DEBRE BERHAN UNIVERSITY

COLLEGE OF COMPUTING

DEPARTMENT OF INFORMATION TECHNOLOGY

Queue Length Aware Ad Hoc on Demand Distance Vector Routing Protocol for Mobile Ad Hoc Networks

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Debre Berehan, Ethiopia

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Eyob Temesgen

A Thesis

Submitted to The Department of Information Technology, College of Computing, Debre Berhan University, in Partial Fulfilment of the Requirements for The Degree of Masters of Science in Computer Networks and Security.

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Examiners' Approval Sheet

Approved by: We the examiners' board approve that this thesis has passed through the defense and review process.

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Declaration

I, the undersigned, hereby declare that this thesis is my original work performed under the supervision of **Dr. Esubalew Yitayal,** has not been presented as a thesis for a degree program in any other university and all sources of materials used for the thesis are duly acknowledged.

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This thesis has been submitted for examination with my approval as university advisor.

Esubalew Yitayal (PhD) _________________

Advisor Signature

Abstract

Now a day's, due to the popularity of portable computers and the increasing demands of users to access computing services in a better way, an alternative way of network service access is required. Thus, mobile ad hoc network (MANET) is one of the alternatives to achieve this requirement by providing infrastructure less services with self-configuring and reduced cost set up capability. Due to the rapid growing rate of multimedia applications (voice, video) in MANETs, quality of service (QoS) support has also grown-up to be supplementary and more important. Particularly, QoS related with latency is very interesting, because latency is the most critical QoS metrics in mobile ad hoc networks mainly for delay sensitive applications.

However, many of an existing MANETs routing protocols are not QoS aware specifically in terms of latency which should be considered as the main design requirement of the routing protocol. Hence, a QoS supporting routing protocol that finds the optimal routing path between two or more mobile devices is needed. Therefore, in this thesis, we evaluated three well known MANET routing Protocols, Dynamic Source Routing Protocol Routing (DSR), Destination Sequenced Distance Vector (DSDV), and Ad Hoc on Demand Distance Vector Routing (AODV), from the perspectives of delivering QoS efficiently based on QoS metrics and designed an efficient routing protocol for (MANETs) that mitigate latency by modifying the header fields of the original AODV routing protocol to consider path delay during path selection using node queue length. The proposed QL-AODV routing protocol is simulated using Network Simulator-2.35 and comparisons are made to analyze its performance based on packet delivery ratio, normalized routing overhead, and average end to end delay for different network scenarios.

As the simulation results reveal that in terms of end to end delay and packet delivery ratio the proposed QL-AODV achieves relatively better performance than both ad hoc on-demand distance vector protocol (AODV) and hop count and time based AODV (HT-AODV) at the expense of higher normalized routing overhead. For instance, the simulation results of QL-AODV when compared to AODV showed an average improvement of 5.43 % and 2.65% in end to end delay and packet delivery ratio, respectively.

Keywords: MANETs, Real-Time Applications, Queue length, AODV, HT-AODV

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List of Abbreviations

AODV	*Ad Hoc on Demand Distance Vector Routing*
CBR	*Constant Bit Rate*
DSDV	*Destination Sequenced Distance Vector*
DSR	*Dynamic Source Routing Protocol Routing*
IEEE	*Institute of Electrical and Electronics Engineers*
IETF	*Internet Engineering Task Force*
MANET	*Mobile Ad Hoc Network*
NAM	*Network Animator*
NRL	*Normalized Routing Load*
NS2	*Network Simulator Version 2*
OTcl	*Object-Oriented Variant of Tool Command Language*
PDR	*Packet delivery ratio*
QoS	*Quality of Service*
RFC	*Request for Comments*
TCP	*Transmission Control Protocol*
UDP	*User Datagram Protocol*
VoIP	*Voice over Internet Protocol*
ZRP	*Zone Routing Protocols*
RREQ	*Route Request Packet*
RREP	*Route Reply Packet*
RERR	*Route Error Packet*
HT-AODV	*Hop Count and Time based Ad Hoc on Demand Distance Vector Routing*

CHAPTER 1: INTRODUCTION

This chapter describes the very basic introduction to the background of this thesis work and gives an overview of the fundamental concepts of MANETs, application areas, main features, models and protocol stack for MANETs. Furthermore, the significance of the study, objective of the study and contributions addressed in improving QoS in delay-sensitive applications over MANETs routing protocols are discussed.

1.1 Background

In today’s computing era, accessing computing services whenever, wherever and whatever they want becomes an essential demand from the users and grows rapidly due to the advancements of various computing technologies and the increasing needs of users. Due to those demands and popularities of portable devices, wireless communication technologies have become an essential way of accessing computing services in a better way. However, due to the rapidly growing interests of users, a new way of accessing such computing resources from environment where an infrastructure deployment is difficult. Thus, Mobile Ad hoc network (MANETs) are one way of accessing such computing resources with its self-configuring, self-organizing and deployment cost reduction capabilities in various application areas.

Broadly Wireless networks [2, 3] are classified into two particular groups: wireless network with infrastructure and wireless network without infrastructure. Wireless network with infrastructure is a collections of mobile nodes, base stations, and access points [1, 4]. Base stations and access points form the core of the network and mostly they are fixed. All routing information is put away in the central system and the host simply needs to pass data to the access point and the required route will be found. In infrastructure-less wireless networks, only mobile nodes exist. Every node works both as a host and a router. Whenever a host gets data, it forwards to another node in the topology, it finds the best route to the destination and forwards the data to the next host [4].

Infrastructure less networks are referred to as Ad-hoc wireless networks. Ad hoc networking began in the early times when the US Department of Defense (DoD) sponsored the Packet Radio Network (PRNET) research program [1]. This program aimed to provide packet-switched networking to the portable battlefield in a hostile environment with no infrastructure and with soldiers, tanks, aircraft, etc., forming the nodes in the network.

Mobile Ad hoc network [6] is a type of infrastructure-less wireless network in which a collection of mobile nodes are forming temporarily. The goal of this architecture is to provide communication facilities between end-users without any centralized infrastructure. In such a network, each node acts as a host as well as a router [1]. In MANET every host is acting as a router to forward the packet to other node and they act as a host also to send and receive packets. This type of network can be used in fire, safety, rescue and disaster recovery operations, conference and campus settings, car networks, personal networking, etc. Figure 1.1 shows the scenario of simple ad hoc network topology.

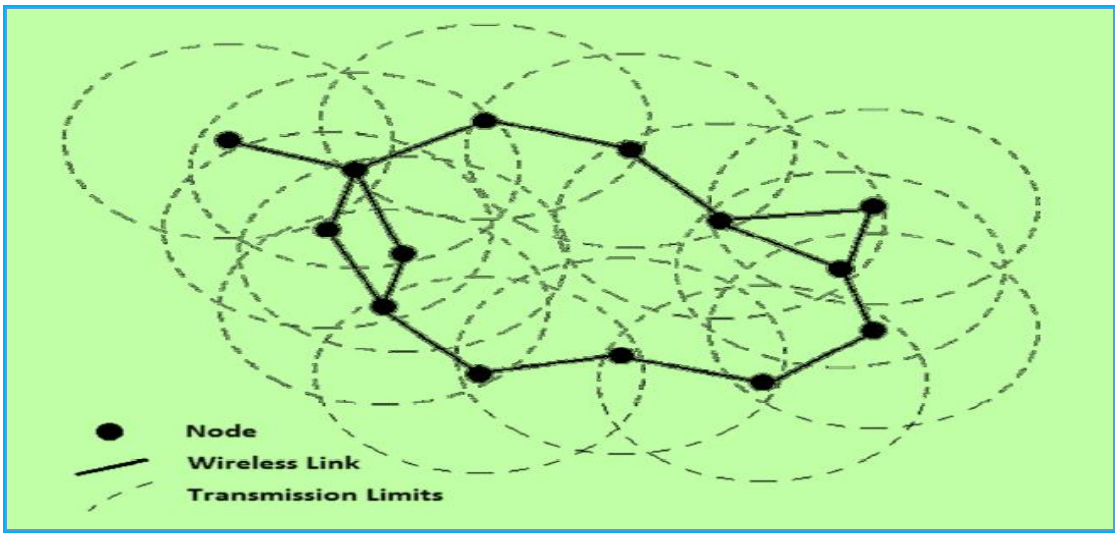

Figure 1.1: Example of Mobile Ad-Hoc Network [3]

However, the biggest challenge in this kind of networks is to find a path between the communication endpoints, which is aggravated through node mobility. To accomplish information exchange among mobile nodes in MANETs routing protocols have a great role. Routing [4] in MANET is the process that a node uses to send packets towards destination network and routing protocol allows one node to share information with other nodes regarding the networks it is aware of concerning in addition as its proximity to different routers. The current trend of connectivity anywhere, anytime, and anyhow brings a new paradigm of accessing real-time multimedia services (voice, video, and text) via MANETs specifically in the area of military, emergency, automotive application, etc. for many people, real-time multimedia services are getting to be one of the interesting networking communication services [4]. A routing protocols developed for wired network are not suitable for MANETs due problems related to convergence and looping. Because, in MANETs the network topologies are changing dynamically as the node leave and join the topology, hence, those conventional routing protocol convergence times are based on periodic updating of routing information's which is against with the routing principle required by MANETs [7].

Thus, scholars proposed various routing protocols specifically for MANETs and those routing protocols are broadly classified into three namely, Proactive, Reactive and Hybrid routing protocols. [3] Even though an ample of routing protocols are proposed by various authors for MANETs, each protocol have its own drawbacks. As seated by IETF, different research areas are available today in MANET. Such as, Quality of Service (QoS), route Optimization, Security, and power management which are the primary ones. Therefore, this research work takes into an account of QoS issues in MANETs routing protocol particularly by focusing on latency constraints so as to minimize the time that might require by a data packet during transmission.

Quality of Service (QoS) is a basic requirement to help interactive multimedia applications, (for example, video and sound transmissions) to have user satisfied network services. Specifically, in multimedia this may incorporate picture quality, delay and speed of reaction [8]. So as to achieve QoS in MANETs, the network is required to ensure a lot of quantifiable measurements, for example, delay, jitter, transmission capacity (bandwidth), packet delivery rate, and so forth. Implementing QoS in MANETs is difficult due to its broadcast and dynamic nature. Unlike wired networks [3], a wireless link's bandwidth is suffering from the transmission of adjacent links. It is also different from cellular networks that only have to guarantee quality of service for one hop.

Most of the Existing MANETs routing algorithms are best effort, they are not designed considering QoS metrics during the route construction process. In this thesis work, considering QoS routing into an account improved QoS routing approach will be designed. Specifically, a mechanism to mitigate latency for delay sensitive applications will be discussed briefly on the upcoming chapters.

1.2 Motivation of the Study

One of the newest fields today is that of ad-hoc networks, mainly called Mobile ad-hoc network (MANET). Within the past few years this field has gained attention due to the proliferation of inexpensive, wireless devices and the network community's interest in mobile computing. Now a day's mobile ad hoc networks have become very much important. Because they can be implemented in infrastructure less connection which is useful to extend the service of traditional fixed infrastructure networks. Such networks are mainly consisting of highly mobile nodes, which are mobile with in specific covering area and can be connected dynamically in an arbitrary manner. They have provided new challenges, which is the result of the unique characteristics of the wireless medium and the dynamic nature of the network topology.

Due to the rapid growth of MANET's application on different areas in today's communication technology, supporting delay sensitive traffic is one of the MANETs promising applicability especially around military services. Thus, following this growing technology, there are various unique characteristics and challenges, such as, dynamic topology change, resource constraint, routing overhead, energy constraint, QoS issues and high end to end delay. From those QoS is one of an open research area which is not addressed fully specifically in delay sensitive applications. Routing is one of the QoS improvement technique in which the routing protocol designers should take in to an account while designing network protocols. However , Most of the existing MANETs routing protocols are not designed considering QoS support, such as AODV, DSDV, DSR ,TORA and etc. [9]. Thus, shortest path is the metrics used by many of an existing MANETs routing protocols. Hence, improvement of an existing routing protocols in MANETs from the perspective of achieving QoS is a substantial consideration. The following two scenarios illustrates the drawbacks of existing MANETs routing protocol regarding to route selection to guarantee QoS.

Scenario 1: Scenario when equal number of hops reached to destination

In the existing AODV routing algorithm, paths are selected using minimum hop count cost metrics. That means the path which have minimum hop count is selected as optimal path. However, selecting path using minimum hop count is not efficient from achieving QoS perspective particularly for QoS sensitive applications.

In Figure 1.2, since there are equal number of hops in both paths, the destination node will choose optimal path randomly. However, the method employed by this scenario doesn't deal with other QoS metrics during route selection.

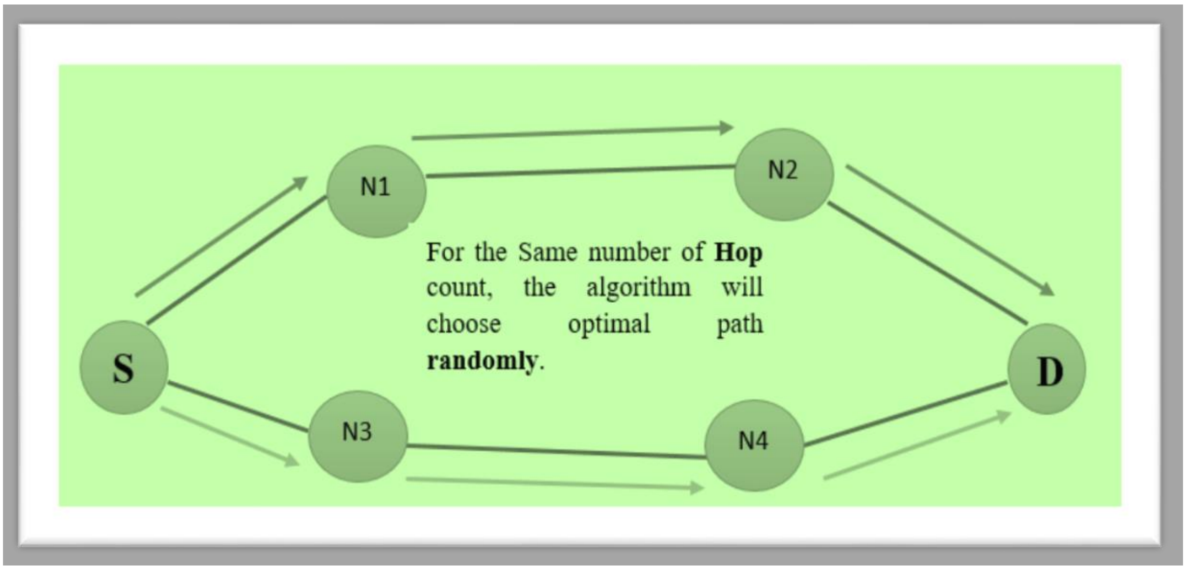

Figure 1.2: Illustration of Path Selection Based on Hop Count

Scenario 2: Scenario when different number of hops reached to destination

As illustrated in Figure 1.3, in the first path, there are three hops, and for the second path, there are four number of hops, thus in this scenario the destination will select the first path, that means the path which have minimum hop counts. However, the selected path in this scenario does not consider QoS requirements. Thus, to encourage QoS Support in MANETs, it is essential to comprehend the measurements that are utilized to determine QoS. Real-time multimedia applications are delay sensitive; the communication should be happened in a timely manner. Thus, considering queue length during route selection is a crucial concern in MANETs routing protocol specifically for delay sensitive applications. Therefore, for supporting QoS, incorporating a latency into the routing setup procedure is a key to finding the optimum path. The aforementioned discussed scenarios are the motivation for the proposed problem statement.

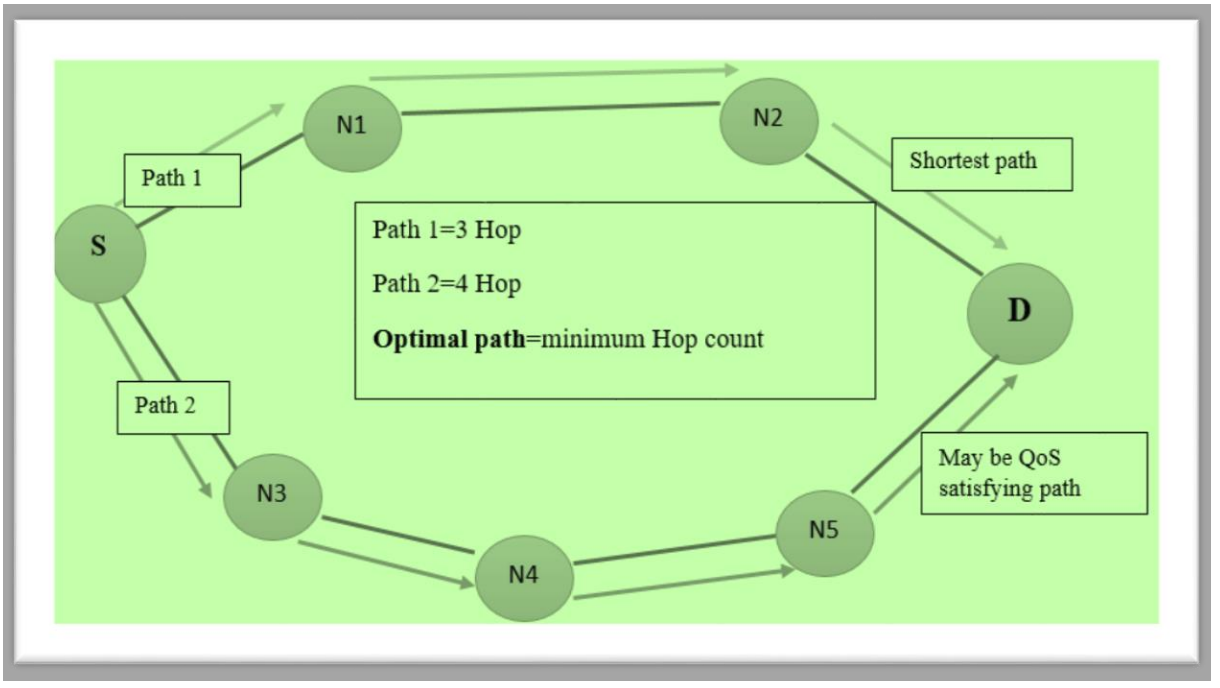

Figure 1.3: Illustration of Path Selection with Different Hop Count

1.3 Statement of the Problem

With the growing rate of real-time applications in MANET, quality of service (QoS) support has grown-up to be supplementary and more important. However, many of existing MANETs routing protocols are not QoS aware which should be considered as the main design requirement of the routing protocol [3]. In MANETs, routing and guaranteeing quality of service (QoS) is much more challenging than wired networks, mainly due to node mobility, multi-hop communications, unpredictable link properties, resource constraints, contention for channel access, and a lack of central coordination.

QoS guarantees are required by most of the multimedia and other delay-sensitive applications. The difficulties in the provision of such guarantees have limited the usefulness of MANETs. However, Many current routing protocols were designed to search for only the shortest route with minimum hop counts [7]. The shortest paths, however, may not always provide the best QoS performance, particularly while the nodes along these paths are congested. Many authors have proposed to improve the quality of service of MANET routing protocol by considering different QoS parameters. Even if a number of routing algorithms are developed, achieving minimum latency during data packet transmission is still an open research area.

Hence, this thesis work develops a Queue length aware MANETs routing algorithm that enhances the existing MANETs routing protocols using node queue length during the route construction process. The QoS requirement studies considered in the thesis is the latency constraint.

1.4 Research Questions

This thesis is to present the Queue length aware routing strategy for MANETs with the goal of overcoming the limitations of methods presented in literature review. By considering this, the following research questions are addressed by this thesis work.

1. What are the possible network conditions that affect end to end delay performance of routing protocols in MANETs?

2. Which existing MANET routing protocol is more efficient from the perspective of delivering efficient QoS?

3. How to design a QoS efficient algorithm that improves end to end delay?

1.5 Objective of the Study

1.5.1 General Objective

The main aim of this thesis work is to study and evaluate existing routing protocol of MANETs in terms of end to end delay and develops a QoS routing algorithm that are capable of minimizing latency for MANETs.

1.5.2 Specific Objectives

To achieve the general objective the following **specific objectives** are identified.

- To evaluate the performance of AODV, DSDV and DSR MANETs routing protocols conceptually and experimentally from the perspective of delivering QoS efficiently.
- To assess the difficulties faced by routing in MANET protocols.
- To propose queue length aware AODV routing algorithm that reduce latency.
- To evaluate the performance of the proposed approach against the existing one.

1.6 Delimitation of the Study

The study is delimited to the investigation of delay sensitive routing protocols of one existing proactive routing protocols of MANETs, namely DSDV and two existing reactive MANETs routing protocols, namely AODV and DSR. The scope of the study is also delimited to a maximum of 60 mobile nodes, 10m/s speed of mobile nodes and 7 source destination connections in a simulation area of 1000m x 1000m. In this study we considered only latency constraints of QoS metrics during route selection and discovery process based on AODV. Considering other QoS metrics during route selection such, as, throughput, mobility and node position are the limitation of this study. Due to the time and budget constraint we couldn't evaluate the proposed approach with other QoS metrics such as, mobility, jitter, residual energy, probability of packet loss and throughput. Evaluating the performance of the developed approach with the state of art version of AODV is also the limitation of this work. Furthermore, incorporating the proposed approach in NS2 as a stand-alone protocol is the limitations of this work.

1.7 Significance of the Study

In recent times, with the raise of portable devices as well as progress in wireless communication, ad hoc networking is gaining importance with the increasing number of wide spread applications. Thus, the contribution of this work will facilitate the services of Mobile Ad-Hoc Networks (MANETs) applications in many important situations such as military, commercial, conferencing, education, emergency services. Devices allow users to access and exchange information regardless of their geographic position or proximity to infrastructure. In contrast to the infrastructure networks, all nodes in MANETs are mobile and their connections are dynamic. The set of applications for MANETs is diverse, ranging from large-scale, mobile, highly dynamic networks, to small, static networks that are constrained by power sources. As MANETs gain popularity, mechanisms that provide us getting quality of MANET services also need to be improved. However, currently, due to lacking of efficient routing protocol, they have certain limitations to fully utilize the potential benefit provided by MANETs. Therefore, this work will enhance the usefulness of MANETs by providing better QoS support routing technique.

1.8 Operational Definitions of Terms

Key terms and variables in the present study were operationally defined as follows:

Mitigate: the term mitigate refers, reduce the latency that may require by a data packet during transmission.

Queue length: refers the available buffered packets at a given time on each node.

Flooding: In the present study, the term flooding is used to describe if a mobile node receives a new packet, it retransmits exactly once or any newly received packet by a node retransmits exactly once.

Transmission range: refers the maximum range over which a packet can be successfully received when there is no interference from other nodes.

1.9 Organization of the Thesis

The remainder of the thesis is organized as follows:

Chapter two contains, the basic review of the background study of the existing routing protocols in MANET. Chapter three describes, the performance evaluation of an existing MANETs routing protocols conceptually as well as experimentally. Recent research works on MANETs QoS improvement as general and QoS improvement in AODV specifically for delay-sensitive real-time multimedia applications are discussed in chapter four. In Chapter five the design of the proposed QL-AODV approach and architectures are briefly described. Furthermore, this portion describes a brief modeling, architecture, proposed algorithm flowchart, and pseudo codes for the proposed approach. Chapter six gives the evaluations procedures of the approach as well as result and discussions also been discussed. Finally, chapter seven concludes the thesis and gives some suggestions for future works.

CHAPTER 2: LITERATURE REVIEW

This chapter presents the fundamental concepts of MANETs such as, evolution of the MANET from the early origin, an overview of MANET, application area, characteristics and routing schemes. The chapter also introduces the overview of QoS in MANET, delay sensitive applications QoS provisioning and the current QoS provisioning in the routing protocols.

2.1 Wireless Networks

Wireless networks [10] are often outlined as a network of devices or nodes that have the computing power and are interconnected to each other with the assistance of a wireless medium. These wireless nodes have the flexibility to communicate with one another either with the assistance of a wireless infrastructure or with the absence of the wireless infrastructure.

2.2 Overview of Mobile Ad Hoc Networks

Broadly, the computer network is categorized into two namely, Wired and Wireless. Particularly wireless communication is also categorized into two sub classes namely, infrastructure based and infrastructure less. From those, MANET is one of the types of infrastructure-less wireless communication network which is formed by wireless self-configuring nodes without having necessarily a fixed infrastructure [11].

2.3 History of Mobile Ad Hoc Networks

In the early 1970s, the Mobile Ad hoc Network (MANET) was called packet radio network which was sponsored by Defense Advanced Research Projects Agency (DARPA). They had a project named packet radio having several wireless terminals that could communicate with each other on battlefields. It is interesting to note that these early packet radio systems preexist the Internet, and indeed were part of the motivation of the original Internet Protocol suite [10].

A mobile ad hoc network (MANET) [2], [12], [13], is an autonomous ad hoc wireless networking system consisting of independent nodes that move dynamically changing network connectivity. In contrast to cellular wireless networks, no static or fixed infrastructure exists in MANET, and no centralized management are often out there. The network can be formed anywhere, at any time, as long as two or more nodes are connected to communicate with one another either directly when they are in radio range of each other or via intermediate mobile nodes because of flexibility that a MANET offers.

The IETF working group charter defines a mobile ad hoc network (MANET) as"*... an autonomous system of mobile routers (and associated hosts) connected by wireless links — the union of which forms an arbitrary graph* [10]. *The routers are free to move randomly and organize themselves arbitrarily; thus, the network's wireless topology may change rapidly and unpredictably. Such networks may operate in a stand-alone fashion, or may be connected to the larger Internet ..."* Whenever a mobile node moves from one network to another network, the network topology and network address assignment get changed. The general mobile ad hoc network topology is shown in figure 2.1 as follows [14].

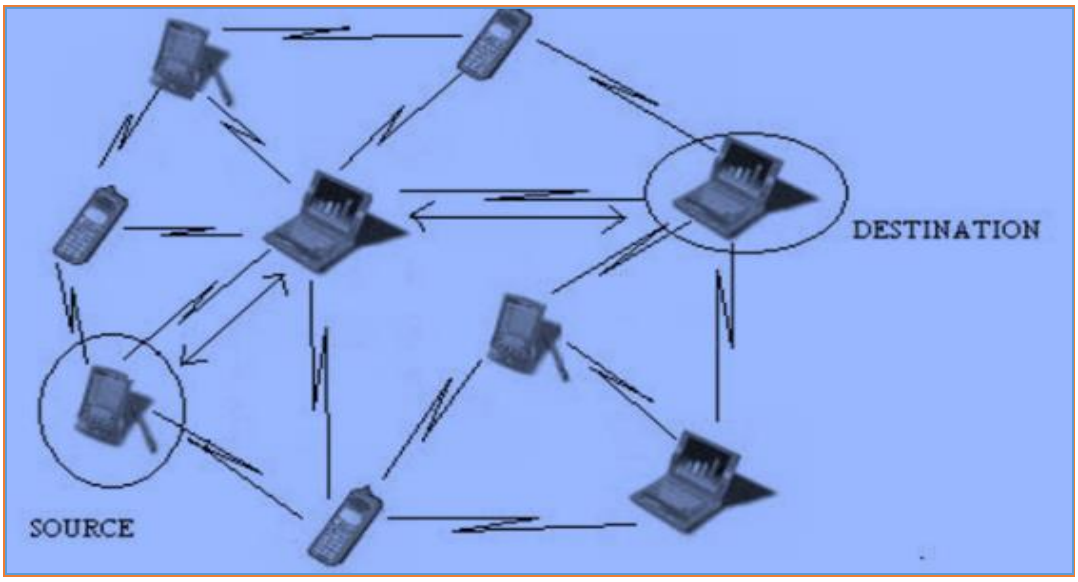

Figure 2.1: General Mobile Ad Hoc Network

2.4 Applications of MANET

With the increase in portable device as well as progress of wireless communication, ad hoc networking is gaining importance because of its increasing number of widespread applications. Ad hoc networking can be applied anywhere and anytime without infrastructure and fixable networks, ad hoc networking allows the devices to maintain connection to the network as well as easily adds and removes devices to and from the network. Following points represents the MANETs applications: [5, 8, 9]. Figure 2.2 illustrates various application areas of MANETs.

Figure 2.2: Various Application Areas of MANET

2.4.1 Military Sector

Ad hock networking enables the military to exploit typical system innovation to keep up a data arrange between the soldieries, vehicles, and military data central command. MANETs are used as an important solution for military operations as it does not require any pre-established infrastructure and remove single point of failure. Therefore, they can be easily deployed in an unknown and hostile area to provide fast military communication.

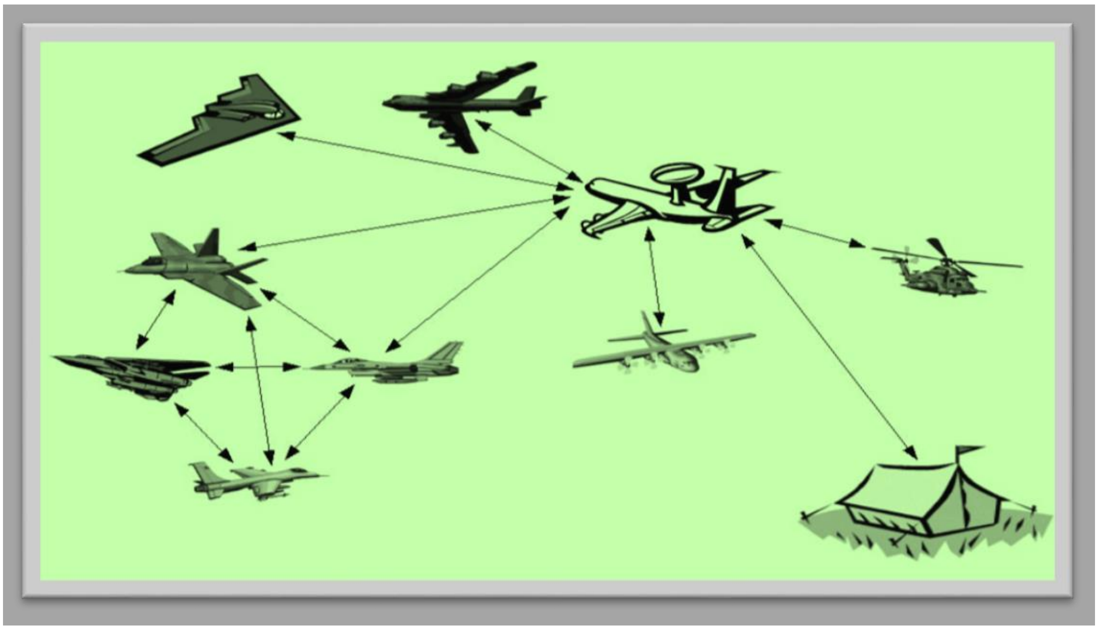

Figure 2.3: MANETs in Military

2.4.2 Sensor Network

A Sensor network is made out of an extensive number of small sensors. These can be used to recognize any number of properties of a territory, for example, temperature, weight, poisons, contaminations, and so forth. Applications are the estimation of ground moistness for horticulture, an estimate of seismic tremors.

2.4.3 Emergency Services

MANETs can be very useful in emergency search and rescue applications, such as in environments where the conventional infrastructure-based communication facilities are destroyed due to earthquake, hurricane, fire, and flood. Immediate deployment of MANETs in these scenarios could be built very quickly to restore communication compared to long time and costly efforts required for constructing wired communications.

2.4.4 Automotive Applications

Automobiles ought to communicate with the street, to traffic lights, and to one another, shaping ad hoc networks of different sizes. The network will give information to the drivers about street conditions, accident-ahead warnings, helping to optimize Traffic flow. One typical example is VANET, in which each vehicle can able to communicate with each other.

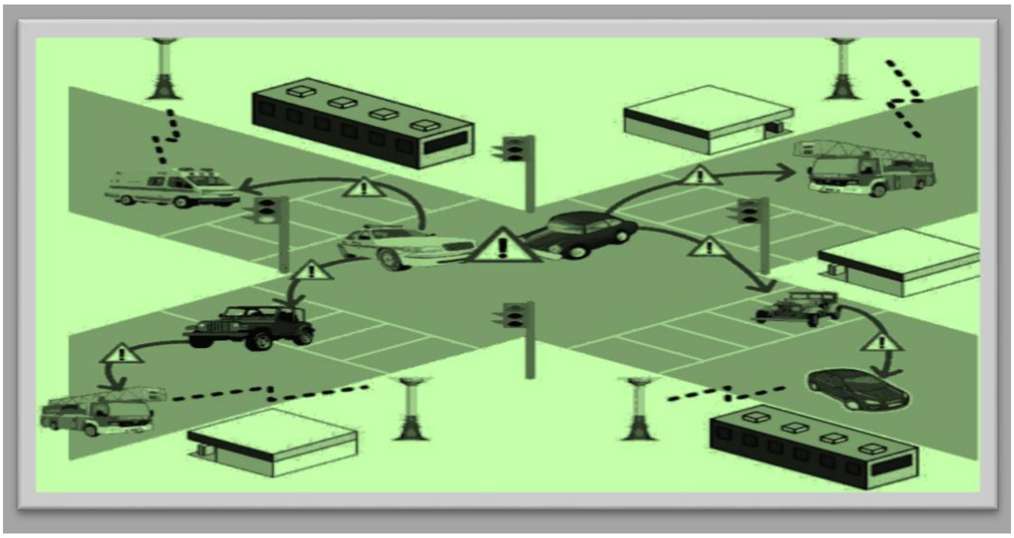

Figure 2.4: Applications of MANET in Automotive

2.5 MANETs Protocol Stack

The MANET protocol stack, [16] which is similar to the TCP/IP suite - is shown in Figure 2.5. The main distinction between these two protocols stacks lies within the network layer. Mobile nodes (which are each host and routers) use an ad hoc routing protocol to route packets. Ad hoc routing is handled by the network layer that successively is split into network and ad hoc routing.

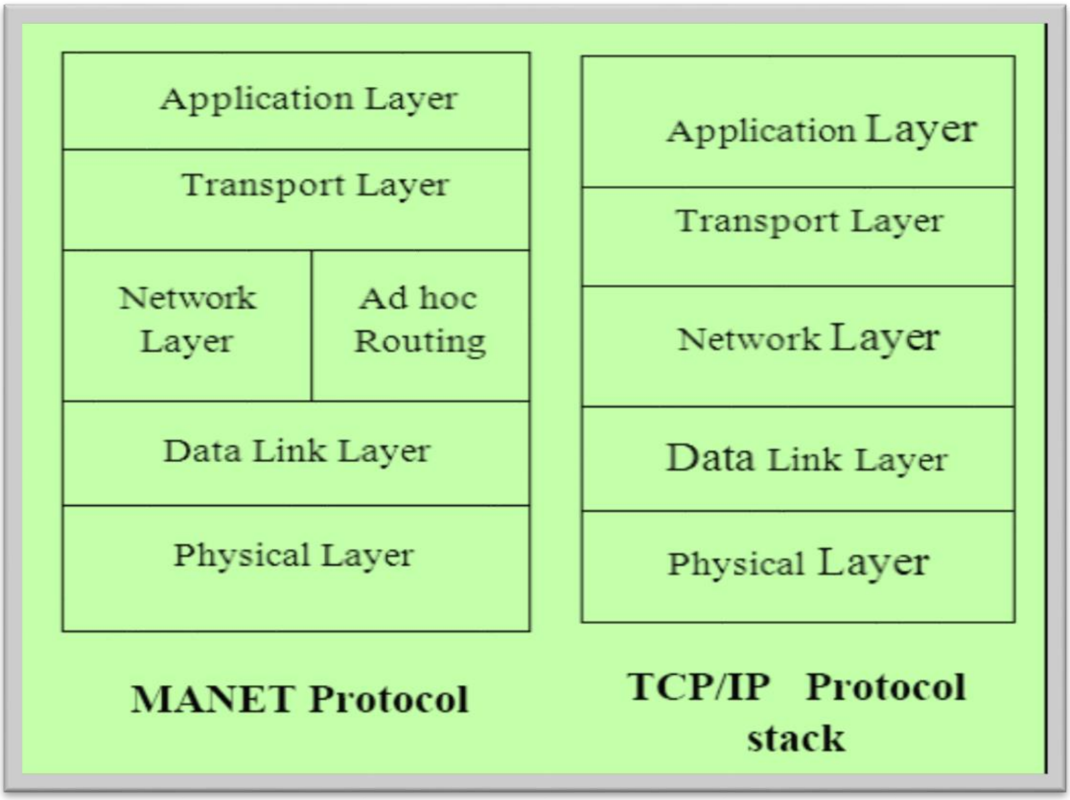

Figure 2.5: MANETs Protocol Stack

2.6 MANETs Architecture

The specific MANET problems and constraints represented important challenges in ad hoc network design. An outsized body of analysis has been accumulated to handle these specific problems, and constraints. In this thesis, we describe the ongoing research activities and the challenges in some of the main research areas within the mobile ad hoc network domain. To present the huge amount of research activities on ad hoc networks in a systematic or organic way, we will use, as a reference, the simplified architecture presented in Figure 2.6 [1].

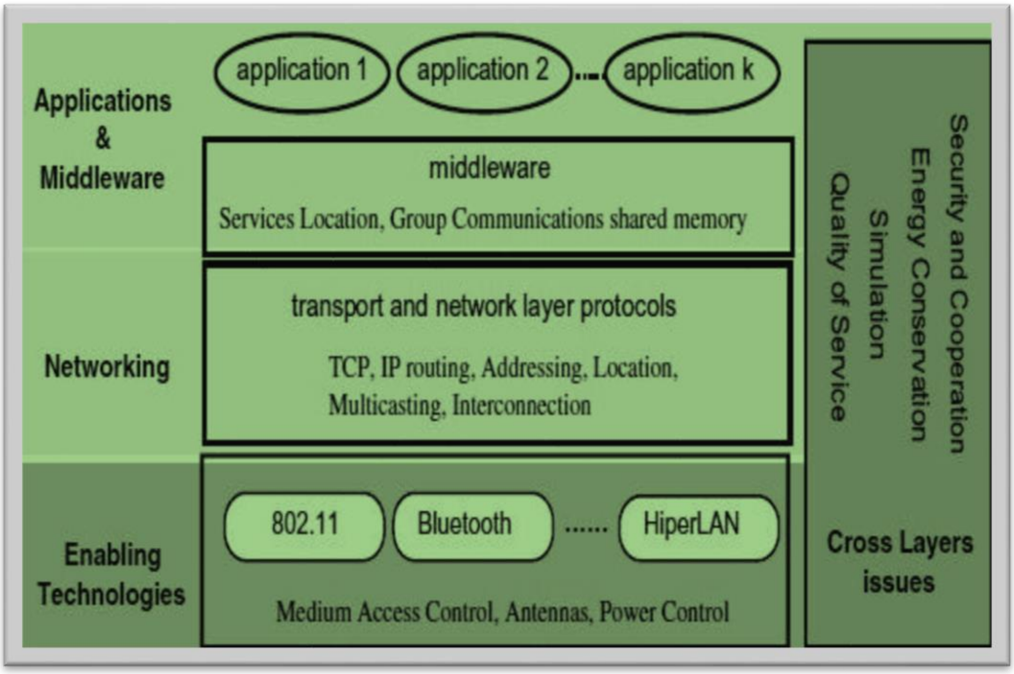

Figure 2.6: MANETs Architecture

2.7 MANETs Technology

Wireless networking hardware requires the utilization of fundamental innovation that deals with radio frequencies and in addition information transmission as appeared in Figure 2.7, IEEE 802.11 is a standard characterizing all parts of Radio Frequency for 802.11 based ad hoc network. IEEE adopted the term ad hoc networks for the IEEE 802.11 Wireless LAN standards and IEEE 802.11 b, a, n, and g, etc. are the most widely used types of versions. In addition, today, Bluetooth and HiperLAN2 are among other alternatives that offer further technologies that can be used in ad hoc communications [7, 8].

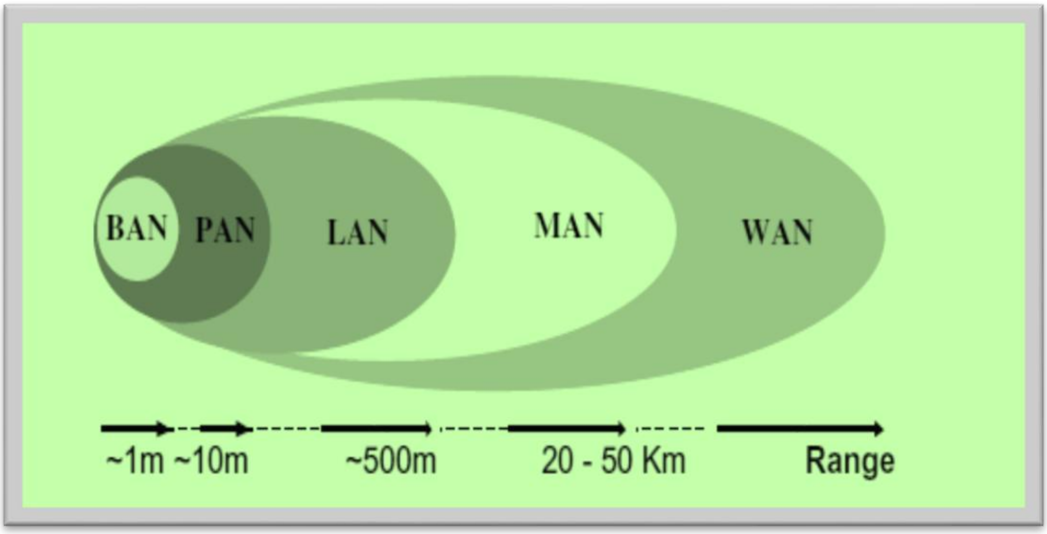

Figure 2.7: MANETs Technology

2.8 MANET: Characteristics, Complexities, and Open Issue

The followings are some of the characteristics, complexities, and open issues, which are specific to MANET [8, 10].

- **Autonomous and infrastructure-less:** MANET does not depend on any established infrastructure or centralized administration such as base stations or access point for their operation and interconnection.
- **Multi-hop routing:** No default router is available every node works as a router and forwards each other's packets to provide information sharing between mobile nodes.
- **Dynamically changing network topologies:** In MANET, nodes can move randomly and arbitrarily. Due to the random movement of nodes, the network topology changes frequently and unpredictably, which results in: -
  - Route changes
  - Frequent network partitions and
  - Packet losses
- **Device discovery:** Nodes can move in and out of the ad hoc networks arbitrarily. Therefore, each node should know and inform the existence of other nodes, which needs a dynamic update to provide up-to-date route selection mechanism.
- **Bandwidth optimization:** Wireless links have basically lower capacity than the wired links.

- **Limited resources:** Mobile nodes depend on limited battery power, processor speed, and storage capacity.
- **Scalability:** Mobile network shall be able to provide all the services in the presence of a large number of nodes.
- **Infrastructure-less and self-operated:** Since there is no fixed Infrastructure or base station that coordinates the operation of mobile Nodes, each node should participate, cooperate, and acts as a router to manage and forward each other's packet.
- **Poor Transmission Quality:** high bit error rate (BER), which results from Signal attenuation, is a typical characteristic of ad hoc networks.
- **Topology maintenance**: Since nodes are moving randomly and arbitrarily, each node should update and maintain their route information periodically to preserve the consistency of the network topology, which may consume much of the scarce power resource.
- **Distributed operation**: The decentralized nature of MANET requires that any routing protocol executes in a distributed manner.
- **Limited physical security**: In MANET, since the topology of the network changes dynamically and nodes can enter and leave the network without any authentication, it is very much vulnerable to different types of Security attacks.
- **Routing:** Routing is a significant point of view with researchers since routing protocols is an essential issue in this field because changes in network topology occur frequently. An efficient and intelligent routing protocol is required to cope with highly dynamic and fluid network conditions.
- **Routing Overhead:** In MANETs, nodes typically change their location and topology at intervals network because of the dynamic nature of MANET.
- **Multiple Accesses:** A major issue is to develop economical medium access protocols that optimize spectral utilize, and hence, maximize combination channel utilization in MANETs.
- **Radio Interface:** Mobile nodes depend on the radio interface or reception apparatus to transmit information. Packet sending or accepting by means of radio interface or reception apparatus procedures in MANETs is a helpful investigation.
- **Power Management:** A power controlling approach would help decrease control utilization and thus dragging out the battery life of versatile nodes. Since most

devices work on batteries, control the executive's turns into an imperative issue is necessary.

2.9 MANETs Advantages and Disadvantages

Mobile Ad hoc network have the following advantages:

- The facility of service access and information access are provided by the mobile nodes regardless graphical position of the mobile nodes.
- Such kinds of networks are easily established anywhere and anytime.
- Effective cost
- MANET is multi-hop network with autonomous terminal and dynamic network topology
- Support is not required for the Development infrastructure.

The disadvantages of the MANET network are specifying the following points:

- Limit bandwidth.
- Limit battery.
- Not supports Authorization.
- Due to volatile network topology it becomes hard to detect the malicious nodes
- The protocols which are used into the wired network are not supported for the wireless network.

2.10 Routing and Routing Protocols in MANETs

One of the major research areas within MANETs is routing strategies. Challenges in MANET routing includes mobility, overhead, scalability, security mechanisms, Internet gateway discovery, and QoS support. QoS routing is an important field within the research area, and standardization has been initiated by the Internet Engineering Task Force (IETF) [10].

As presented in [14] MANETs routing protocols are classified broadly into three classifications named as proactive, reactive and hybrid. The main difference between reactive and proactive categories is all about how to collect route information. On-demand routing protocols collect routing data only if required by exploitation the route discovery procedure. On the other hand, table-driven protocols constantly propagate routing information.

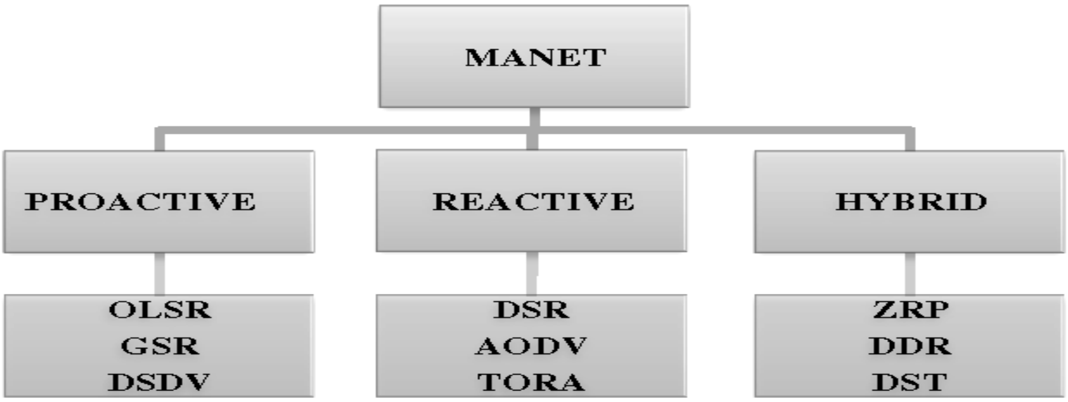

Figure 2.8:Classifications of MANETs Routing Protocols

Each of these three basic types has its own advantages, disadvantages, and appropriateness of use in certain types of ad hoc networks depending on the mobility, a number of nodes involved, node density, underlying link layer technology, and general characteristics of the environment and applications being supported.

2.10.1 Proactive Routing Protocols

Proactive routing protocols learn the network topology before forwarding. In the second classification, nodes do not exchange any routing information. An originator node obtains a path to a particular destination only if it has to send some information thereto.

Destination-Sequenced Distance Vector Routing (DSDV)

Destination sequenced distance vector routing (DSDV) is adopted from the traditional Routing Information Protocol (RIP) to specially appointed systems directing. It includes another trait, grouping number, to each course table section of the regular RIP. Utilizing the recently included succession number, the versatile nodes can recognize stale course data from the new and along these lines keep the development of routing loops. Alternatively, DSDV [12, 13] is a modification of conventional Bellman-Ford routing algorithm. This algorithm includes another header field called sequence number, to each route table entry at every node. The routing table is kept up at every node and with this table, a node transmits the packets to other nodes stations in the network. These stations list all the accessible destinations and the hop counts required to reach every destination in the routing table.

It is designed to address the looping problem of the conventional distance vector routing protocol and to make the distance vector routing more suitable for ad hoc networks routing. DSDV requires that each mobile station in the network must constantly advertise to each of its neighbors, its own routing table. Since the entries in the table may change very quickly, the advertisement should be made frequently to ensure that every node can locate its neighbors in the network. This agreement is placed to ensure the shortest number of hops for a route to a destination. In this way, the node can exchange its data even if there is no direct communication link. The data broadcasted by each node will contain its new sequence number, a destination address, the number of hops required to reach the destination and the new sequence number, originally stamped by the destination.

Surveys on the routing protocols showed [12, 13] the performance of DSDV is high in networks which have less number of nodes and less mobility. When the number of nodes in the network grows the size of the routing tables and the bandwidth required to update them also grows. These will lead to high overhead which is the main weakness of DSDV. DSDV also poses a period of convergence before which routes will not be known and packets will be dropped. In addition, in DSDV routing loops can occur while the network is reacting to a change in the topology. It has a high degree of complexity, especially during link failure. Fluctuation is another problem of DSDV. In some simulation studies [18], DSDV is much more conservative in terms of routing overhead but because link breakages are not detected quickly more data packets are dropped.

2.10.2 Reactive Routing Protocols

The first types of routing protocols are based on the periodically exchanging of routing information between the different nodes, each node builds its own routing table which it can use to find a path to a destination. In bandwidth starved and power-starved environments, it is interesting to keep the network silent when there is no traffic to be routed. Reactive routing protocols do not maintain routes but build them on demand [14, 5]. A reactive protocol finds a route on demand by flooding the network with Route Request packets. These protocols have the following advantages:

- No big overhead for global routing table maintenance as in proactive protocols.
- Quick reaction for network restructure and node failure.

Therefore, these routing protocols perform better QoS in terms of packet delivery ratio, end to end delay and incur lower routing overhead especially in the presence of high mobility and high network density, [21] Compared with the other routing protocols, they need relatively unconditional low storage, and the routes are available only when they are needed.

Ad hoc on Demand Distance vector routing protocol (AODV)

AODV [22] uses the on-demand approach to discover and identify a specific route. When a node requires sending data, AODV uses route discovery using control messages like route request (RREQ) and route reply (RREP) to find the route to the destination. In AODV neighbor nodes store the route information of their next hop neighbor. This enables AODV to evaluate the shortest distance and safe path. To discover a path a source node broadcasts a route request message to its immediate neighbors. Neighbor's in-turn send the route request packet to their neighbors. This process continues until the destination is reached. When the RREQ packet transmission. Once the data packet is transmitted the route information will be cleared. AODV discovers and identifies a route only when a node requires sending or receiving data. During error, while transmission or link failure a route error (RERR) message will be generated and sent to the source node to find an alternative path. The main advantage of AODV is that a route is discovered and identified on demand. AODV faces severe drawback as intermediate nodes may forward to unreliable routes if the source sequence number is very old and the intermediate nodes have a higher, but not related to the latest destination sequence number. AODV is appropriate for QoS routing when a loop-free and up to date route is required. In this routing protocol, to know their current destination route, every mobile node preserves routing table of next hop. Once a source node desires to establish a communication session, it initiates to send packets to the destination if it has a current route to the destination in its routing table. Otherwise, it initiates a path discovery process by broadcasting a route request message. As on-demand routing protocol [12, 17], AODV uses periodic broadcast of Hello Message to track neighboring nodes. This periodic propagation causes network overhead in AODV. In AODV a routing path to a particular packet is discovered at the time of needs. This initial search latency may degrade the performance of interactive applications. Similarly, the quality of the path is not known prior to call setup. It can be discovered only while setting up the path. Moreover, the quality of the path must be monitored by all intermediate nodes in an active session at the cost of additional latency and overhead.

Destination Source routing (DSR)

This is an on-demand source routing protocol. In DSR [13,17] the route paths are discovered after the source sends a packet to a destination node in the ad-hoc network. DSR requires no periodic updates of any kind at any level within the network. It uses source routing through which the sender knows the complete hop by hop route to the destination. These routes are stored in route cache. A data packet carries the source route in the packet header. DSR consists of two mechanisms, route discovery and route maintenance [20]. Route discovery functions by flooding the network with route request packets. Each node receiving a route request packet rebroadcasts it unless it is the destination or it has a route to the destination. The route carried back by the route replay packet is cached at the source for future use. For route maintenance, whenever a link on a source route is broken, the source node is notified using a route error packet. In MANETs, DSR can be chosen to provide soft QoS guarantees in different areas of MANET applications when better QoS parameters like reliability, packet delivery, overhead, etc. should be taken into account for routing of packets. The protocol provides a reliable route for packet transmission with a minimum network overhead. Due to source routing, DSR has major scalability problem [19]. Nodes use routing caches to reply to route queries. This results in uncontrolled replies and repetitive updates in hosts caches. In addition, early queries cannot stop the propagation of all query messages which are flooded all over the network. Therefore, when the network becomes larger, the control packets and message packets also become larger. This could degrade the protocol performance after a certain amount of time.

2.10.3 Hybrid Routing Protocols

These types of protocols combine the advantages of proactive and reactive routing protocols [18]. The routing is initially established with some proactively prospected routes and then serves the demand from additionally activated nodes through reactive flooding. The choice for one or the other method requires predetermination for typical cases. The main disadvantage of hybrid routing protocols is that the nodes that have high-level topology information maintain more routing information, which leads to more memory and power consumption. An example of such a protocol is the Zone Routing Protocol (ZRP). ZRP divides the topology into zones and seeks to utilize different routing protocols within and between the zones based on the weaknesses and strengths of these protocols [18].

2.11 QoS Issues in MANETs

Due to the rapid popularity of MANETs, real-time multimedia applications are becoming growing. Most of the multimedia applications require their own special QoS requirements [11] like, minimum end to end delay, available bandwidth, tolerable jitter (the inter-packet delay) and the minimum probability of packet loss. As described in [24] Quality of service can be defined as a set of service that should be fulfilled by a network. Thus, achieving QoS in MANET is a challenging task due to various unique characteristics nature of MANETs.

While it is hard to provide QoS in traditional networks, MANETs and wireless networks all become more challenges on account of their attributes. Conventional Internet QoS conventions can't be effectively moved to the wireless scenario, because of the error-prone nature of wireless connections and the high movement of portable devices. This is true for MANETs where each node moves dynamically, causing the multi-hop network topology to change randomly and at unrespectable times.

- **QoS Parameters in MANETs**

Because of various requirements of different applications, the services required and the QoS parameters change for each application. For example, for multimedia applications (real-time data traffic), the data rate and delay are the key factors where timing is a critical issue. Generally, QoS parameters can be grouped into three categories:

i. **Additive**: It is the sum of the metrics on all links along the path like an end to end delay and jitter are additive QoS parameters. For example, end to end delay of a path is equal to the summation of delays at each link. Examples: Delay, Delay variation (jitter), and Cost.

ii. **Multiplicative**: It represents the product of the metric values on all links over a path. For example, probability of packet loss p (u, v) for a packet to reach v from u is the product of packet loss probabilities at each intermediate individual link. Example: Loss probability.

iii. **Concave**: It considers the minimum metric value over a path. Parameters like bandwidth, security, and an end to end reliability are concave parameters. Bandwidth along a path from u to v is the minimum bandwidth along with the links on the path. Examples: Bandwidth (here bandwidth is the residual bandwidth that is available for network flow).

Therefore, in MANET nodes cooperative and intermediate nodes participate from source to destination route formation. The required QoS parameter on a given path can be calculated by one of the given ways depending on the nature and behavior of the QoS parameter. However, it is shown that in the multi-hop environment to consider a pair of two multiplicative or additive or one additive and one multiplicative constraint for satisfying QoS needs are Nondeterministic Polynomial time (NP) Completeness problem. In normal practice for reducing combinatory explosion, one concave constraint (like bandwidth) and one additive constraint (like an end to end delay) or multiplicative constraint (like packet loss) are considered for QoS guarantee.

2.12 QoS Routing in MANETs

Most of the existing MANET routing protocols are not QoS aware, because of this various scholar proposed a QoS improvement mechanisms for MANET [7]. However, Achieving QoS in MANET for real-time applications as the required level is persisted as a challenge yet. QoS routing is [25] "*a routing process that guarantees to support to a set of QoS parameters during establishing a Route*". The QoS routing in MANETs is needed only to support the multimedia real-time communication like Video-on-demand, news-on-demand, web browsing, traveler information system, etc. These applications require a QoS guarantee not only over a single hop but also over the entire wireless multi-hop. The QoS routing supports QoS-Driven selection and QoS Reporting and provides path information at each router [26].

- **QoS Routing two Factors**
  - The QoS routing schemes can help admission control. Routing protocol does not provide a route to the destination, but also computes the QoS, that is supportable on a route during the process of route computation. It accepts a new connection request if it finds a suitable loop-free path from the source to a destination having necessary resources (bandwidth) available to meet the QoS requirements of desired services, otherwise, the connection request is rejected.
  - QoS routing scheme that considers multiple constraints provide better load balance by allocating traffic on different paths subject to the QoS requirements of different traffics.

Figure 2.9 shows clearly the effects of routing on QoS support routing protocols with that of non QoS supports. That is, the first which does not show clear video as it uses non QoS support routing protocols while the later uses QoS satisfying protocols.

- The followings are the Targets of QoS Based Routing [26].
  - To find a feasible path between source and destination, which
    - Satisfies the QoS requirements for each admitted connection and
    - Optimizes the use of network resources

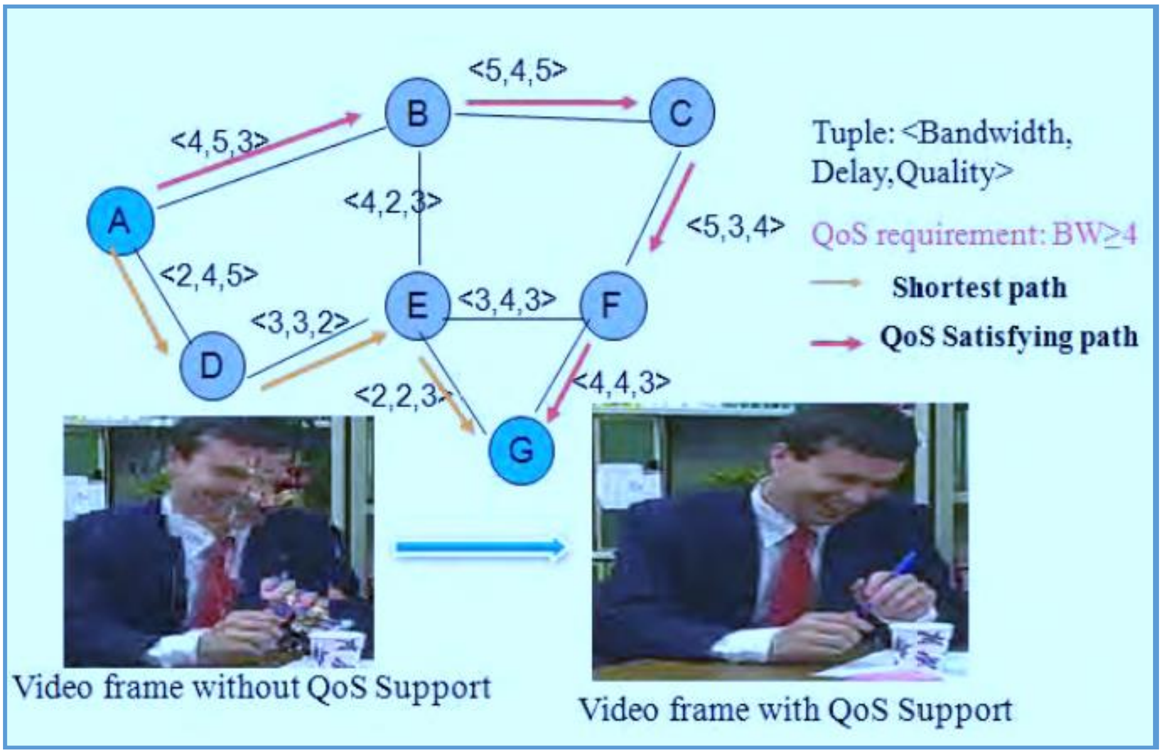

Figure 2.9 Sample Video Streaming

Thus, routing protocols may need to offer different ways or methods to select the best path based on the QoS metrics on the discovered paths. Some constraints can be relevant to one service but not to another. Each service has a set of QoS constraints that has to be met in order to deliver that service; thus, it is important to define these constraints and the minimum/maximum value for each constraint to be used in the routing process.

CHAPTER 3: PERFORMANCE EVALUATION of DSDV, DSR and AODV ROUTING PROTOCOLS in MANET

This section explains the detailed experimental and conceptual evaluations of the performance of the two reactive ad hoc routing protocols (AODV, DSR) and one proactive routing protocol (DSDV) with respect to end to end delay, packet delivery ratio and average throughput. The main aim of this performance evaluation is to select best QoS support routing protocol from the available well known MANETs routing protocols for further QoS improvement and to prove that why AODV routing protocol is selected from the other available routing protocols to use as a base routing protocol to implement the proposed QoS improvement approach.

The choice of these protocols for comparison is due to the fact that they cover a variety of design choices: -

- The use of periodic message transmission (DSDV) versus an on-demand route
- The feedback mechanism used for route maintenance to indicate a link failure, forward a packet to the next hop in the case of DSR, AODV i.e. a broken link is only notified to those nodes along an active route which affects due to the broken link versus flooding broken link message throughout the network i.e. network wide broadcast in the case of DSDV.
- The forwarding algorithm used to find a route, such as hop-by-hop routing (DSDV, AODV) versus source routing (DSR).

3.1 Simulation Tools

In this sub section, the widely used simulator for MANETs to evaluate the protocols performance is analyzed. The selection of a development environment and simulation tools to be used for the implementation and evaluation of the proposed solution will be described in this Section. There are different ways of doing an experiment for various research works, such as using analytical model, emulation, real testbed and Simulation to measure the behavior and performance of protocols in wireless networks as general. The construction of real testbeds for any predefined scenario is usually an expensive or even impossible task if factors like mobility, testing area.

Additionally, most measurements are not repeatable and require a high effort. Therefore, simulations are needed to bypass these problems [1, 2].

Simulation-based software environment is used to study the behavior of a networking system and relevant protocols. [28] There are plenty of MANETs simulators currently in Use for computer networks and protocols evolution and testing purpose, For instance, NS-2, NS-3, OMNET++, SWAN, OPNET, QUALNET, J-SIM, GLOMOSIM, etc. All these network simulators have varied factors to be considered in simulating a MANET environment. Thus, selecting an appropriate network simulator and assessing which one will provide optimum performance and suitability of network simulator for implementing and evaluating the proposed work is crucial. Here we have summarized surveys on various network simulators as follows:

Authors in [29] pointed out that various simulators have different features and they have their own advantage and disadvantages, furthermore, none of the simulation tools fulfills all the requirements. According to this paper, authors made analysis on various available simulation tools and they selected NS-2 and OMNET++ as the best choices for the MANETs.

Another author(s) in [30] made a detailed analysis on many of existing wireless network simulators and they point out that the simulator has long listing features and characteristics but none of the simulator that can support all of them. Thus, according to their analysis result, they conclude that NS2 is the best simulation tool available today for both wireless and wired networks including to its popularity, supportability and flexibility support. OMNET++ is also can be put as a successor of NS2 due to its GUI supportability and having various good features. However, NS2 is the most popular simulation tools in the area of academic research specifically.

Another author (s) In [31], described a brief introduction to various network simulators with their distinct characteristics and they gave a clear guide for the researchers to focus their attention on the software that meets specific requirements. The paper pointed out that NS-3 is the best choices for the MANETs; it supports a wide range of protocols in all range of protocols in all layers.

As described in [32] various simulators like NS-2, NS-3, and OMNET++ are evaluated. The authors have analyzed these simulators on the basis of the factors like the impact of simulation runtime on the network size and probability of dropping packets. They have also considered the memory usage as metrics in order to analyze the memory requirements of various simulators. The large variation in runtime performance as well as in memory usage was found when the simulation results were analyzed. The following table summarizes the comparisons between different simulation tools in different criteria's [28].

Table 3:1: Comparison of Network Simulators

Network Simulators	License	Interface	Parallelism	Popularity	Granularity
NS-2	Open source	C++, TCL	No	88.8%	Finest
GloMoSim	Open source	Parsec	SMP/beowulf	4%	Fine
Opnet	Commercial	C	Yes	2.61%	Fine
OMNet++	Free for academic and educational use	C++	MPI/PVM	1.04%	Medium
QualNet	Commercial	Parsec (C-based)	SMP/beowulf	2.49%	Finer
J-Sim	Open source	Java	RMI-based	0.45	Fine
SWANS	Open source	Java	No	0.3%	Medium

Summary

As we have observed from the surveys , [29]–[31], NS-2, OMNET++ and NS3 are the best choices which provide better performance and simulation environment for MANETs. Therefore, considering issues discussed above, criteria like the ability to run large networks, availability of varieties of modules, debugging and tracing support, popularity, flexibility and dynamic topology creation, we have selected NS2 for implementing and evaluating our proposed work.

3.2 NS2 as a Candidate Simulator to Evaluate the Proposed Approach

Network Simulator (Version 2) [31] widely known as NS2, is simply an event-driven simulation tool that has proved useful in studying the dynamic nature of communication networks. Simulation of wired as well as wireless network functions and protocols (e.g., routing algorithms, TCP, UDP) can be done using NS2. In general, NS2 provides users with a way of specifying such network protocols and simulating their corresponding behaviors. Due to its flexibility and modular nature, NS2 has gained constant popularity in the networking research community. The architecture of ns-2 is shown in the figure below.

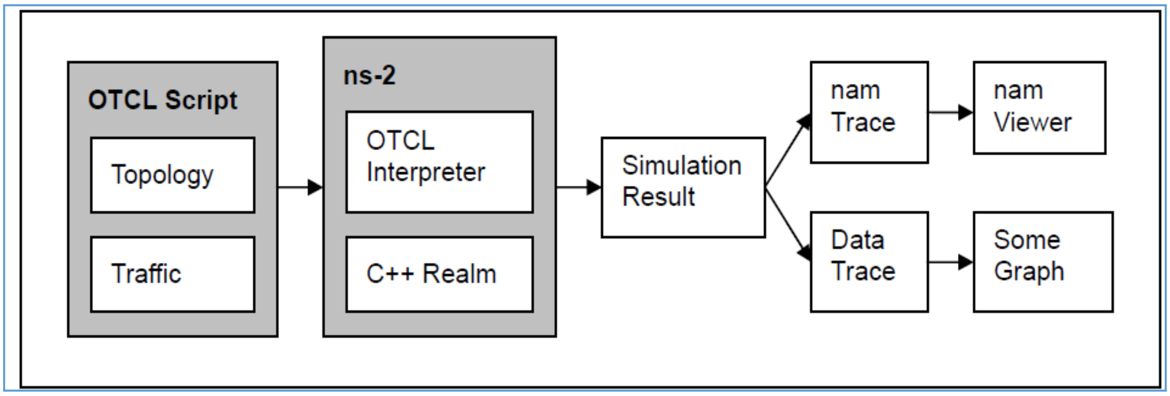

Figure 3.1: Overall Architecture of NS2

NS2 consists of two key languages: C++ and Object-oriented Tool Command Language (OTcl). While the C++ defines the internal mechanism (i.e., a backend) of the simulation objects, the OTcl sets up simulation by assembling and configuring the objects as well as scheduling discrete events (i.e., a frontend). NS2 uses OTcl to create and configure a network and uses C++ to run the simulation. All C++ codes need to be compiled and linked to create an executable file. Since the body of NS2 is fairly large, the compilation time is not negligible. OTcl, on the other hand, is an interpreter, not a compiler.

Any change in an OTcl file does not need compilation. Nevertheless, since OTcl does not convert all the codes into machine language, each line needs more execution time. In summary, C++ is fast to run but slow to change. OTcl, on the other hand, is slow to run but fast to change. It is, therefore, suitable to run a small simulation over several repetitions (each may have different parameters). NS2 is constructed by combining the advantages of these two languages.NS2 provides users with an executable command *ns* which takes on an input argument, the name of a Tcl simulation scripting file. In most cases, a simulation trace file is created and is used to plot graph and/or to create animation. To interpret these results graphically and interactively, tools such as NAM (Network AniMator) and XGraph are used. To analyze a particular behavior of the network, users can extract a relevant subset of text-based data and transform it into a more conceivable presentation.

Marc Greis' Tutorial

The very first thing to do for a new user of NS is to read Marc Greis' tutorial. The purpose of this tutorial is to make it easier for new NS users to use NS and NAM, to create their own simulation scenarios for these tools and to eventually add new functionality to NS.

NS by Example

On the web page of NS, there is a link to another tutorial for NS. This tutorial has been written by Jae Chung and Mark Claypool and its purpose is to give new users some basic idea of how the simulator works, how to setup simulation network codes, how to create new network components and so on. In particular, it explains the linkage between the two languages used in NS, namely C++ and OTcl. One can find some very good examples and brief explanations in this tutorial, which is the second tutorial to study after reading Marc Greis' tutorial.

NS Manual, NS Search, and NS Mailing List

In the NS Manual, one can find the answer too many questions. A link to this Manual can be found on the web page of NS. However, if no answer can be found in the Manual the NS mailing list archives should be searched. The archive keeps all previous emails sent to the ns-users mailing list. The ns-users mailing list should be used if an answer still (after looking in the Manual and searching the archives) has not been found. Everyone that has subscribed will receive this email and will hopefully reply.

NS-2 Network Animator (NAM)

Network Animator (NAM) is an animation tool for viewing network simulation traces and real-world packet traces [38] it supports topology layout, packet-level simulation, and various data inspection tools. Before starting to use NAM, a trace file has to be created. This trace file is usually generated by NS-2 as discussed above. It contains topology information for example node and links as well as packet losses. During the simulation, the user can produce topology configuration, layout information and packets traces using tracing events in NS-2. Once the trace file is generated, NAM can be used to animate it. Upon starting, NAM will read the trace file, create the topology, pop up a window, do layout if necessary and pause at time 0. Through its user interface, NAM provides control over many aspects of animation.

3.3 Performance Metrics

In this section the researcher explores the appropriate QoS metrics that should be used to evaluate the performance of the proposed protocol efficiently. Thus, various research works have been reviewed related to QoS evaluation metrics selection for delay sensitive routing protocols in MANETs. Different performance metrics are used in the evaluation of routing protocols which represent different characteristics of the entire network performance. Depending on the type of application different evaluation metrics are used [24]. Performance of MANETs routing protocols can be evaluated using a number of quantitative metrics those are mentioned in RFC 2501. As described on [7, 8], end to end delay, packet delivery ratio, throughput, jitter and normalized routing overheads are the most critical metrics which should be considered in establishing route especially for delay sensitive applications . Thus, in this thesis work, we used an average end to end delay as main evaluation metrics and normalized routing overhead, throughput and packet delivery ratio as additional QoS metrics to evaluate the performance of existing MANETs routing protocols as well as the proposed QL-AODV against the existing one. Thus, the following performance evaluation metrics are used to evaluate the QoS performance of three selected well known MANETs routing algorithm named as, AODV, DSR and DSDV.

Average End to End Delay (AEED): This is the average time delay for data packets from the source node to the destination node. This metric is calculated by subtracting “time at which first packet was transmitted by source” from “time at which first data packet arrived to destination”. This includes all possible delays caused by buffering during route discovery latency, and processing at intermediate nodes.

Packet delivery ratio (PDR): It describes the loss rate and maximum throughput that the network can support. For all our simulations we have kept the number of data packets sent out as constant so that the number of packets successfully received at their destinations will give us a comparison as to how efficient the underlying routing algorithm is under similar traffic load. A high value of PDR indicates that most of the packets are being delivered to the higher layers and is a positive sign of performance.

Throughput (THP): It is the total number of delivered data packets divided by the total duration of simulation time. In this case, the throughput of each of the routing schemes in terms of number of messages delivered per one second is evaluated.

3.4 Simulation Scenario

The Simulation environment is setup in such a way that, the node variations are 10, 20 and 30 with the simulation area of 1000m x 1000m and traffic model constant bit rate (CBR) in a rectangular area. The size of each packet is also 512 bytes.

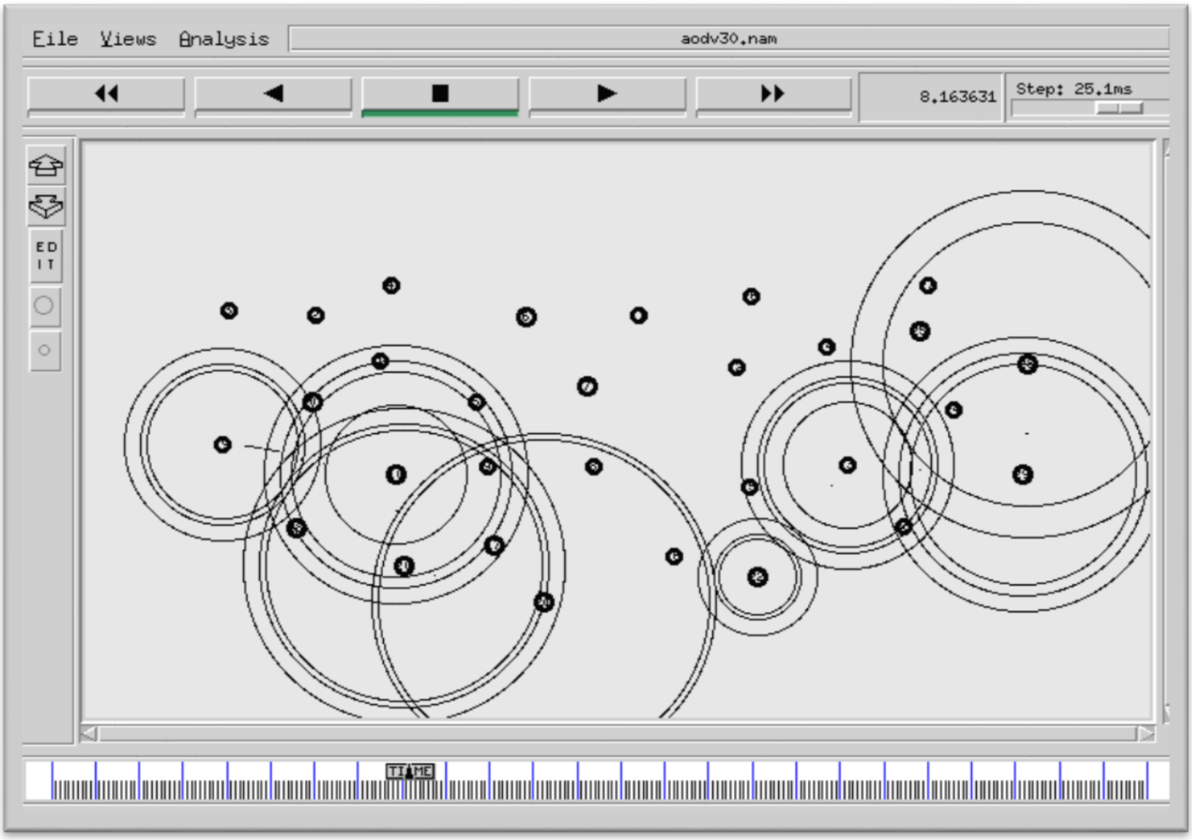

Figure 3.2: NAM Output for Simulated Network Topology of 30 Nods

The following simulation parameter set ups are used for writing the Tcl script.

Table 3:2: Simulation Parameters

Parameter	Value
Operating system and simulations	Ubuntu, NS2(version 2.35)
Simulation area	1000m x 1000m
Radio propagation	Two ray ground
Channel type	Wireless channel
Traffic model	CBR
Routing protocol	AODV, DSR, DSDV
Mobility model	Random waypoint
Number of nodes	10,20,30
Simulation time	30s
MAC type	IEEE 802.11n
Packet size	512 bytes
Link layer type	LL
Antenna	Omnidirectional
Interface queue	50

Average end to end delay:

In Figure 3.3, we observe that average end to end delay of AODV is less than DSR and DSDV. The reason is that AODV doesn't include path list during data transmission as DSR does and AODV doesn't maintain route information all the time as DSDV does.

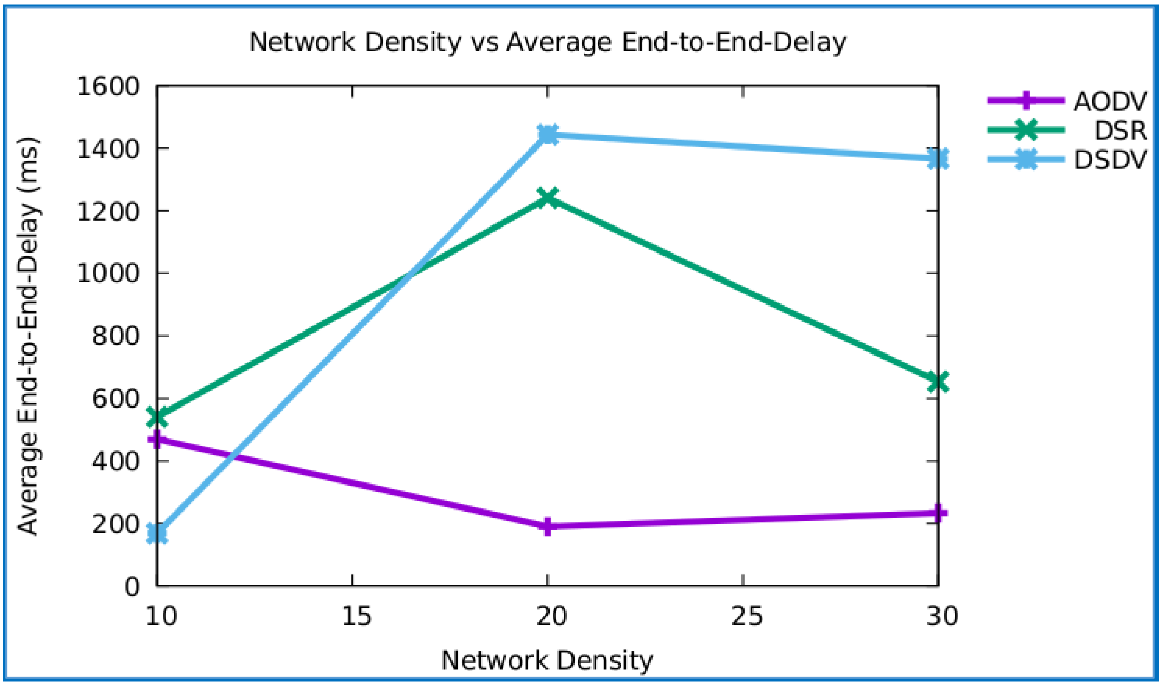

Figure 3.3: Comparison of End to End Delay Vs Network Density

Packet delivery ratio:

Figure 3.4 illustrates that AODV provides high packet delivery ratio than DSR and DSDV. This is because of that on demand nature of the AODV routing algorithm reduces from having high overhead.

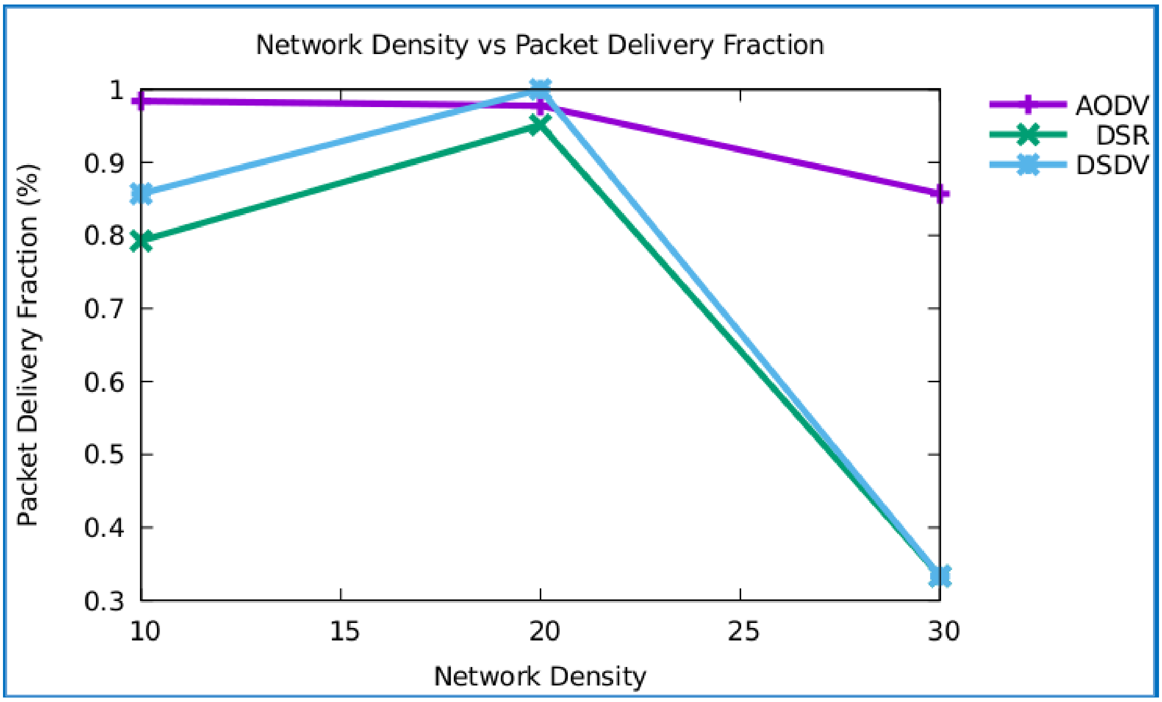

Figure 3.4: Comparison of Packet delivery ratio Vs Network Density

Average throughput:

As Figure 3.5 shown as the average throughput of DSR is better than the other two protocols. This is due to the fact that DSR uses catching mechanism for route discovery procedure.

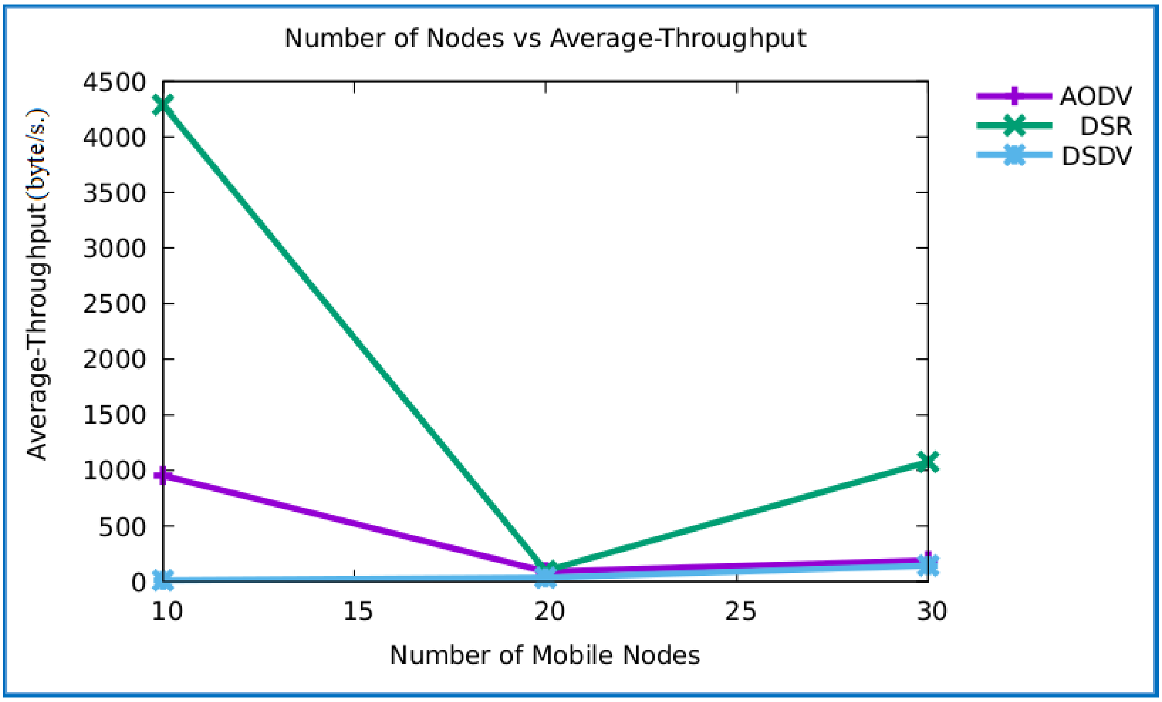

Figure 3.5: Comparison of Average Throughput

3.5 Result Analysis and Discussion

As the simulation result reveal, the performance of reactive routing protocols as general are much better than proactive in the manners of end-to-end delay and packet delivery ratio. End to end delay is higher in DSDV followed by DSR and AODV have the lowest and most stable end to end delay performance. AODV stays better as the number of nodes become large in the perspective of end to end delay, however, DSDV and DSR protocols become unstable as network size increases. Furthermore, for lower number of nodes, AODV suffers from higher delays than DSR. This happens due to the fact that AODV has periodic activities (exchange of HELLO messages) and does not use cache to store the routes. DSR outperforms AODV in lower traffic density and when the number and size of the network is low (e.g., less than 20 nodes).

As the simulation result shown that, DSDV and DSR show better performance in term of throughput as compared to AODV. Therefore, according to the above experimental analysis, in this thesis, we have selected AODV routing protocol as a candidate to implement the proposed QoS improvement approach.

Summary

This chapter provided a detailed experimental analysis on three well known MANETs routing protocols named as, AODV, DSDV and DSR and interpret the experiment results. As it can be seen that in the simulation results, AODV outperforms than the others two routing protocols in terms of end to end delay and packet delivery ratio. However, even if AODV is an efficient MANETs routing protocol, AODV have a drawback regarding to optimal path selection to achieve QoS requirements efficiently. Thereby, AODV uses minimum hop count as a cost metrics to select a path for data transmission. Since, the existing AODV path selection method is unaware of the queue status of each intermediate nodes, the node which does not have sufficient buffer space could be part of an established route, leading to occur network congestion frequently. Thus, this thesis work focused on making AODV more QoS aware routing protocol.

3.6 AODV as a Candidate for Further QoS Improvement

First in this thesis work, we compared the performance of three well known routing protocols DSDV, AODV and DSR in three metrics. As the performance of AODV has been found better in our simulation than DSR, and DSDV we are interested to modify AODV routing protocol to implement our QoS improvement approach with the goal of improving latency.

3.7 More on AODV Routing Protocol

As described [11, 12] AODV is one of the widely used on-demand routing protocol in mobile ad hoc networks, which means the route discovery process starts whenever a need is there by one of the communicating nodes. AODV takes some advantages from DSDV and DSR to be efficient in terms of various issues. Thus, it takes techniques like periodic hello messaging and sequence numbering from DSDV and routes discovery using flooding from DSR. An important feature of AODV is the maintenance of time-based states in each node: a routing entry not recently used is expired. In case of a route is broken the neighbors can be notified.

Basic Route Discovery Process

To maintain route discovery and route maintenance issues, AODV uses a three basic types of messages formats namely, RREQ (route request), RREP (route replay) and RERR (route error) messages. Thus, as the node wants to send a data to the other node, the node which wants to send a data (i.e. source node) first checks its routing table weather it has a route to destination or not, if it does not have a route to a destination, the source node should generate RREQ packet by specifying all necessary field information of the message format and it will broadcast the packet to all the neighbor nodes. Each intermediate node receiving RREQ packet will update information about to source and perform reverse route to the source.

An intermediate node (i.e. receiving neighbor node) will replay RREP if it is either it has a valid route to a destination or the node itself is a destination node. Otherwise, if none of the two conditions are not satisfied, the node will rebroadcast (forward) the RREQ packet to all its neighbor nodes. Finally, once the RREQ packet reaches to the destination, the destination node checks its address with the one specified in RREQ which come from the source and it will prepare RREP packet to a source, then, RREP packet can be unicast along a path to that Originator. The sequence number in AODV is mainly used to avoid route loop and to identify the freshness of the route. Thus, a large destination sequence number indicates the most recent routes. Whenever the destination selects the optimal path it prefers to choose a route which has a large sequence number or in case more than one rote to a destination is there, the destination node looks a route.

The route discovery procedure can be explained diagrammatically as shown in figure 3.6. The Diagram is taken from [33] with modification to include the reverse and forward routes set up. If node *A* wants to send data to a destination *G* and does not have a valid route to *G*, it floods RREQ messages (lines seen in solid red color) to its neighbors (*B* and *C*). The intermediate nodes then cache the received message and flood the request to their respective neighbors if they don’t have fresh enough route to *G*. while receiving requests, the intermediate nodes save the route back to the originator that will be used to forward reply (lines seen in dotted black color). When the RREQ reaches *G*, node *G* prepares a RREP (lines seen in dotted green color) and this reply is unicasted to the originator using the partial route established during the propagation of RREQ messages. The intermediate nodes then forward the RREP to the originator by adding forward path (lines seen in solid blue color) to their table. When node *A* receives a reply, it immediately starts to forward data to *G* using the established route.

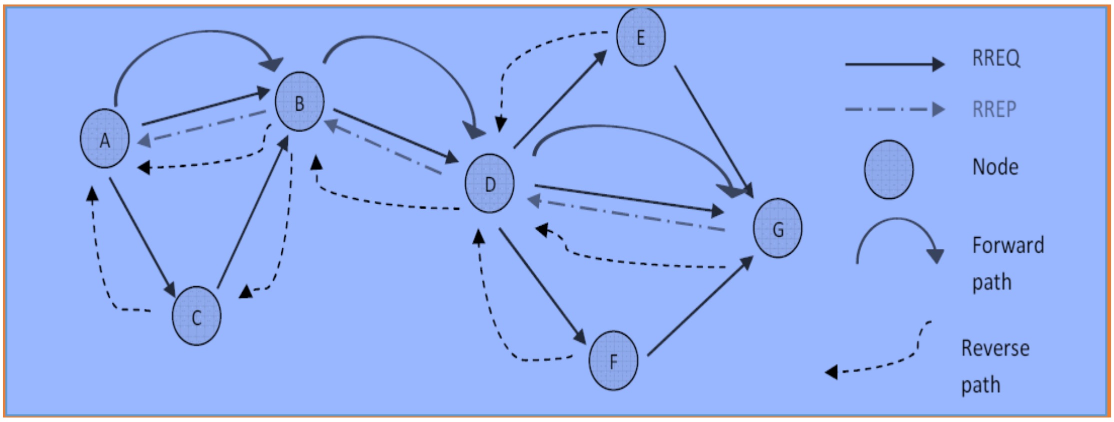

Figure 3.6: Basic Route Discovery Procedure of AODV

Basic Route Maintenance Procedure

Nodes notice link standing by periodically broadcasting HELLO packets. Once a broken link in a route is detected, firstly, the node lists those inaccessible destination nodes within the unreachable space and the other node that uses those unreachable areas for the following hop on the naïve routing table, then a route error(RERR) message is employed to advice different nodes that the loss of that link has occurred. The RERR message indicates those destinations (possibly subnets) that are not any longer approachable within the means of the broken link. If a node has received RERR packets and use of the notified invalid route, it'll do a replacement route discovery method. Once the destination node detects AN invalid link that is connected with it'll not take the initiative to get RERR packets, however, build its sequence variety and one.

Table 3:3 AODV Message Types

No.	Message type	Purpose	Used in stage
1.	RREQ	Used to find routes and is initiated by a source node	Route discovery
2.	RREP	Response to RREQ message	Route discovery
3.	RERR	Notifies link failures	Route maintenance
4.	HELLO	Provides connectivity information	Local connectivity may also trigger route update

Drawbacks of AODV

It is possible that a valid route is expired. Determining reasonable expiry time is difficult, because the nodes are mobile, and sources' sending rates may differ widely and can change dynamically from node to node.

Moreover, AODV can gather only a very limited amount of routing information; route learning is limited only to the source of any routing packets being forwarded. This causes AODV to rely on a route discovery flood more often, which may carry significant network overhead. Uncontrolled flooding generates many redundant transmissions which may cause so-called broadcast storm problem. The performance of the AODV protocol without any misbehaving nodes is poor in larger networks. The main difference between small and large networks is the average path length. Along the path is more vulnerable to link breakages and requires high control overhead for its maintenance. Furthermore, as the size of a network grows, various performance metrics begin decreasing because of increasing administrative work, so-called administrative load.

AODV is vulnerable to various kinds of attacks because it is based on the assumption that all nodes will cooperate. Without this cooperation, no route can be established and no packet can be forwarded. There are two main types of uncooperative nodes: malicious and selfish. Malicious nodes are either faulty and cannot follow the protocol, or are intentionally malicious and try to attack the network. Selfishness is noncooperation in certain network operations, i.e. dropping of packets which may affect the performance, but can save the battery power.

3.8 Open Issues in AODV Regarding QoS

- **Methods of Route Selection**

In the existing AODV routing algorithm paths are selected using hop count metrics that means the path which has minimum Hop count is selected as the optimal best path. However, minimum hop count is not efficient in fulfilling QoS requirements particularly for delay sensitive applications such as, video , voice and multimedia streems.

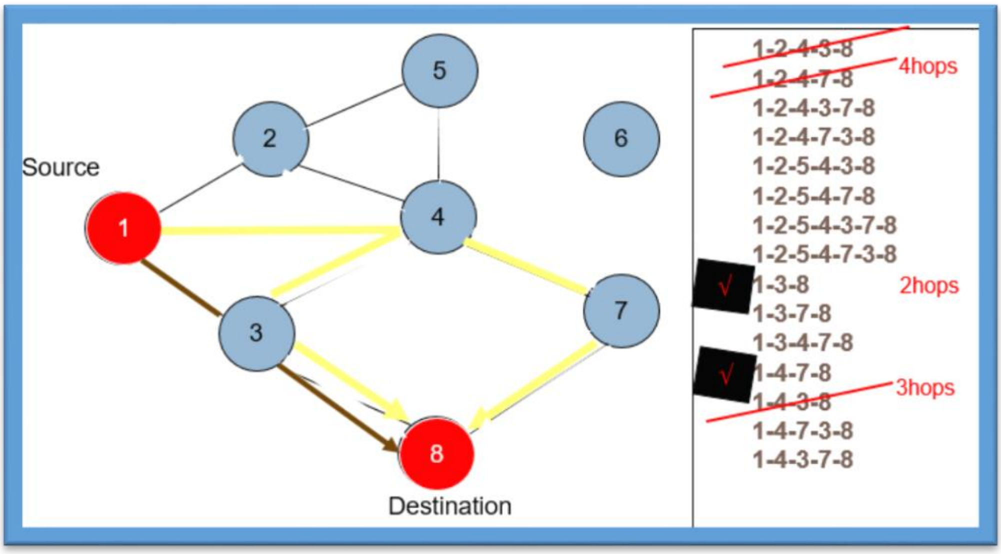

Figure 3.7: Illustration of Route Selection Process in Existing AODV Protocol

As illustrated in Figure 3.7, since there are multiple paths available, the destination node will choose the optimal path based on the shortest hop count. However, the path that will be selected might not be efficient from the perspectives of achieving QoS requirements. Thus, this study gives emphasis on making AODV QoS aware by modifying the route selection strategy of the existing AODV routing algorithm so as to minimize latency for delay sensitive applications.

CHAPTER 4: RELATED WORK

4.1 Overview

The main aim of this chapter is to present the related research works regarding MANETs QoS routing protocol in AODV. Recently, wireless communication between mobile users is becoming more popular than ever before. They are able to support robust and efficient operations by incorporating the routing functionality into mobile hosts. Because of the rising popularity of multimedia applications and potential commercial usage of MANETs, QoS support in Ad-Hoc networks has become a topic of great interest in the wireless area, and several research directions are proposed to enhance the services provided by MANET applications. Since many of the existing MANETs routing protocols were not designed considering QoS metrics during the route construction process, various enhancement approaches have been proposed different proposals to address the issues of QoS improvement over AODV routing protocols so far to support delay-sensitive applications in which QoS requirements are mandatory.

4.2 QoS efficient routing approach using bandwidth

Real time and complex multimedia applications, like voice, video and large data transfer, require some sort of service guarantee by the network. A recent growth in the use of multimedia applications has led to the need of Quality of Service (QOS) in MANETs. The network should be able to guarantee a set of predetermined services to the end user, mainly in terms of bandwidth. Bandwidth estimation is, thus, a critical component for providing QoS support in MANETs. Estimating the remaining bandwidth, at a given time, in MANETs is complex as the medium is shared among neighboring nodes. This requires an efficient estimation technique for the available bandwidth on a link between two neighboring nodes at any time. Much of such techniques have been suggested in the past. Therefore, in this section, the author reviews some of the efficient bandwidth estimation techniques proposed by various authors to guaranty QoS requirement for QoS required applications.

The work done in [5] introduces a QoS improvement mechanism based on AODV by considering residual Bandwidth during route selection and maintenance process. Hence, in this approach, the residual available bandwidth is calculated at each node throughout the route. RREQ, RREP, and RERR of the existing AODV routing packets have been modified so as to add additional fields at the header format. The algorithm discovers multiple routes based on bandwidth availability in addition to hop count. Route maintenance is more efficient than the existing standards of AODV. These characteristics make the protocol more suitable for real-time data and voice transmission applications in MANETs under 802.11. However, this approach lacks considering other critical QoS metrics particularly for delay sensitive applications such as nodes available buffer size during route selection, beside of this, in this approach there might be the probability of rejection of RREQ packets if the specified condition might not be satisfied in most cases. Furthermore, there will be a situation where two paths may have the available bandwidth above the requested bandwidth by the applications and the path which might be congested may be selected since the approach does not considered the buffer spaces of each intermediate node.

In [36], the authors made a comparative study and performance evaluation of the reactive quality of service routing protocols that are best suited for MANETs. The study has been done by considering parameters like average jitter, overhead, throughput and a total number of packets sent and received. The results were analyzed using simulation method and QUALNET simulator was used for the analysis. Finally, the authors concluded that compared to most reactive protocols AODV is better for QoS routing.

Authors of [37] developed a modified version of AODV named as SQ-AODV to consider residual energy during route discovery and route selection process based on AODV routing algorithm. The algorithm also considers how a protocol can quickly adapt the network conditions so as to improve the quality of service in existing AODV routing protocol. The proposed approach has shown increased PDR, better node expiration time, low control overhead and low packet delay, compared to the existing AODV routing protocol. However, SQ-AODV has not incorporated the available buffer size of each intimidate nodes in to an account during route discovery and route selection process. This is because, even if the approach developed by this paper considers residual energy of each node to extend the network life time, the path which have sufficient available energy might not have sufficient available free buffer space to forward the data packet in a tolerable manner.

4.3 QoS efficient approach using path delay

The other main critical metric to be considered to guaranty QoS issue is delay. Thus, to guarantee the minimum required path delay for delay sensitive applications various proposals were proposed by many authors as discussed in the following section.

The authors in [38] proposed an optimized route discovery and selection schema considering only those routes which have minimum hop count and total path delay. For calculating path delay, the algorithm estimates the current delay at each node with the assumption that the node traversal times are constant. Before forwarding the RREQ, an intermediate node must compare the current value of its LOCAL_DELAY to the remaining value of the difference between the Max-Delay value extension, and the value in the TOT_Delay extension. If the remaining delay is less, the node must discard the RREQ and the route request is dropped immediately. The approach showed performance improvement over an existing best effort AODV in many cases. However, this approach fails in providing effective RREQ packet flooding considering node buffer information, which is the phenomena that may leads to high probability of packet loss and network congestions.

In [9] the authors proposed cross layer approach to improve the performance of MANET routing protocols particularly AODV protocol. The proposed model utilizes signal to noise ratio measurements along the routing path and selects the path with high quality of service rather than the path with minimum number of hops. In this approach, when a route request packet arrives at the destination or an intermediate node with a route to the destination, a route replay packet will be generated. This reply packet is then sent back to the source node following the reverse route contained in the route request packet. Each intermediate node will update the signal to noise ratio (SNR) value if its link value of SNR is lower than the existed recorded value in the route reply packet. If the SNR value of its link is greater than the recorded value, the node will not update the value. The process will continue until the route reply packet reaches the source node. Now, the source node will select the route based on the value of best of worse available value of SNR. The work is experimentally tested and simulation results show that the proposed model gives better performance in terms of delivery ratio, delay and packet drop compared to the existing AODV protocol. However even if the signal strength of the path has been considered by this work it needs further improvement regarding to reduce the probability of the occurrence of network congestion that may occur due to having insufficient buffer size by each intermediate node. This is because, the approach doesn't take an account the available buffer spaces of each intermediate node during route construction process.

The paper in [24] Present an enhanced AODV based QoS Routing Algorithm in MANET for delay-sensitive applications by considering multiple route selectin metrics. Author(s) modified message formats of an existing AODV routing algorithm so as to consider additional QoS metrics during the route construction process. As described in their work, whenever a source node initiates RREQ packet the applications should specify required QoS constraints including, maximum delay, bandwidth, and link quality. Then, algorithm will search for a route that could satisfies them during route discovery process depending on the constraints specified. According to their simulation result, their work showed as overall performance compared with the existing one. However, in this approach there might be a high probability of rejection of the RREQ packet whenever the specified condition might not be fulfilled which leads to unnecessary resource wastage due to unnecessary invocations of retransmission of control packets. the availability of high overhead due to additional header file at message format, and increased energy consumptions are also the limitations of this work. Furthermore, this approach considered multiple metrics during route selection process, however , using multiple metrics for route selection is so difficult because of the difficulties of driving a cost metric function and, hence, considering multiple QoS constraint makes the QoS routing problem NP-complete[39].

The work done on [40], introduced an enhanced hop-count and packet travel time based enhanced routing algorithm, named HT-AODV to improve the QoS for MANETs. in the existing AODV routing protocol, there is a situation were paths with same hop count reach to destination and the algorithm selects the path randomly. The approach proposed by this paper considers the packet transmission time when multiple paths with same hop count reach to the destination. as the simulation result shows, the approach achieves, reduced end to end delay, increased packet delivery ratio. Therefore, in this thesis work we focused on the delay constraint when studying QoS aware routing for supporting delay sensitive applications.

Summary

Thus, it is found that most approaches considered various QoS metrics such as bandwidth, signal strength, residual energy and path delay in route construction process over an existing MANETs routing protocols so as to improve QoS for QoS sensitive applications. Particularly, some of the proposals focused considering bandwidth and delay during path establishment phase depending on the applications requirement. However, even if various authors provided various improvement approach to improve QoS routing in MANET, it is found that minimizing latency for delay sensitive application persisted an open research area.

Hence, in this thesis work we will be focused on considering node queue length during route selection and route discovery phases so as to minimize the latency for delay sensitive applications based on AODV MANETs routing protocol.

CHAPTER 5: THE PROPOSED QUEUE LENGTH AWARE AODV

As mentioned in the previous sections the existing MANETs routing algorithms are not efficient enough for QoS demanding applications [11],[41]. Hence, mechanisms for improving the services of MANET applications, in particular when we consider multimedia traffic are needed to be designed. Hence, in this thesis we proposed, QoS improvement approach based on AODV by considering node queue length during route construction process to reduce latency for QoS required applications. Consequently, the chapter presents the architecture, pseudocode, flowcharts and detail working flow explanation about the proposed QL-AODV routing algorithm. A different approach is followed in both route discovery and route selection procedure to consider node queue length during route selection process.

5.1 Architecture of QL-AODV Algorithm

In this Section, we describe and present the overall architecture of our proposed QL-AODV algorithm to show the high-level operations of the proposed approach. In MANETs scenario, an intermediate mobile node receives and store packet in their buffers and then forward the packet to an output link if it is available in a situation where number of packets are being processed and queued in the buffer. As described in Figure 5.1, a cross-layer based QoS improvement architecture is provided for our proposed QL-AODV routing algorithms. To get the buffer information of each node from the link layer and to use this information during route discovery and selection procedure at the network layer there should be a cross layer communication between network layer and link layer. Thus, the following proposed architecture illustrates how network layer and link layer interacts so as to share queuing information during route construction by the routing protocol.

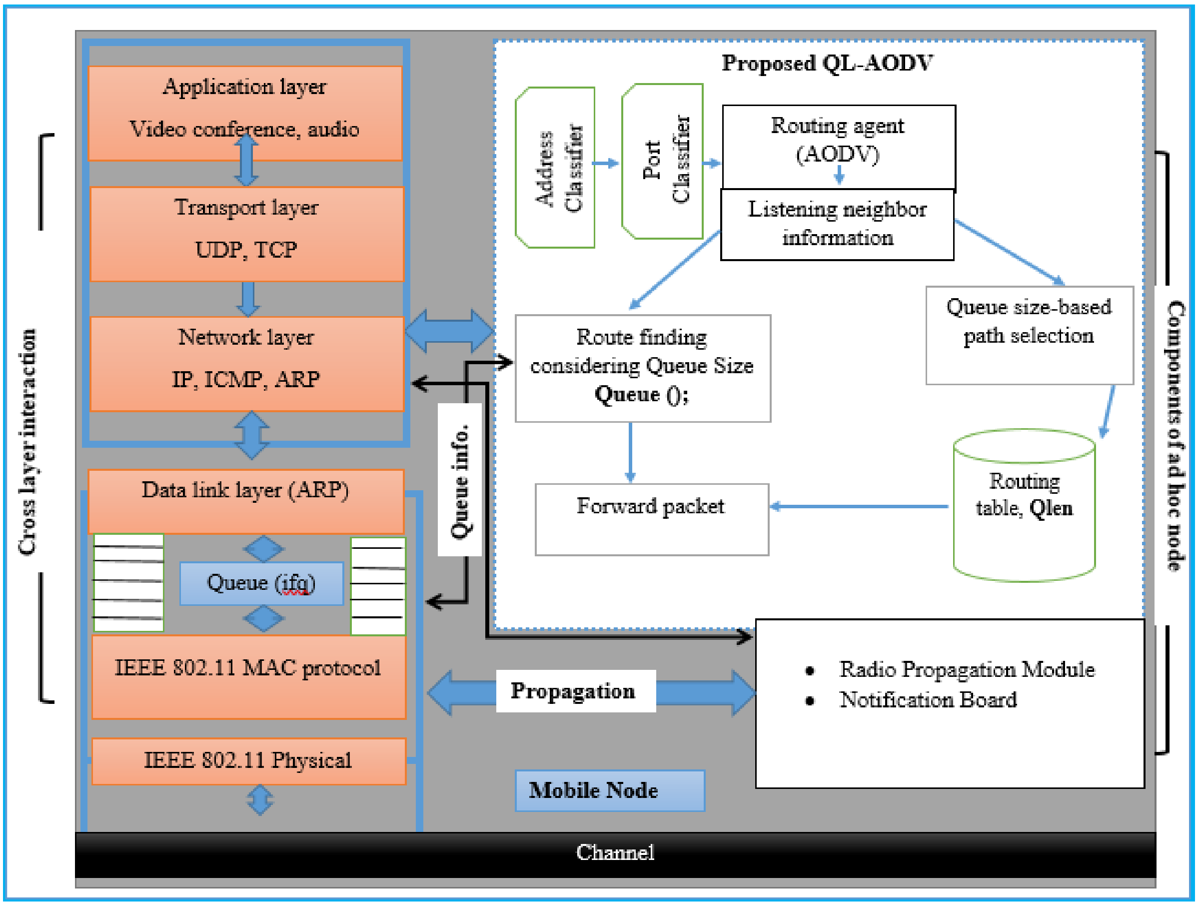

Figure 5.1: Architecture of QL-AODV Algorithm

5.2 Design of QL-AODV Algorithm

As it was mentioned in the related work section, we have seen that the existing AODV routing algorithm is not successful in considering node queue size during the route construction process as route selection cost metrics [37], [39]. Thus, the proposed improvement approaches of this study on the selected AODV MANETs routing protocol is a queue length aware improved routing algorithm for both route discovery and route selection mechanisms.

The basic Existing AODV routing algorithm uses minimum hop count criteria to establish routes between sources and destinations. However, selecting the route with minimum hop is not usually the best route in terms of achieving QoS requirements. A node which might not have sufficient available buffer size could be included on the established path, leading to have high probability of packet loss and network congestion and link breakage which affects directly the overall performance of the network highly. Thus, the routing algorithm should consider available node queue length during route selection process beyond the minimum hop count to achieve efficient QoS requirements. Therefore, in this thesis work we considered a node queue length-based route selection scheme to minimize latency over an existing AODV routing algorithm for delay sensitive applications. Furthermore, this approach also provides a guarantee that packet might not loss due to un expected buffer overflow at the intermediate node during data transmission by following Max-Min-Path (MMP) based queue length maintenance by RREQ packet.

Accordingly, first, the proposed algorithm will retrieve the length of the queue at each node, since we have modified the routing table header fields by adding one more extra field to maintain node queue length at a particular time. Meanwhile, each node maintains the number of buffered packets in its buffer at any given time. The route request (RREQ) packet maintains the maximum of the queue length value available in route request packet (RREQ) and the queue length value available in each intermediate node routing table, and then, queue length field of route request (RREQ) packet will be updated with the maximum of these two values. Finally, the node will rebroadcast the RREQ packet with the updated queue length field of RREQ packet if the node itself is not destination or does not have route to source.

The reason behind considering the maximum of queue length values during route discovery is that, the buffer of the nodes located in the center of the network topology would be easily exhausted, because of maintaining high load, and hence it leads to various problems such as, packet loss, link breakage, resource wastage.

Whenever a source node wants to send a data to a destination and if it does not have known route in its routing table, then, the node will broadcast route request packet containing updated queue length field of route request (RREQ) packet. Once each intermediate node receives RREQ packet and if it has a route to a destination it will send RREP to the source. Otherwise, the intermediate node will calculate its current available queue length and updates to RREQ Queue length field. This rebroadcast process will be repeated until the request will reached to the destination node. Once the destination node receives RREQ packet, the destination will check each received path's queue length and the node will compute optimal path by considering the node queue length values of each received paths.

After the destination node computes the optimal path it will send route replay packet (RREP) packet to the source node so as the source will send the information through the chosen path to the destination node. When receiving the primary RREQ, the destination node might wait a while interval to induce a lot of routes, then select the route with the minimum queue length value and reply an RREP packet. Once the source node receives the RREP packet, it starts sending packets of information through this route to the destination node. Flowchart for the proposed algorithm route construction mechanism is explained in Figure 5.2.

Flow Chart and Pseudo Code for QL-AODV Algorithm

The flowchart presented in Figure 5.2 illustrates, the generation of route request (RREQ) packet and the processing of RREQ message at intermediate node, considering node queue length while establishing route. Hence, whenever the source node has data to transmit to the destination node it invokes the route discovery process so that, RREQ maintains the available queue length for each node, that means, the maximum queue length value among queue length values in RREQ (i.e. rq_qlen) and queue length value in each intermediate node (i.e. rt_qlen) will be considered and RREQ packet replaces its current queue length value by the maximum of this two values, where , rq_qlen, means the variable that holds queue length value at RREQ packet and rt_qlen is a variable that holds the queue length value at each intermediate nodes routing table.

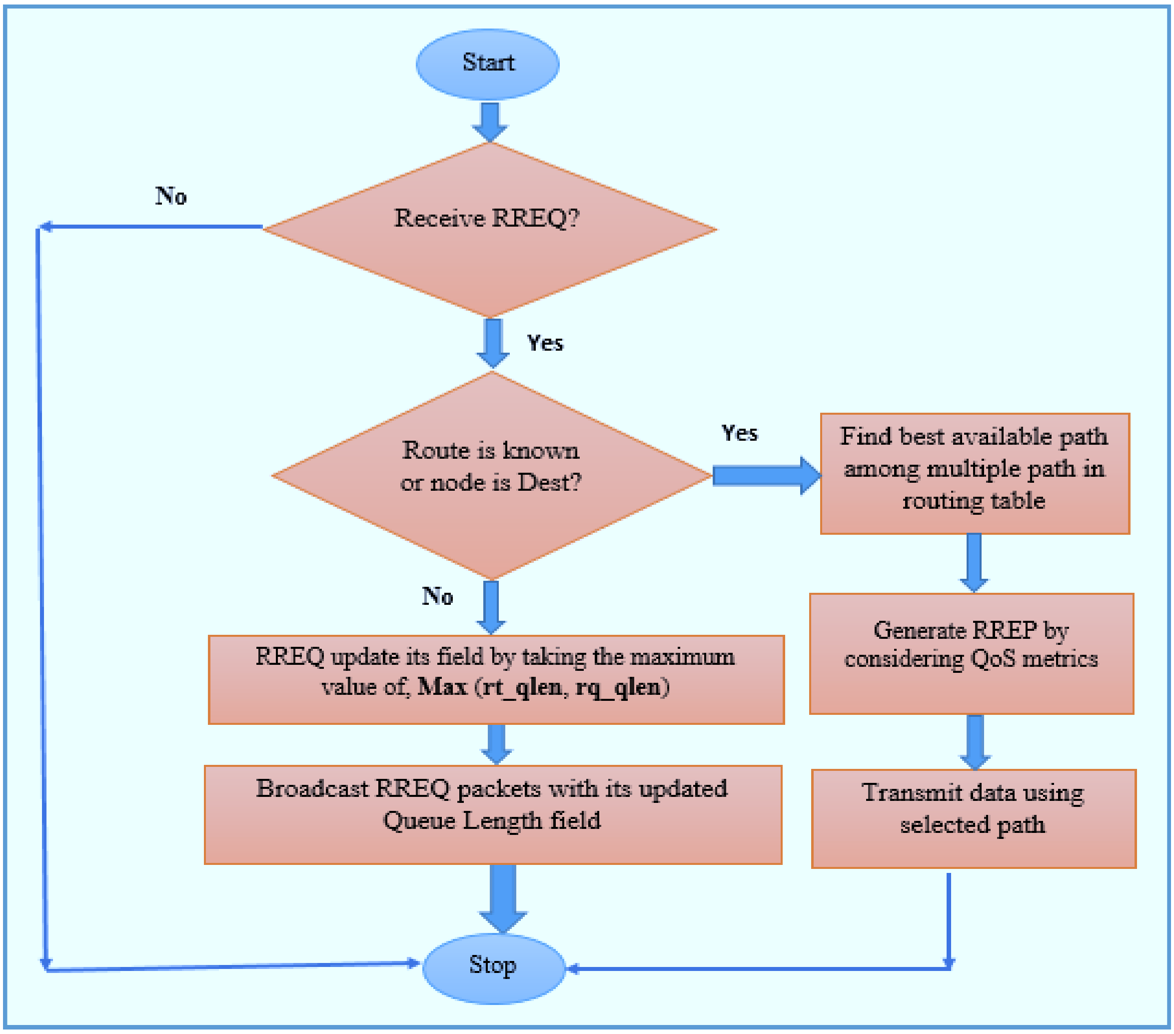

Figure 5.2: Flow Chart of QL- AODV Algorithm

Figure 5.3 illustrates, how QL-AODV operates considering queue length during route discovery as well as route selection process. Accordingly, each node maintains their queue length at a given time and RREQ will take the maximum value of the queue length value available in intermediate nodes routing table and RREQ packet.

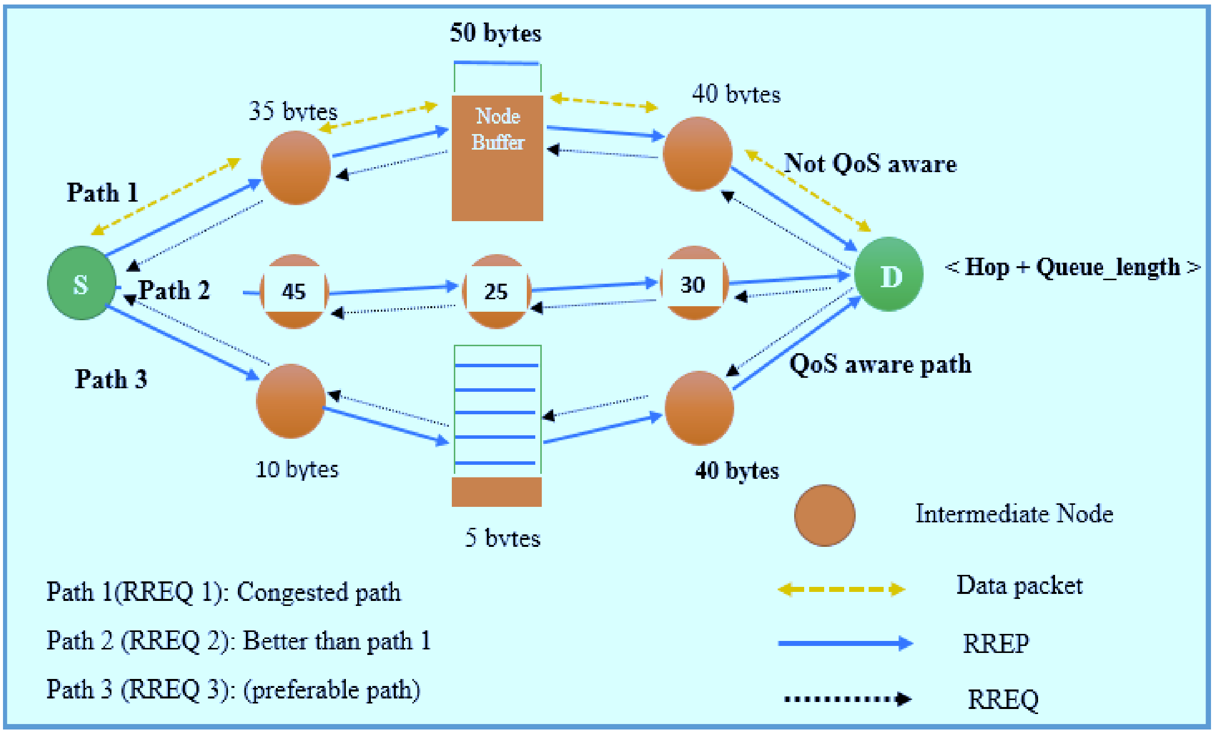

Figure 5.3: Example of QL-AODV Operation

5.3 Implementation of QL-AODV Algorithm

Modification on Different Message Modules of AODV

Various classes and methods of existing AODV algorithm in NS2 have been modified. In NS-2, ***aodv.cc*** and ***aodv.h*** files implement and define the AODV routing protocol. ***Aodv.cc*** is organized into functions; the functions are designed based on their task on routing activity. Some of the Existing AODV **C++** modules and files are modified in this work, to implement the proposed QL-AODV algorithm. All files and modules of AODV exist in **ns-allinone- 2.3.5** module. First, we modified a **priqueue.cc/.h**, which is existed under, **ns-allinone- 2.35/ns-2.35/queue** module so as to get the queue length for each node at the link layer. Then, **aodv_rtable.h/.cc** and **aodv_packet.h** have been modified to incorporate the additional header fields at the route entry header format. Finally, the **aodv.cc/h** is modified to access the queue length of each node form the link layer by calling the function which holds the queue length of each node from link layer to consider node buffer information during route discovery and route selection procedure. Moreover, in ***aodv.cc***/ file, there are methods that we have modified such as, ***receiveRequest***, ***sendRequest***, ***receiveReplay,*** and ***send reply*** to consider node buffer information during route discovery and selection procedures along with the previous header files of the algorithm.

5.3.1 Modification on RREQ Packet of QL-AODV

RREQ packets message formats are modified with one more additional field named as **RREQ_QLEN,** that can maintain the available queue size of each intermediate nodes during route discovery process.

Table 5:1 :Modified RREQ Packet Format

Type	D	Flags	Reserved	Hop Count
RREQ ID				
Destination IP Address				
Destination Sequence Number				
Originator IP Address				
Originator Sequence Number				
RREQ_QLEN				

5.3.2 Modification on RREP Packet of QL-AODV

After completion of RREQ, the destination node should compute optimal route based QoS parameters considering the Minimum Queue Length and send to the source. The computation is focused by considering queue size of the path for reliable delivery of data. Once the route information to the destination node is computed, it will be stored in the routing table of the source node. RREP packet is modified with the additional field called **CUR_QLEN,** so as to choose the optimal path by considering the node queue length. The modified RREP packet format is shown in Table 5.2.

Table 5:2: Modified RREP Packet Format

	Prefix	Flags	Reserved	Hop Count
Destination IP Address				
Destination Sequence Number				
Originator IP Address				
Lifetime				
CUR_QLEN				

5.3.3 Modification on Routing Table Entries of QL-AODV

One more additional route entry information has been added to the original AODV route entry information named as **QLEN.** The route entries for QL-AODV in the routing table consists the following fields.

Table 5:3 :Modified Routing Table Entry

1	2	3	4	5	6	7
BROD_ID	SRC_ADDRS	SRC_ID	DEST_ADDRS	DEST_ID	NEXT HOP	**QLEN**

Modification of RREQ at Intermediate Nodes

Given simple MANETs network with n nodes, with source node S, 1 hop neighbor set N, and 2 hop neighbor set N2, the QL-AODV algorithm discovers QoS route as follows:

Table 5:4 Modification of RREQ at Intermediate Node

```
Notations:

    S =Source Node,
    D =Destination Node
    I =Intermediate Node,
    SN = sequence number
    N = any Mobile node

Process:

An intermediate node I receives a RREQ;
 IF (I have a route to destination)
     sendRREP();
 ELSE IF
    I update the RREQ queue length field
    MAX (Queue_length_of_RREQ , Queue_length_of_current_node)
     IF Queue_length_of_current_node > Queue_length_of_RREQ then
        Queue_length= Queue_length_of_current_node(), and
         I Rebroadcast RREQ ()
        END IF
       END IF
     END IF

Modification of RREQ at Intermediate nodes
```

Modification of RREP at destination Node

As described in Table 5.5, the destination node after waiting some time it prepares RREP to send to the source node via the reverse route of the path that received by considering queue length of each nodes in to an account.

Table 5:5 Selection of best path at destination node

Notation:

S *= Source Node,* ***D*** *= Destination Node*

I *= Intermediate Node,* ***SN*** *= sequence number*

Input: *N path*

Process:

1. ***FOR*** *every received RREQ at destination*
2. ***IF (****received sequence number > stored sequence number)*
3. ***Then*** *select new route*
4. ***ELSE IF***
5. *received sequence number == stored sequence number,* ***then***
6. *Compute cost value for each received RREQ*
7. P_n=**Min** (**Max**(x))
8. *Create reverse path (Prepare RREP)*
9. *Send RREP with the minimum value of* p_n *to source*
10. ***ELSE***
11. *Discard RREQ ()*
12. ***END IF***
13. ***END IF***
14. ***END FOR***

Output: *optimal path*

Selecting best path at destination node

CHAPTER 6: PERFORMANCE EVALUATION

The main objective of this chapter is to provide a brief discussion regarding to the performance evaluation scenarios of the proposed QL-AODV routing protocol against with the hop count and Time based AODV (HT-AODV, for short), and the Ad hoc On demand distance vector (AODV, for short). Achieving QoS in MANETs is a very challenging task due to the dynamic nature of network topology and lack of centralized control. Routing has a great role where researchers should take into an account to improving QoS for delay sensitive applications. Thus, this thesis work provided a QoS improvement approach over the existing AODV routing protocol by modifying the way that route can be constructed in the existing AODV routing algorithm.

6.1 Simulation Scenario and Model

The proposed QL-AODV, HT-AODV, and the AODV routing protocols are compared and contrasted in a typical MANET environment of 1000m x 1000m simulation area with a maximum of 60 nodes under different mobility speed scenarios. The parameters to be evaluated are Packet delivery ratio (PDR), average end to end delay (AEED) and normalized routing overhead (NRL). A number of node variation to be taken are 10, 30 and 60 that represents sparse, medium and dense networks respectively. The transmission range used for this simulation is 250m with 550 interference range. Furthermore, drop tail priority queue is used as a queuing algorithm with the maximum of 50 packets queue size per each node.

The node uses omni directional antenna for communication, this is because, since the direction of the communication is unknown, the node should listen the signal in all direction. In addition, two ray ground propagation model is also used as a signal propagation model, this is because of that, the two-ray ground reflection model considers both the direct path and a ground reflection path. The simulation setups consist of three different settings, each specifically designed to assess the impact of a particular network operating condition on the performance of QL-AODV routing protocol. First the impact of network density is examined by varying the number of mobile nodes. The second simulation scenario tests the impact of load density on the performance of the proposed QL-AODV routing protocol by varying number of source-destination pairs for a fixed number of nodes placed on a 1000m x 1000m topological area.

The third simulation scenario considers the effects of node mobility on the performance of the routing protocols by varying the maximum speed in a fixed number of mobile nodes.

6.1.1 The Mobility Model

The movement scenario files used for each simulation are characterized by a Speed and pause time. The simulation carried out with movement patterns generated for different velocity 1m/s,5m/s and 10m/s. The "setdest" program of NS-2 simulators used which generates node-movement files using the random waypoint algorithm. In realistic situations, MANETs consists of mobile nodes that move and generate traffic randomly. Thus, to generate the mobility scenario random waypoint mobility model is used for this research. Random waypoint (RWP) is the most commonly used mobility model by various research works in MANETs widely [41, 42], in this model, a mobile node starts from its location in the simulation area and moves toward a random destination with a speed uniformly selected between minimum speed and maximum speed. On reaching the destination, the mobile node pauses for a period of time and then moves again in a newly selected direction and speed. Different variations of mobility speed also been tested with 1m/s, 5m/s, 10m/s with the analogy of *Man Walking, Bicycle and Car* respectively.

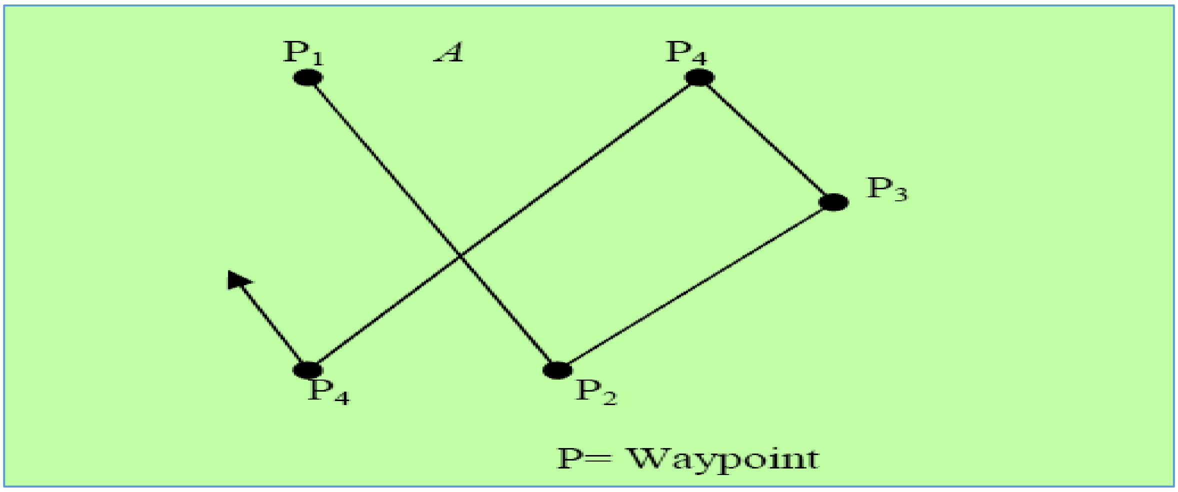

Figure 6.1: Random Waypoint Mobility Model

6.1.2 The Traffic Models

Traffic-scenario generator script "cbrgen.tcl" is used to create CBR traffic connections between wireless mobile nodes. During the course of the simulation different size connections growing in accordance with the number of nodes considered were setup between the nodes in the network with the traffic rate of 4 packets per seconds where each packet size was 512 bytes.

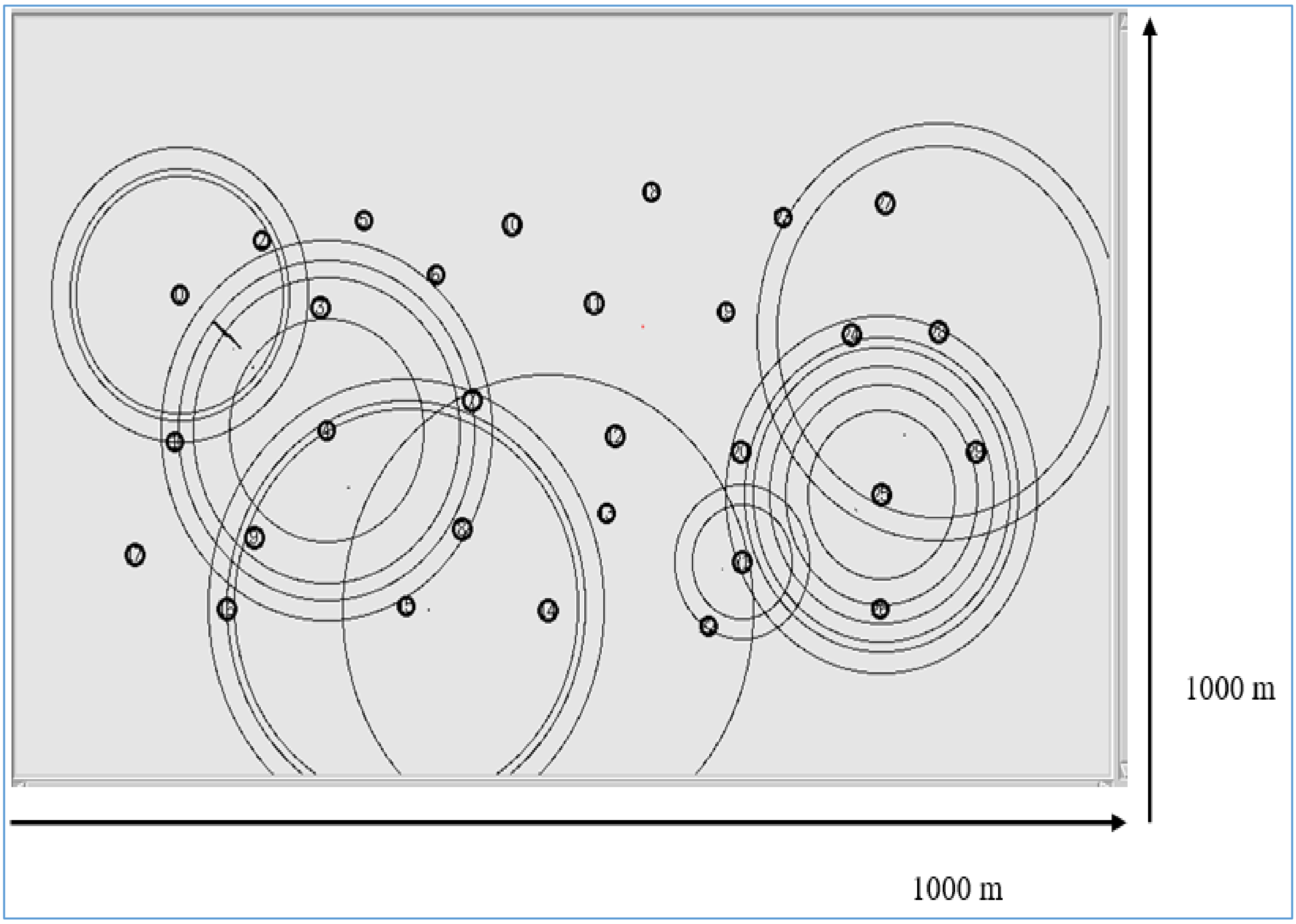

Figure 6.2: MANET Simulated Network a 30 Node Topology Using NAM

Table 6:1: Simulation parameters

Parameter	Value
Operating system and simulations	Ubuntu, NS2 (version 2.35)
Simulation area	1000m x 1000m
Channel type	Wireless channel
Transmission range	250 meters
Interface queue length	50
Mobility speed	1-10 m/sec
Traffic source	1-7
Number of trials	10
Packet size	512 bytes
Traffic	CBR
MAC protocol	IEEE 802.11n
Interface queue type	Priority queue
Routing protocol	AODV, QL-AODV, HT-AODV
Mobility model	Random waypoint
Number of nodes	10,30,60
Simulation time	30ms
Antenna	Omnidirectional

6.2 Performance Metrics

Based on the analysis we have conducted in chapter three the following evaluation metrics are used to evaluate the performance of QL-AODV routing protocol against the existing one.

a. Average End to End Delay (AEED)

The end-to-end delay is defined as the time between the point in time the source wants to send a packet and the moment the packet reaches its destination. It includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, and propagation and transfer times. This metric describes the packet delivery time: the lower the end-to-end delay the better the application performance.

b. Packet Delivery Ratio (PDR)

This is the total number of delivered data packets divided by a total number of data packets transmitted by all nodes. For all our simulations we have kept the same traffic model. So, a routing scheme having a higher packet delivery ration results in the lower packet loss rate. This evaluation metric will give us an idea of how well the scheme is performing in terms of packet delivery at different network density.

c. Normalized Routing Overhead (NRL)

Normalized routing overhead is the number of routing packets transmitted per data packet delivered at the destination. The bandwidth consumed by all the control packets of the routing protocol is measured as control packet overhead. This quantity helps to determine the scalability of a given routing protocol.

6.3 Result Analysis and Discussion

This section presents a detailed analysis of the simulation result based on the generated trace file of the simulation along with the justification. The simulation was done for ten times iteratively, by changing the position and movement of the nodes, source destination connection and their speeds and average value was taken.

6.3.1 Impact of Network Density

This section examines the impact of network density on the performance of three routing protocols namely; AODV, QL-AODV, and HT-AODV. In this simulation scenario, we test the routing protocols by varying the number of nodes. The simulated network consists of a number of nodes of 10, 30 and 60. The size of nodes to be taken is 10, 30, and 60 that represents sparse, medium and dense networks respectively.

Packet delivery ratio:

In Figure 6.3, the packet delivery ratio is plotted against the network density. As the figure shows that, the percentage of packets delivered for each of the routing protocols decreases when the network density is set high (i.e. 60 nodes) and low (i.e. 10 nodes). This is due to the fact that, in a dense network there is an excessive redundant retransmissions of control packets (e.g. RREQ packets) because of the channel contention and packet collisions, thereby lowering the bandwidth available for data transmission whereas in sparse network, the request packets fail to reach to destination nodes due to poor connectivity.

As shown Figure 6.3, compared with AODV, and HT-AODV, QL-AODV has the highest packet delivery ratio particularly when the network density is high because, QL-AODV selects a route that are not congested under the consideration of node queue length while it selects route. So that, the number of dropped data packets due to node's buffer overflow at the intermediate nodes and probability of link breakage decreases and hence the packet delivery ratio increases. As it can be seen in the diagram an average increment of 3.17% packet delivery ratio has been achieved in QL-AODV, as the number of node size increases QL-AODV outsmarts than the standard AODV and HT-AODV routing protocol. For example, when the number of nodes is 10, 1.2% packet delivery increment has been gained and when the number of nodes 30, 1.31% improvement was achieved and finally when the number of nodes increased to 60, QL-AODV outperforms by 7% as illustrated in Figure 6.3. HT-AODV considers packet transmission time when same number of hops are reached to the destination to reduce the time required to transmit data packets, and, that is why HT-AODV has higher packet delivery ratio compared to the standard AODV.

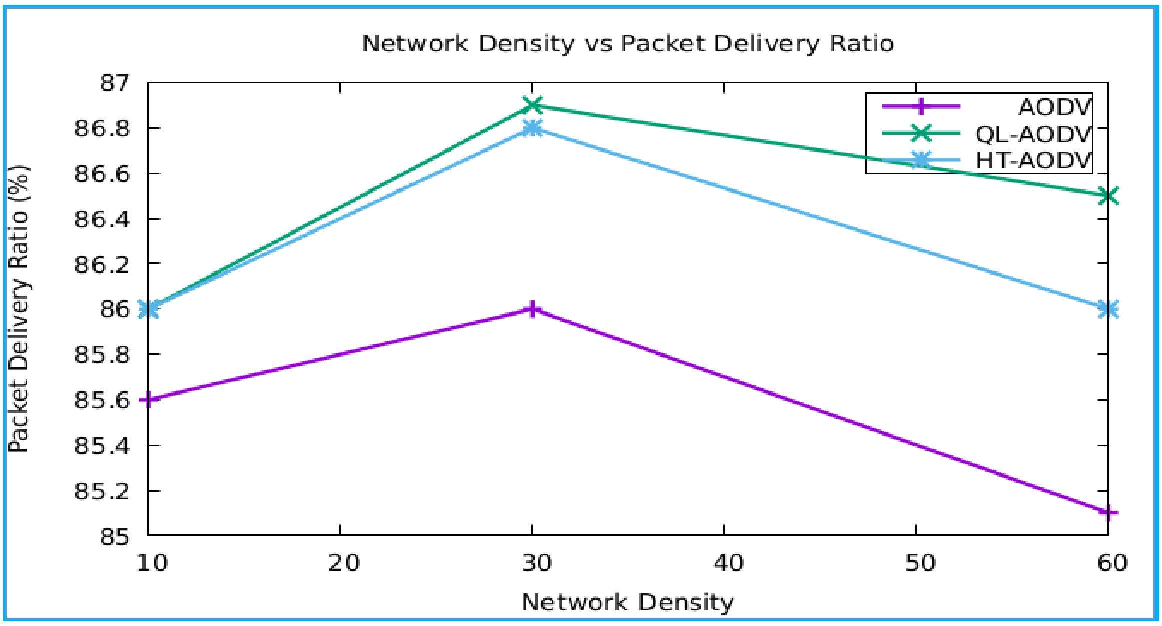

Figure 6.3: Packet delivery ratio with Network Density

Normalized routing overhead:

As it can be seen in Figure 6.4, the routing overhead of AODV, HT-AODV and QL-AODV were evaluated. The normalized routing overhead generated by each of the considered routing protocols increases almost linearly as the network density increases. This is due to the fact that the larger network density in a network the more RREQ packets generated and retransmitted. Accordingly, the normalized routing overhead generated by QL-AODV is slightly increased at sparse network, meanwhile, at node number 10, and shows decrement when the number of nodes increases (i.e. at node 60). This is because, since, QL-AODV routing protocol chooses route which is not congested hence, the route which have a long life time. The amount of retransmission and generating control packets are decreased specially as the network sizes are increased. However, when the number of nodes becomes 30, QL-AODV and AODV routing protocols perform comparably.

At node number 10, QL-AODV experienced by 10% of normalized routing overhead, this is because some extra header fields were added on the existing AODV routing algorithm while implementing the proposed algorithm and this leads to have slight normalized routing overhead increment. However, when the number of nodes increase, for example as illustrated in the Figure, when the network size is 60, -5% of normalized routing overhead decrement has been achieved. In general, normalized routing over head for QL-AODV is increased approximately by 1.67% than the AODV.

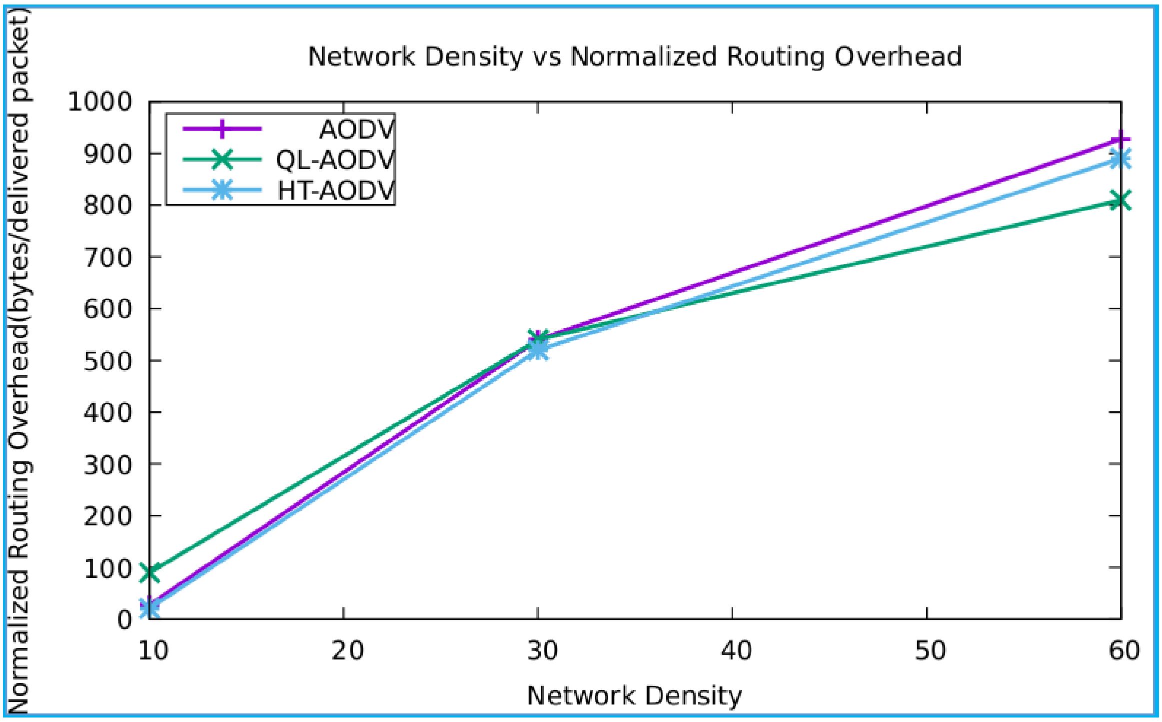

Figure 6.4: Normalized Routing Overhead with Network Density

Average end to end delay:

Figure 6.5 plots the impact of network density on the performance of the three routing protocols in terms of end-to-end delay. As the result shows that, end-to-end delay for each of the routing protocols increases for both sparse and dense networks. This is due to the fact that in dense network a greater number of routing packets is generated and transmitted and hence the interference between neighbor nodes, packet collisions and channel contention increases. Therefore, the time required to reach to destination increases. On the other hand, when the network is sparse, due to poor connectivity the routing packets fail to reach to destination nodes and thus increase the end to end delay.

In Figure 6.5, we observe that the average end to end delay of QL-AODV is improved when compared to HT-AODV and AODV. This is because of that, the existing AODV routing protocol uses minimum hop count only as a cost metrics to select route which might have the congested path and finally it leads to higher end to end dely. HT-AODV routing protocol considers packet transmission time when same number of hops reached to destination, however, the protocol did not considered queue status of each node. Our proposed approach follows Max-Min based route discovery by considering the queue length of each intermediate nodes and this is why the proposed routing protocol showed less end to end delay compared to the AODV and HT-AODV. In general, at network size 10, QL-AODV outsmarts AODV approximately by -3 %, and when the number of nodes become 30, it showed -5 % end to end delay improvement. Similarly, when the number of nodes is 60, -12% end to end delay improvement have been attained. This statistical record shows that, as the number of nodes is increasing QL-AODV becomes outsmart than AODV and HT-AODV routing protocols. This is because QL-AODV considers the buffer status of each intermediate nodes beside of the minimum hop count during route selection process, as a result the rate of congestion and link breakage is reduced, and hence, the amount of retransmission invocation and route maintenance control packets are reduced, Consequently, average end to end delay is reduced. HT-AODV has higher end to end delay compared to QL-AODV and has less end to end delay than AODV. Since, the probability of reaching same hop count to destination is rare, in most cases, HT-AODV performs the same with the standard AODV. In general, in average -6.66% of an end to end delay improvement has been attained by QL-AODV routing protocol compared to the standard AODV routing protocol.

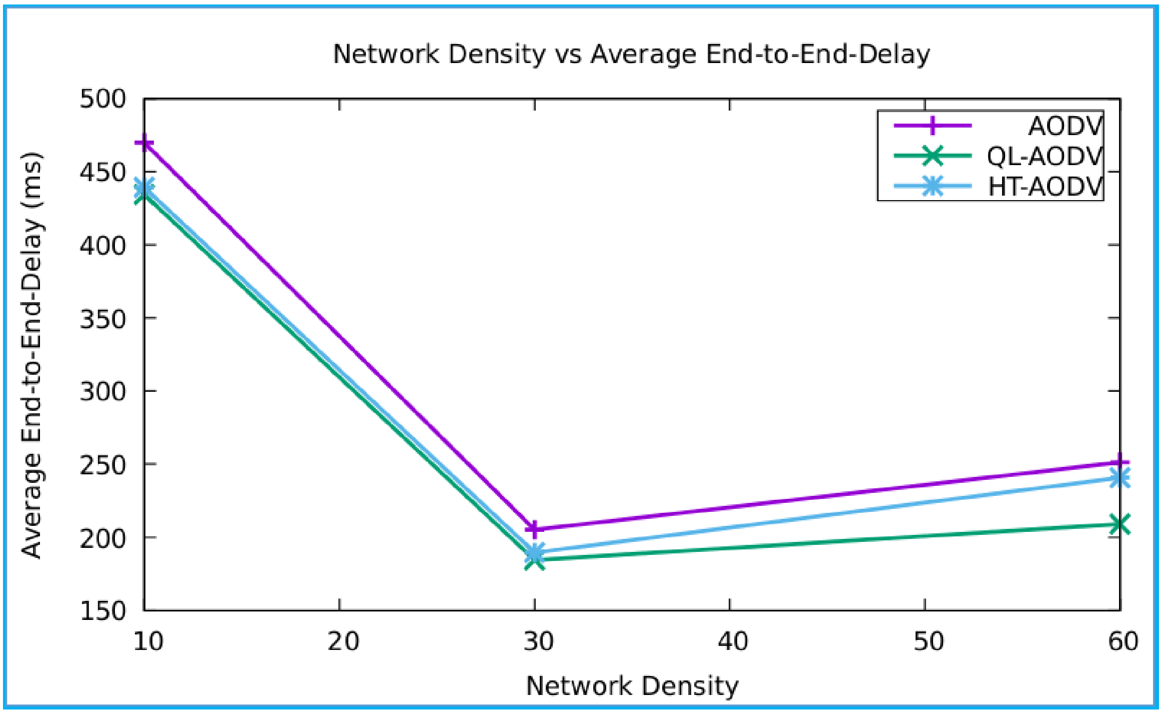

Figure 6.5:Average End-to-End Delay with Network Density

6.3.2 Impact of Numbers of Communicating Nodes

This is another experimental setup to test the performance of QL-AODV, HT-AODV and AODV routing protocols by varying network load in terms of multiple communication flows (i.e. source-destination pairs). The numbers of source-destination connections (or flows) have been varied over a range of 1 to 7 with a fixed number of nodes, mobility speed, and simulation time. To investigate the impact of traffic load, the numbers of source-destination connections (or flows) have been varied over a range of 1 to 7 flows. The source destination pair for each of the connections is chosen at random.

Average end to end delay:

The results in the Figure 6.6 shows that, as the number of source destination pairs increases, end-to-end delay experiences by a data packets are also increase for QL-AODV, HT-AODV and standard AODV routing protocols. This is because when the source-destination pair's increases, the packets flow through the network also increases, thus more packets are generated and disseminated in the network which results an increase in contention, interference between neighbor nodes and packet delay at intermediate nodes queue. These phenomena lead to an increase in end to end delay.

QL-AODV outperforms in terms of achieving an average end to end delay than the existing one. The reason is that QL-AODV considers node queue length during path selection beyond the hop count and it selects the optimal path that have less queue length. So that, network congestion and unnecessary invocation of route discovery is reduced. QL-AODV reduces an end to end delay approximately by -5.8% compared to AODV when the connection flows are 1. in a connection flows of 3, end to end delay is reduced by approximately -2%. Similarly, -6.7% and -7% end to end delay reduction has been attained for connection flow 5 and 7 respectively. Generally, QL-AODV reduces an average end to end delay by -5.3% compared to AODV.

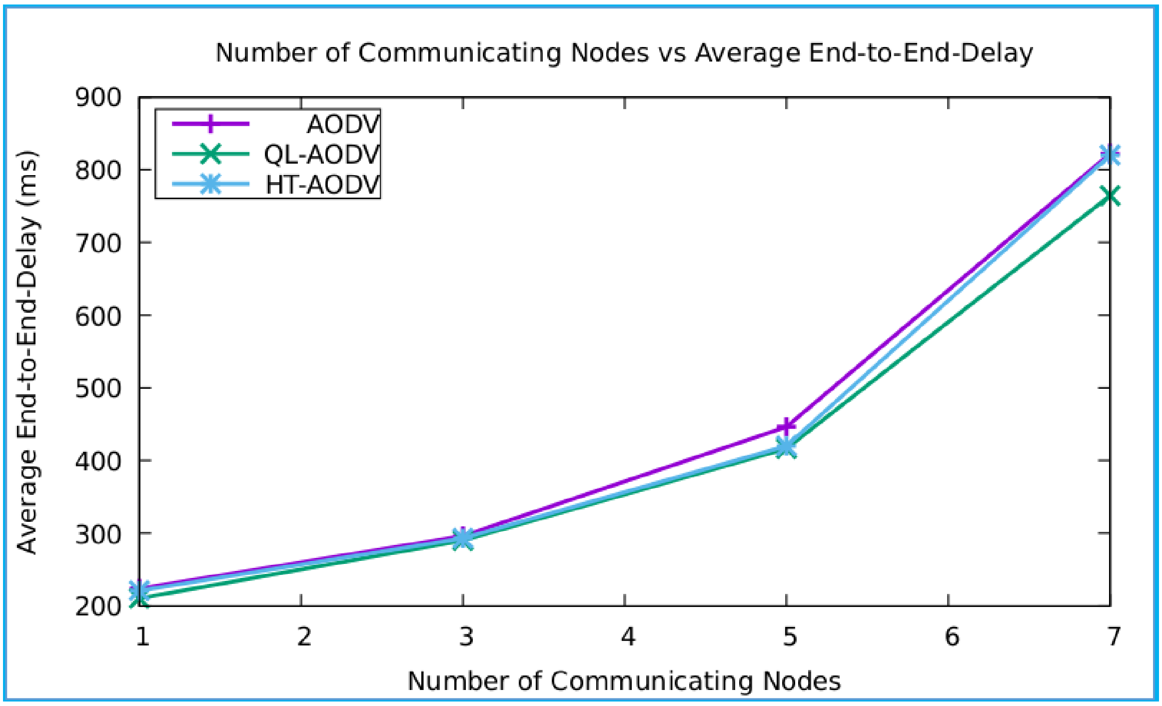

Figure 6.6: Average End to End Delay with Network Traffic

Normalized routing overhead:

In Figures 6.7, the normalized routing overhead generated by the three routing protocols is plotted against the offered traffic load. The Figures show that the routing overhead of each of the three routing protocols increases as the offered flows increases. This is because when the offered load is increased by increasing the source-destination pairs, the routing packets generated and transmitted through the network is also increased. Thus, as stated in the Figure 6.7, the normalized routing overhead for QL-AODV in sparse network is increased and decrease as the network size increases. This shows that, QL-AODV is good for dense network than AODV in terms of normalized routing overhead. This is due to the fact that, QL-AODV selects a route that have long life by considering the queue length of intermediate nodes. In average, normalized routing overhead is increased approximately by 2.85% in QL-AODV over AODV.

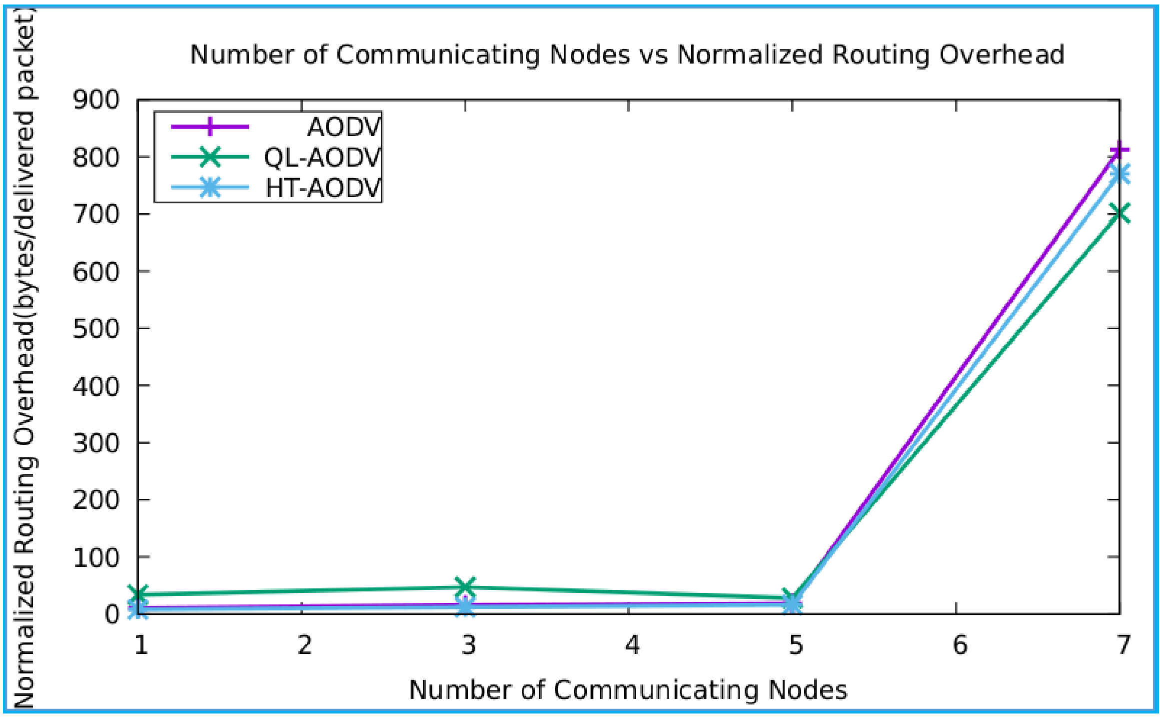

Figure 6.7: Normalized Routing Overhead with Network Traffic

Packet delivery ratio:

Figure 6.8 demonstrates, the performance of the routing protocols in terms of packet delivery ratio when the simultaneous communications are varied from 1 to 7. As the network traffic is increased the performance of three routing protocols are decreased as shown in Figure 6.8. This is because, when source destination flows are increased, the participant nodes in the networks are increased and accordingly, the congestion and contention rate through the network is increased. This occurrence reduces the available bandwidth for actual data transmission. Thus, causing degradation of the overall network delivery ratio. Figure 6.8 tell the improvement of QL-AODV over existing AODV routing protocol in terms of packet delivery ratio while having varied source destination connections, this is due to the fact that, QL-AODV selects a route considering node queue size beyond the minimum hop count, so that the probability of occurrence of network congestion and number of packet loss due to buffer over flow at the intermediate node decreases. Generally, QL-AODV outsmarts the existing AODV routing protocol approximately by 2.25% of packet delivery ratio.

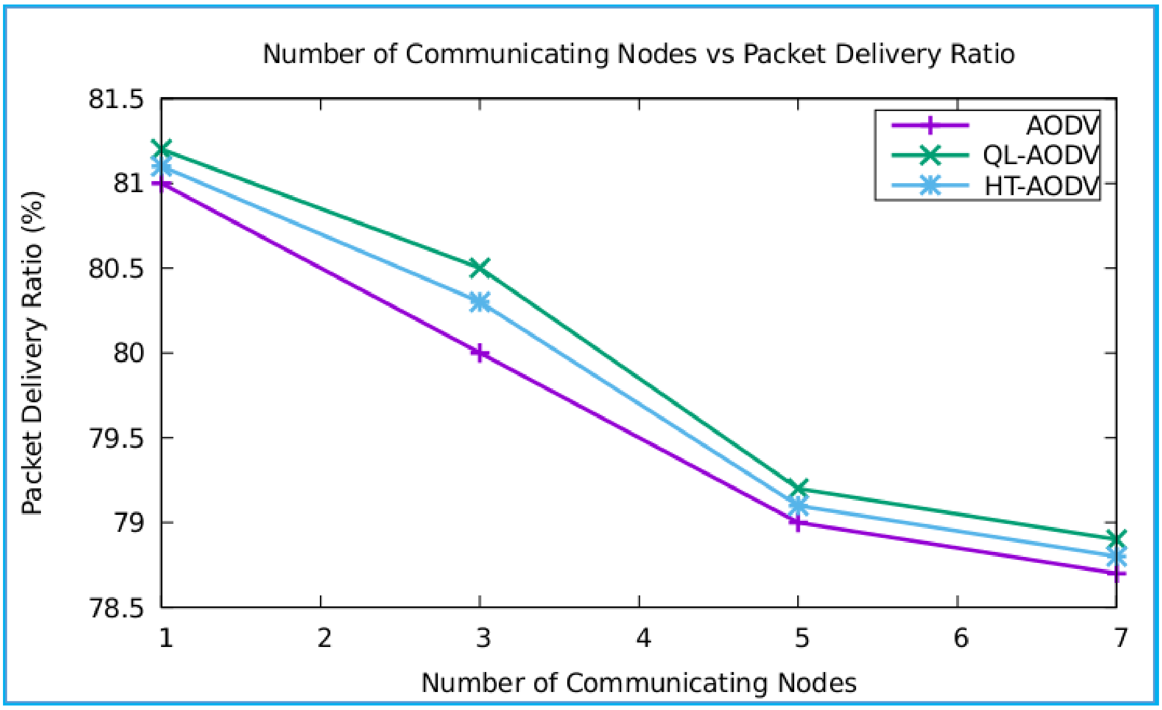

Figure 6.8: Packet delivery ratio with Network Traffic

6.3.3 Impact of Mobility Speed of the Mobile Nodes

In this experimental setup, we analyses the impacts of node mobility on the performance of three routing protocols named as, QL-AODV, HT-AODV and standard AODV. In this simulation, the network size consists of 30 nodes over 1000m x 1000m simulation area with random way point mobility model. We studied each movement scenario under three different speeds; Low, medium and high-speed. Furthermore, the network has been varied from 1m/sec to 10m/sec.

Normalized routing overhead:

Figure 6.9 illustrates, the normalized routing overhead generated by the three routing protocols against the maximum node speed over the given simulation area. The results depict that the routing overhead generated by each of the routing protocols increases with increased maximum node speed. This is because when node mobility increases, the frequency of breaking routes/ route discontinuity increases, thus more RREQ packets are generated and disseminated to maintain broken paths or to establish new paths. These activities potentially contributed an increase on the overall normalized routing overhead.

Accordingly, the normalized routing overhead generated by QL-AODV shows increment for sparse network and decrement for dense network compared to HT-AODV and AODV. In sparse network normalized routing overhead of QL-AODV is increased, the reason is that, since the random waypoint mobility model is used for this simulation scenario and hence, the speed of nodes is given from specified maximum and minimum range randomly, there might be a situation where high mobility speed is assigned in sparse network and

this causes the algorithm to have more normalized this leads to have high normalized routing overhead. In case of AODV there is a high probability of increased link breakage which leads to retransmission and dissemination of more routing packets to maintain the broken links. For instance, at node size 10 and 30, QL-AODV increases approximately by 4% and 2% respectively. However, when the network size increases to 60 QL-AODV reduces the normalized overhead approximately by -4%. This shows that, as the network becomes dynamic, the congestion rate also increases and, since QL-AODV considers the queue states of each node it selects the path which is not more congested to transmit a data. In general, QL-AODV increases the normalized routing overhead approximately by an average of 0.67% compared to AODV routing protocols.

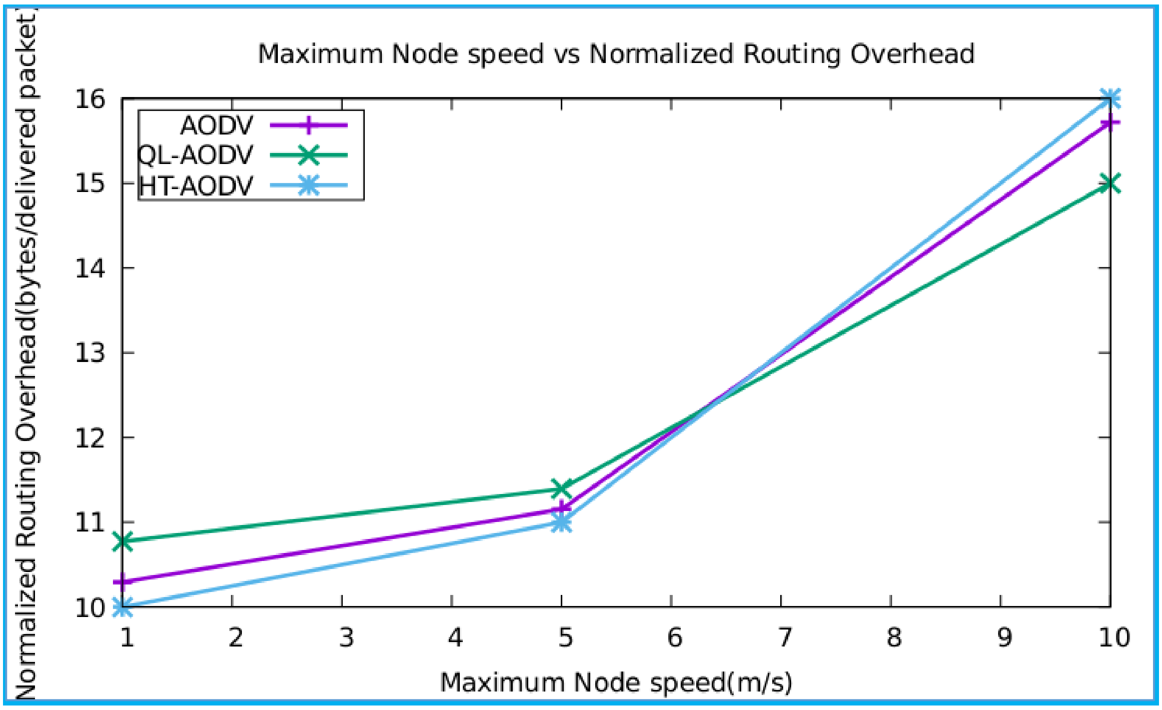

Figure 6.9:Normalized Routing Overhead with maximum speed

Packet delivery ratio:

As it can be seen in Figure 6.10, packet delivery ratio is reduced as the speed of node increases for three of the routing protocols. The reason is that, as the node mobility speed increase the network becomes very dynamic and frequent link failures is also increases. In the high-speed network topology, the network topology changes more frequently and unpredictably which increases the number of link breakages drastically, then, the broken routes resulting from the frequent topology changes cause to have more re-request of route discovery and maintenance processes which also increases the RREQ packets generated and distributed in the network. As a result, the number of packet loss increases as shown in Figure 6.10, resulting in reduced delivery fraction. However, even if delivering packets efficiently in a network that have high mobility is difficult, QL-AODV performs better than the existing AODV routing protocol and HT-AODV as mentioned in Figure 6.10. This is because of that, QL-AODV considers the load of the path in to an account by selecting an optimal path which is stable in terms of the availability of queue length at each intermediate node. Generally, QL-AODV outperforms the existing AODV approximately by 5.01% in terms of packet delivery ratio.

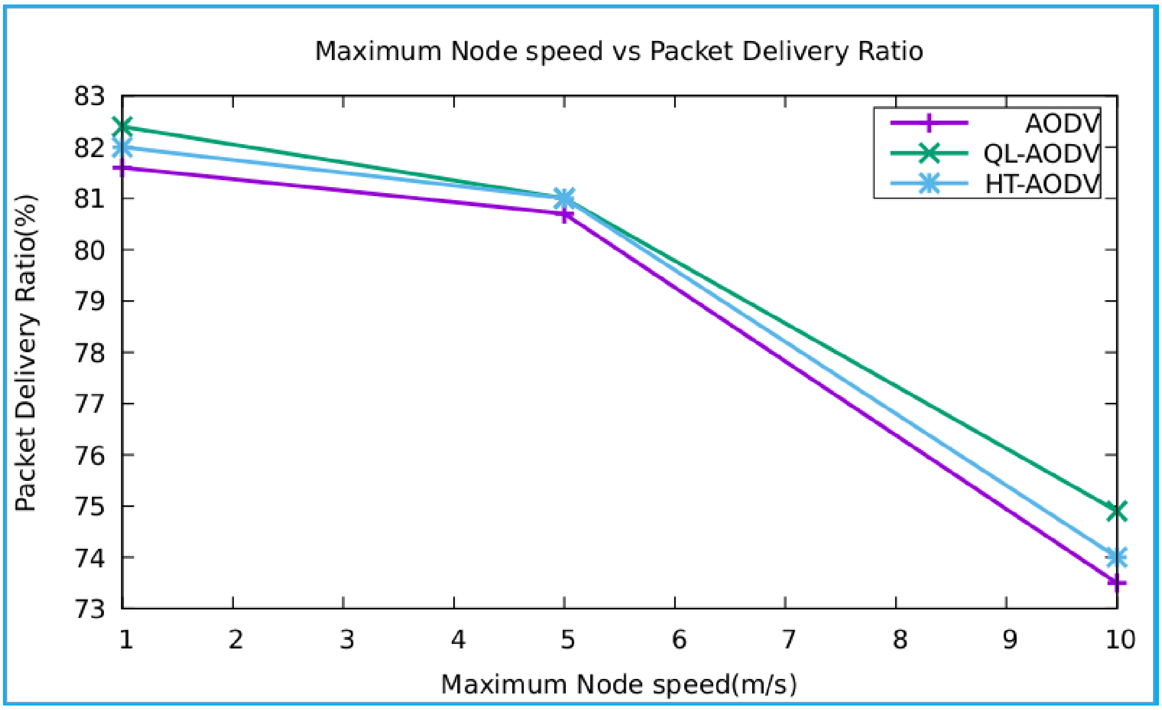

Figure 6.10: Packet Delivery Ratio with Maximum Speeds

Average end to end delay:

The average end-to-end delay of QL-AODV, HT-AODV and AODV for different speeds is stated in Figure 6.11. The average end to end delay is increased as the nodes maximum speed increases. The average delay incurred in each of the three protocols increases with increased maximum node speed. This is because in a relatively high speed, most of the originated RREQ packets fail to reach their destinations due to the increased probability of packet collisions and channel contention caused by excessive redundant retransmissions of the RREQ packets. This potentially increases the time required for data packets to be transmitted from the source to destination nodes due to the delay of data packets waiting at the source and intermediate nodes' queue. Moreover, frequent broken links can also lead to stale routes at mobile nodes which can result in an overall increase in the end-to-end delay of data packets.

As specified in figure 6.11, QL-AODV shows a significance improvement in terms of average end to end delay when compared to HT-AODV and AODV. The reason behind this is that, QL-AODV considers node buffer size when it selects route by the destination node and it resolves the situation where each intermediate node could be exhausted due to having insufficient buffer size to transmit the data packets which could leads to high probability of packet loss.

The end to end delay is showing improvement with QL-AODV at all speed scenarios. For instance, at speed 1m/s the end to end delay is reduced by -3% and at speed 5m/s the maximum of -8% end to end delay improvement was achieved. In general, the average end to end delay reduction is attained -4.3%.

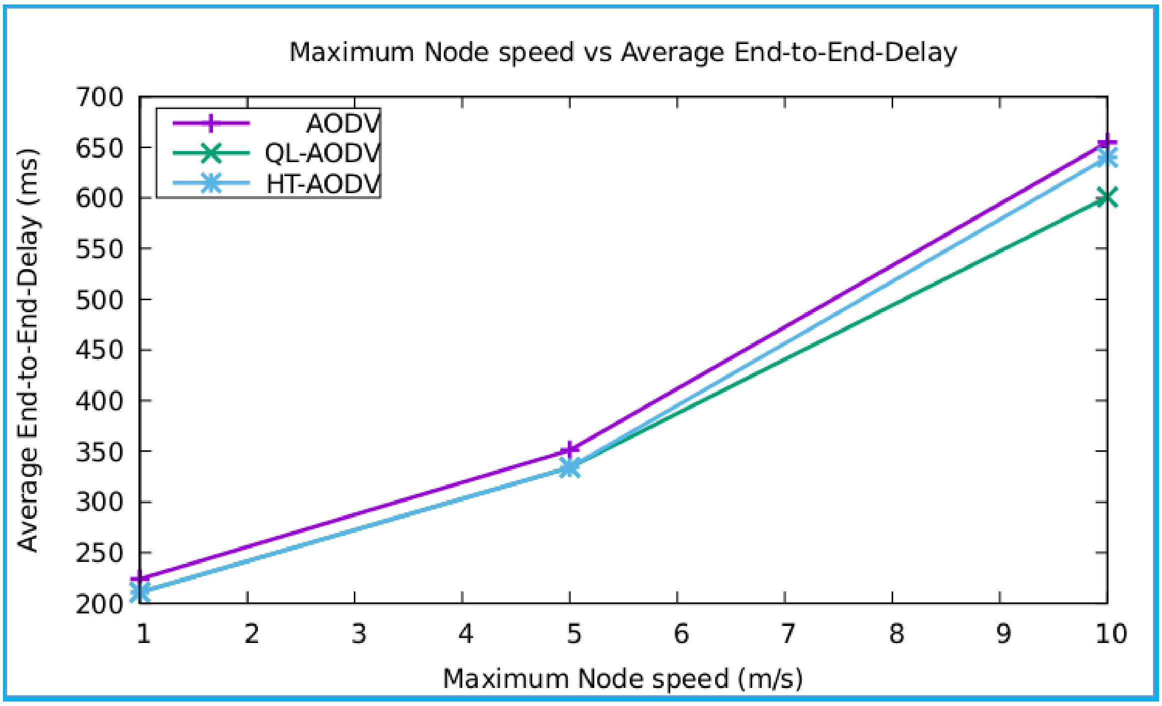

Figure 6.11: Average End to End Delay with Maximum Speed

Summary

In this chapter, we have provided an evaluation study on QL-AODV, AODV and HT-AODV routing protocols. As our objective of providing a better QoS routing considering node queue length to mitigate latency in MANETs. The performance of the routing protocols is measured in terms of the most widely used QoS performance metrics in the existing performance analysis of MANETs routing protocols that include normalized routing overhead, packet delivery ratio and average end-to-end delay. Performance analysis has been conducted considering various simulation scenarios. First, the impact of the network density on the performance of the routing protocols is conducted by varying the number of nodes placed in a fixed area. Second, the impact of the offered load on the performance of the routing protocols is examined by varying the number of source-destination connections (offered load/flows for short). Finally, the performance analysis of the routing protocols has been studied under varying node mobility by varying the maximum node speed in the network.

Thus, the simulation results confirm that, QL-AODV performs better particularly in average end to end delay and packet delivery ratio with the slight reasonable increment of normalized routing overhead.

CHAPTER 7: CONCLUSION AND FUTURE WORK

Based on the general observation of the simulation results the following conclusions is made.

7.1 Conclusions

The main contribution of this thesis was the development of queue length aware AODV routing protocol that can minimize latency for delay sensitive applications. our proposed QL-AODV algorithm allows the AODV to consider node queue length during route selection process beyond considering the minimum hop count so as to improve the overall performance of the original AODV as presented so far.

In this thesis first, we made a performance comparative analysis on three well-known MANETs routing protocols namely DSDV, AODV, and DSR. Several literatures have been reviewed and comparative analysis has been done using NS-2 simulator. Accordingly, both the reviewed literature and the results of the experimental analysis have proved that AODV to be a promising candidate to best perform in QoS incorporation. Therefore, as the performance of AODV has been found better in our simulation than DSR, and DSDV we have used AODV as a base protocol to implement our proposed approach.

As the main target of this thesis work was to develop an efficient QoS aware routing strategy protocols, the researcher has focused on QoS related metrics and three evaluation metrics namely packet delivery ratio, normalized routing overhead and end to end delay have been selected to evaluate the performance of the proposed algorithm. The researcher explores various MANETs research works and review standards and scholar’s recommendation to select appropriate QoS related evaluation metrics and the above-mentioned metrics have been selected accordingly. The investigation on selecting widely used simulation tool for MANETs has conducted and based on the criteria’s that the researcher used during analysis, NS 2.35 simulator has been selected to evaluate the performance of HT-AODV, AODV and QL-AODV routing protocols. in selecting the widely used network simulator, the researcher considered different evaluation criteria’s such as popularity, license and compatibility.

In conclusion, the proposed QL-AODV routing protocol which is based on the nods queue length route construction approach performs better in terms of packet delivery ratio and end-to-end delay with reasonable slight normalized routing overhead increment compared to the AODV and HT-AODV routing protocols. This confirms that QL-AODV is better for delay sensitive applications than the standard AODV and HT-AODV routing protocols.

7.2 Future Work

The proposed Queue length aware routing approach allows a better performance for QoS requiring MANET applications like multimedia data communication. It was promised to resolve the problems of the existing routing protocols by considering latency constraint so as to improve the protocols performance in many aspects. The result shows that QoS support routing is improved in terms of end to end delay, packet delivery ratio and packet loss. However, due to the rapid increase in the use of multimedia applications over MANETs, needs satisfaction of more than one QoS metrics is required also and future work would be focusing to consider other QoS metrics to make QL-AODV more QoS efficient.

The followings are summarized future works of the thesis:

- Efficient forwarding probability using node's queue length could be used to control flooding route request (RREQ) through the network.
- Testing the approach to other reactive routing protocols such as DSR
- DiffServ of the IETF recommendation to differentiate packets and treat them based on their QoS requirement.
- Testing the approach in a real testbed experimentation

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APPENDIX

A: NS2-Tcl Script to Configure Network

```
#===================================================================#

set val(chan)   Channel/WirelessChannel ;# channel type
set val(prop)   Propagation/TwoRayGround ;# radio-propagation model
set val(netif)  Phy/WirelessPhy            ;# network interface type
set val(mac)    Mac/802_11                 ;# MAC type
set val(ifq)    Queue/DropTail/PriQueue    ;# interface queue type
set val(ll)     LL                         ;# link layer type
set val(ant)    Antenna/OmniAntenna        ;# antenna model
set val(ifqlen) 50                         ;# max packet in ifq
set val(nn)     10                         ;# number of mobilenodes
set val(rp)     AODV                       ;# routing protocol
set val(x)      830                        ;# X dimension of topography
set val(y)      601                        ;# Y dimension of topography
set val(stop)   30.0                       ;# time of simulation end
set opt(cp) "./eyob/cbrgen" ;# connection pattern file
set opt(sc) "./eyob/setdest" ;# node movement file.

#==============================
#       Initialization
#==============================

#Create a ns simulator
set ns [new Simulator]

#Setup topography object
set topo       [new Topography]
$topo load_flatgrid $val(x) $val(y)
create-god $val(nn)

#Open the NS trace file
set tracefile [open aodv10.tr w]
$ns trace-all $tracefile

#Open the NAM trace file
set namfile [open aodv10.nam w]
$ns namtrace-all $namfile
$ns namtrace-all-wireless $namfile $val(x) $val(y)

set chan [new $val(chan)];#Create wireless channel

#==============================
#     Mobile node parameter setup
#==============================

$ns node-config -adhocRouting  $val(rp) \
                -llType        $val(ll) \
                -macType       $val(mac) \
                -ifqType       $val(ifq) \
                -ifqLen        $val(ifqlen) \
                -antType       $val(ant) \
                -propType      $val(prop) \
                -phyType       $val(netif) \
                -channel       $chan \
                -topoInstance  $topo \
                -agentTrace    ON \
```

```
               -routerTrace   ON \
               -macTrace      ON \
               -movementTrace ON
#===================================
#        Nodes Definition
#===================================
#Create 10 nodes
set n0 [$ns node]
$n0 set X_ 161
$n0 set Y_ 442
$n0 set Z_ 0.0
$ns initial_node_pos $n0 20
set n1 [$ns node]
$n1 set X_ 190
$n1 set Y_ 200
$n1 set Z_ 0.0
$ns initial_node_pos $n1 20
set n2 [$ns node]
$n2 set X_ 397
$n2 set Y_ 457
$n2 set Z_ 0.0
$ns initial_node_pos $n2 20
set n3 [$ns node]
$n3 set X_ 449
$n3 set Y_ 217
$n3 set Z_ 0.0
$ns initial_node_pos $n3 20
set n4 [$ns node]
$n4 set X_ 310
$n4 set Y_ 291
$n4 set Z_ 0.0
$ns initial_node_pos $n4 20
set n5 [$ns node]
$n5 set X_ 366
$n5 set Y_ 94
$n5 set Z_ 0.0
$ns initial_node_pos $n5 20
set n6 [$ns node]
$n6 set X_ 544
$n6 set Y_ 501
$n6 set Z_ 0.0
$ns initial_node_pos $n6 20
set n7 [$ns node]
$n7 set X_ 613
$n7 set Y_ 352
$n7 set Z_ 0.0
$ns initial_node_pos $n7 20
set n8 [$ns node]
$n8 set X_ 606
$n8 set Y_ 148
$n8 set Z_ 0.0
$ns initial_node_pos $n8 20
set n9 [$ns node]
$n9 set X_ 730
$n9 set Y_ 338
$n9 set Z_ 0.0
$ns initial_node_pos $n9 20
#===================================
#        Agents Definition
#===================================
#Setup a UDP connection
set udp0 [new Agent/UDP]
$ns attach-agent $n0 $udp0
set null1 [new Agent/Null]
```

```
$ns attach-agent $n9 $null1
$ns connect $udp0 $null1
$udp0 set packetSize_ 512
#===================================
#       Applications Definition
#===================================
#Setup a CBR Application over UDP connection
set cbr0 [new Application/Traffic/CBR]
$cbr0 attach-agent $udp0
$cbr0 set packetSize_ 1000
$cbr0 set rate_ 1.0Mb
$cbr0 set random_ null
$ns at 1.0 "$cbr0 start"
$ns at 2.0 "$cbr0 stop"
#===================================
#       Termination
#===================================
#Define a 'finish' procedure
proc finish {} {
    global ns tracefile namfile
    $ns flush-trace
    close $tracefile
    close $namfile
    exec nam aodv10.nam &
    exit 0
}
for {set i 0} {$i < $val(nn) } { incr i } {
    $ns at $val(stop) "\$n$i reset"
}
$ns at $val(stop) "$ns nam-end-wireless $val(stop)"
$ns at $val(stop) "finish"
$ns at $val(stop) "puts \"done\" ; $ns halt"
$ns run
```

B: QL-AODV Sample C++ Code Modification

```
==========================================================================
PriQueue::filter(nsaddr_t id)
{
        Packet *p = 0;
        Packet *pp = 0;
        struct hdr_cmn *ch;
        for(p = q_->head(); p; p = p->next_) {
         ch = HDR_CMN(p);
         if(ch->next_hop() == id)
                        break;
         pp = p;
        }
        /*
         * Deque Packet
         */
        if(p) {
         if(pp == 0)
                q_->remove(p);
```

```
else
        q_->remove(p, pp);
}       return p;
}
/*
 * Called at the end of the simulation to purge the IFQ.
*/
//added by eyob
```

```
//function to return queue length at link layer
int PriQueue::queue_length()
{
int eyob;
    eyob=q_->length();
  return eyob;
}//end of eyob
```

===

C: HT-AODV sample C++ Code Modification

```
========================================================
struct hdr_aodv_request {
        u_int8_t        rq_type;     // Packet Type
        u_int8_t        reserved[2];
        u_int8_t        rq_hop_count;   // Hop Count
        u_int32_t       rq_bcast_id;    // Broadcast ID
        nsaddr_t        rq_dst;         // Destination IP Address
        u_int32_t       rq_dst_seqno;   // Destination Sequence Number
        nsaddr_t        rq_src;         // Source IP Address
        u_int32_t       rq_src_seqno;   // Source Sequence Number
        double          rq_timestamp;   // when REQUEST sent;
        double          rq_ptt;//added by eyob
  // This define turns on gratuitous replies- see aodv.cc for implementation contributed by
  // Anant Utgikar, 09/16/02.
```

```
//#define RREQ_GRAT_RREP       0x80
inline int size() {
int sz = 0;
/*
        sz = sizeof(u_int8_t)               // rq_type
             + 2*sizeof(u_int8_t)           // reserved
             + sizeof(u_int8_t)             // rq_hop_count
             + sizeof(double)               // rq_timestamp
             + sizeof(u_int32_t)  // rq_bcast_id
             + sizeof(nsaddr_t)             // rq_dst
             + sizeof(u_int32_t)  // rq_dst_seqno
             + sizeof(nsaddr_t)             // rq_src
             + sizeof(u_int32_t);// rq_src_seqno
*/
        sz = 7*sizeof(u_int32_t);
        assert (sz >= 0);
        return sz;
}
};
struct hdr_aodv_reply {
        u_int8_t        rp_type;        // Packet Type
        u_int8_t        reserved[2];
        u_int8_t        rp_hop_count;           // Hop Count
        nsaddr_t        rp_dst;                 // Destination IP Address
```

```
        u_int32_t      rp_dst_seqno;          // Destination Sequence Number
        nsaddr_t       rp_src;                // Source IP Address
        double         rp_lifetime;           // Lifetime
        double         rp_timestamp;          // when corresponding REQ sent;
        double         rp_ptt;//added by eyob
```

//Modification on route selection

```
 if ( (rt->rt_seqno < rp->rp_dst_seqno) ||   // newer route
      ((rt->rt_seqno == rp->rp_dst_seqno) &&
       (rt->rt_hops > rp->rp_hop_count)) ) { // shorter or better route
  // Update the rt entry
  rt_update(rt, rp->rp_dst_seqno, rp->rp_hop_count,
            rp->rp_src, CURRENT_TIME + rp->rp_lifetime); }
//Modified by eyob
 else if ((rt->rt_hops == rp_hop_count) &&
        ((rt->rt_ptt > rp->rp_ptt))) { // shorter or better route
  // Update the rt entry
  rt_update(rt, rp->rp_ptt,
            rp->rp_src, CURRENT_TIME + rp->rp_lifetime);
//end of eyob
  // reset the soft state
  rt->rt_req_cnt = 0;
  rt->rt_req_timeout = 0.0;
  rt->rt_req_last_ttl = rp->rp_hop_count;
if (ih->daddr() == index) { // If I am the original source
```

```
 // Update the route discovery latency statistics

 // rp->rp_timestamp is the time of request origination

   rt->rt_disc_latency[(unsigned char)rt->hist_indx] = (CURRENT_TIME - rp->rp_timestamp)

                              / (double) rp->rp_hop_count;

   // increment indx for next time

   rt->hist_indx = (rt->hist_indx + 1) % MAX_HISTORY;

 }
```

D: AWK Scripts for Evaluation Metrics Calculations

D.1 Packet delivery ratio

```
BEGIN {
sends=0;
recvs=0;
}
{
# CALCULATE PACKET DELIVERY RATIO
if (( $1 == "s") && ( $7 == "cbr" ) && ( $4=="AGT" )) {
sends++; }
if (( $1 == "r") && ( $7 == "cbr" ) && ( $4=="AGT" )) {
recvs++; }
}
END {
PDR = (recvs/sends)*100; #packet delivery ratio
printf("Packet Delivery Function = %.2f\n",PDR);
}
```

D.2 Average End to End delay

```
BEGIN{
recvnum=0;
}
{
time = $2;
packet_id = $6;
# CALCULATE end to end
DELAY
if ( start_time[packet_id]
== 0 )
start_time[packet_id] =
time;
if (( $1 == "r") && (
$4=="AGT" )) {
end_time[packet_id] =
time; }
else { end_time[packet_id]
= -1; }
END {
for ( i in end_time )
{
start = start_time[i];
end = end_time[i];
```

```
packet_duration = end -
start;
if ( packet_duration > 0 )
{ sum += packet_duration;
recvnum++;
}
}
delay=sum/recvnum;
printf("Average end to end
delay(ms)=
%.2f\n",delay*1000);
}
```