protocol. AODV has less (better) normalized routing traffic than OLSR in high density network (80 nodes) and also it is better in low density network when few clients are communicating with server. On the other hand, OLSRs' normalized routing load is getting down compared with AODV when number of communicating nodes (clients) increase.

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APPENDICES

Appendix A: Definition and Calculation of Confidence Intervals

Confidence interval is a value that describes the uncertainty of the obtained real value. The calculated confidence interval value used to make a range that surrounds the mean value, by adding and subtracting to the real value. It provides different information that obtained from hypothesis test. The testing of a hypothesis yields a decision on any obtained statistical or significant difference. The range is built on in a way that makes us know how likely it is to attain true value. The level of confidence is called the specified probability and confidence limits are called the confidence interval end points.

Conventionally the level is used to create confidence intervals which are set to 95%; this means that 95% of the constructed confidence intervals must contain the correct value of the variable of interest.

Calculation of the Confidence Intervals

- **Computing best estimation value**: using results of simulation runs (run1, 2 .., 4), the mean value ($\overline{X}$) will be calculated using the following formula.

$$\overline{X} = \frac{\sum_{j=1}^{M} X_j}{M}$$

For example, the simulation results of four runs obtained of a performance metric in Figure 4.29 has a mean value as shown in Figure 4.30.

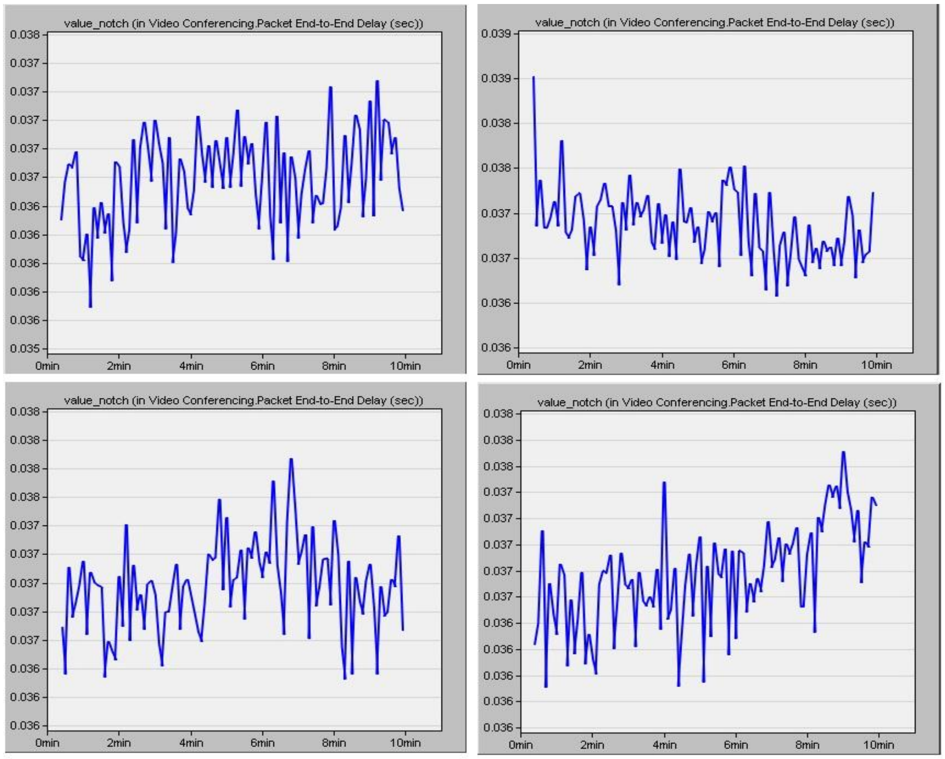

Figure 4.30. Simulation results of four runs

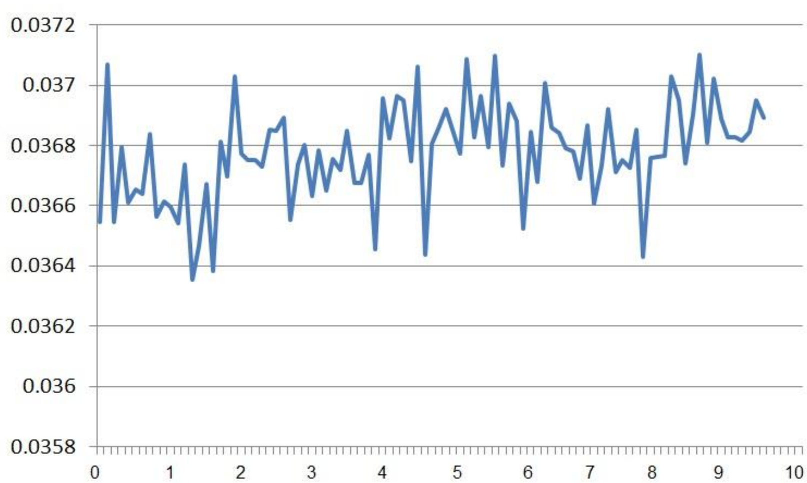

Figure 4.31. Mean graph Obtained for four runs

- Finding the estimation value of simple variance by this formula:

$$\sigma_X{}^2 = \frac{1}{M-1}\sum_{m=1}^{M}(X_m - \overline{X})^2$$

- Finding the value of (*b*), that is a range used to be added and subtracted to the mean value. Figure 4.31 illustrate the confidence interval for the above simulation results.

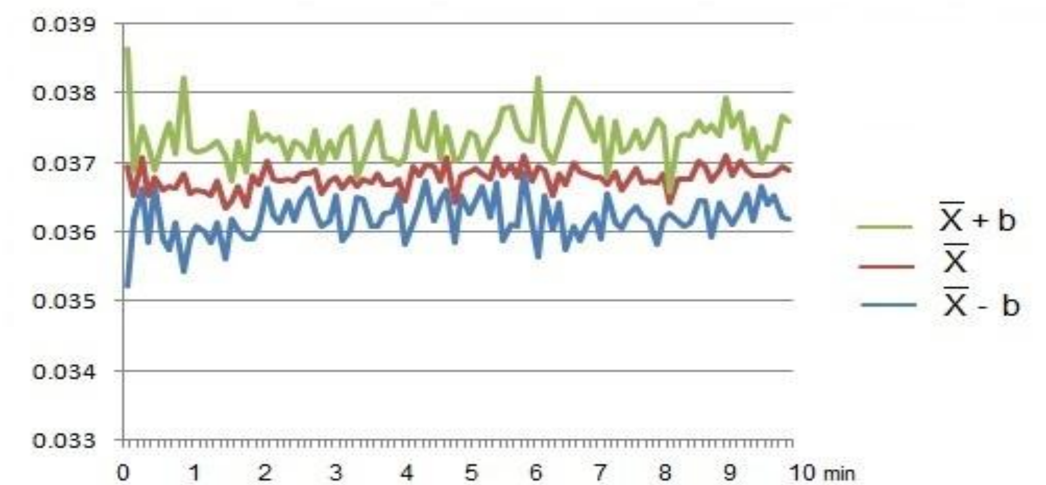

Figure 4.32. Confidence interval graph

Appendix B: Confidence Intervals of Results

Table A1. Confidence Intervals of AODV Protocol with 25 Non-mobile Nodes in the Network

Performance Metrics	Number of clients		
	1	3	5
Number of Hops per Route	1.569 ± 0.084	2.562 ± 0.324	2.78 ± 0.249
Route Discovery Time (sec)	0.037 ± 0.017	0.059 ± 0.029	0.10 ± 0.018
Routing Traffic Received (pkts/sec)	50.09 ± 4.939	305.2 ± 298	397 ± 271.7
Routing Traffic Sent (pkts/sec)	10.370 ± 1.058	81.34 ± 19.52	109 ± 79.09
Packet Delay Variation (sec)	0.0004 ± 0.0002	0.087 ± 0.019	0.24 ± 0.11
Packet End-to-end delay (sec)	0.025 ± 0.001	0.053 ± 0.010	0.11 ± 0.019

Table A2. Confidence Intervals of AODV Protocol with 80 Non-mobile Nodes in the Network

Performance Metrics	Number of clients		
	1	3	5
Number of Hops per Route	1.267 ± 0.088	1.609 ± 0.093	2.274 ± 0.451
Route Discovery Time (sec)	0.141 ± 0.071	0.793 ± 0.418	0.188 ± 0.017
Routing Traffic Received (pkts/sec)	385 ± 29.19	1618 ± 277.3	5629 ± 4380
Routing Traffic Sent (pkts/sec)	25.80 ± 1.97	128.4 ± 25.8	498 ± 403
Packet Delay Variation (sec)	0.026 ± 0.020	0.065 ± 0.042	0.363 ± 0.09
Packet End-to-end Delay (sec)	0.024 ± 0.002	0.043 ± 0.010	0.189 ± 0.063

Table A3. Confidence Intervals of AODV Protocol with 25 Mobile Nodes in the Network

Performance Metrics	Number of clients		
	1	**3**	**5**
Number of Hops per Route	1.65 ± 0.21	2.62 ± 0.187	3.071 ± 0.177
Route Discovery Time (sec)	0.171 ± 0.039	0.22 ± 0.163	0.216 ± 0.056
Routing Traffic Received (pkts/sec)	53.78 ± 13.2	224.7 ± 24.4	224.7 ± 24.4
Routing Traffic Sent (pkts/sec)	11.81 ± 2.70	62.9 ± 3.17	150 ± 33.23
Packet Delay Variation (sec)	0.019 ± 0.008	0.12 ± 0.053	0.359 ± 0.315
Packet End-to-end delay (sec)	0.044 ± 0.009	0.104 ± 0.05	0.197 ± 0.051

Table A4. Confidence intervals of AODV protocol with 80 mobile nodes in the network

Performance Metrics	Number of clients		
	1	**3**	**5**
Number of Hops per Route	1.28 ± 0.125	1.72 ± 0.230	2.365 ± 0.11
Route Discovery Time (sec)	0.26 ± 0.1707	0.23 ± 0.119	0.240 ± 0.06
Routing Traffic Received (pkts/sec)	392 ± 121.4	2131 ± 1064	6450 ± 1366
Routing Traffic Sent (pkts/sec)	6450 ± 1366	181.08 ± 100	592 ± 120.9
Packet Delay Variation (sec)	0.017 ± 0.003	0.50 ± 0.308	0.931 ± 0.088
Packet End-to-end Delay (sec)	0.037 ± 0.010	0.07 ± 0.017	0.22 ± 0.040

Table A5. Confidence Intervals of OLSR Protocol with 25 Non-mobile Nodes in the Network

Performance Metrics	**Number of clients**		
	1	**3**	**5**
Routing Traffic Received (pkts/sec)	406.5 ± 1.35	392.2 ± 3.01	392.5 ± 7.69
Routing Traffic Sent (pkts/sec)	67.5 ± 0.24	72.2 ± 0.98	77.9 ± 1.87
Packet Delay Variation	0.0001 ± 0.0005	0.001 ± 0.002	0.009 ± 0.003
Packet End-to-end delay (sec)	0.021 ± 0.0004	0.03 ± 0.007	0.08 ± 0.01

Table A6. Confidence Intervals of OLSR Protocol with 80 Non-mobile Nodes in the Network

performance Metrics	**Number of clients**		
	1	**3**	**5**
Routing Traffic Received(pkts/sec)	9397.5 ± 140.6	9682 ± 74.9	10363 ± 96
Routing Traffic Sent(pkts/sec)	524.5 ± 8.41	587.13 ± 5.7	677 ± 7.6
Packet Delay Variation (sec)	0.0001 ± 0.00003	0.0004 ± 0.0001	0.029 ± 0.02
Packet End-to-end delay (sec)	0.022 ± 0.0005	0.039 ± 0.006	0.139 ± 0.01

Table A7. Confidence Intervals of OLSR Protocol with 25 Mobile Nodes in the Network

Performance Metrics	**Number of clients**		
	1	**3**	**5**
Routing Traffic Received(pkts/sec)	397.4 ± 36.03	381.3 ± 43.2	390 ± 15.3
Routing Traffic Sent(pkts/sec)	70.03 ± 6.4	73.6 ± 13.3	79.6 ± 3.43
Packet Delay Variation (sec)	0.001 ± 0.0005	0.014 ± 0.01	0.041 ± 0.02
Packet End-to-end delay (sec)	0.043 ± 0.033	0.061 ± 0.02	0.11 ± 0.013

Table A8. Confidence Intervals of OLSR Protocol with 80 Mobile Nodes in the Network

Performance Metrics	**Number of clients**		
	1	**3**	**5**
Routing Traffic Received(pkts/sec)	9091 ± 183.9	9535 ± 298.8	9866 ± 264.5
Routing Traffic Sent(pkts/sec)	519.6 ± 19.32	591.1 ± 15.8	652.8 ± 38.72
Packet Delay Variation (sec)	0.0004 ± 0.0002	0.011 ± 0.009	0.046 ± 0.027
Packet End-to-end delay (sec)	0.027 ± 0.011	0.068 ± 0.034	0.132 ± 0.027