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Priority Aware QoS Enhancement in AODV Routing Protocol in MANETs

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This is to certify that the thesis prepared by Ayele Gobezie, titled: *Priority Aware QoS Enhancement in AODV Routing Protocol in MANETs* and submitted in partial fulfillment of the requirements for the Degree of Master of Science in Computer Science complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

Mobile Ad hoc Networks (MANETs) are constructed from mobile nodes that cooperate among themselves to transmit traffic flows for communication without infrastructure support in distributed coordination fashion in wireless communication system.

Quality of Service (QoS) is one of the critical issues in MANETs and several researches have been done so far. However, the characteristics of infrastructure-less and limited resource, QoS provisioning in multiple class of services in MANETs imposed a challenging task.

We proposed enhanced priority aware QoS in Ad hoc on Demand Distance Vector (AODV) routing protocol in MANETs. In this thesis we treated services according to traffic type on the basis of services priority level for QoS requirement. Traffic are classified and scheduled according to the type of service which aims to serve better high priority traffic over low priority traffic services that fulfil the QoS requirement for flow of traffics. The proposed system maximizes the performance of QoS in MANETs by reducing congestion.

The scheduler in the proposed system is a weighted round robin algorithm which schedules classified traffic that provides the intended QoS fairly among high priority and low priority traffic classes as well as managing the resources effectively. Admission control is applied to admit traffic flow based on the state of the network and AODV is modified to support QoS to perform routing efficiently.

Simulation experiment is done under different network scenarios to demonstrate and justify the effectiveness taking important QoS metrics in NS-2. From the experiments conducted and based on facts identified from analysis the proposed solution significantly outperforms AODV.

Keywords: Quality of Service, Mobile Ad hoc Networks, Traffic classes, Scheduling.

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Table of Contents

List of Figures

List of Algorithms

Abbreviations

AODV	Ad hoc on-demand Distance Vector
CBR	Constant Bit Rate
DSDV	Destination Sequenced Distance Vector
DSR	Dynamic Source Routing
IARP	Intra-Zone Routing Protocol
IEEE	Institute of Electrical Electronics Engineering
IERP	Inter-Zone Routing Protocol
MANETs	Mobile Ad hoc Networks
NS-2	Network Simulator
OLSR	Optimized Link State Routing
QoS	Quality of Service
RERR	Routing Error
RFC	Request for Comments
RREQ	Route Request
TC	Topology Control Message
ToS	Type of service
VoIP	Voice over Internet Protocol
WRR	Weighted Round Robin
ZRP	Zone Routing Protocol

Chapter 1 : Introduction

1.1 Background

Computing is a science which enables human beings to use different technologies. Nowadays, the invention of new technologies arises due to the demand of ease of daily life and the use of mobile Ad hoc Networks becomes more popular and interesting in day to day activities. But how the connection will be established between those different devices and how those devices effectively communicate with each other without any delay is a real issue that is needs to be considered.

MANET (Mobile Ad hoc Network) is a type of Ad hoc network that can change locations and configure itself any time. MANETs are types of ad hoc network which use mobile nodes in wireless connections to connect to various networks. The structure of the network changes dynamically, hence they have autonomous nodes and configure themselves dynamically without any central administration [1].

MANETs are the most promising and rapidly growing technology which are based on self-organized and rapidly deployed networks [2]. These are self-configuring networks of mobile nodes connected by wireless links that form an arbitrary topology. MANETs require a dynamic and efficient routing protocol that can respond quickly to network topology changes [3].

Thus, since the network topology can change frequently and is unpredicted, resulting in route changes, routing in Ad hoc networks remains a primary challenge [4]. MANETs routing protocols can be classified into three as, proactive, reactive and hybrid routing protocols and our research is based on the reactive one.

Proactive (table-driven) routing protocols perform the routing work in static scenarios or in small networks and reactive (on-demand) routing is more effective for dynamic environments or large networks [5].

The major aim of reactive routing protocol is to minimize the traffic load on the network [4]. Every node in Ad hoc On-Demand Distance Vector (AODV) routing protocol maintains information of only active paths to the destination nodes. It is a type of reactive routing protocol where the routes are created when required. It is the most widely used reactive routing protocol and it works by route discovery and maintenance of the established route.

As on-demand routing protocol, AODV uses periodic broadcast of hello messages to track neighboring nodes. This periodic propagation causes network overhead in AODV [6].

Quality of Service (QoS) in MANETs [6] is a set of service requirements that needs to be met by the network during transportation of packet streams from the source to the destination. That means the network should provide some kind of guarantee about the level of service provided to an application.

In this research, we try to improve or enhance QoS for AODV routing protocol in MANETs using priority aware technique which means the priority is given based on the type of service. We propose priority aware technique and different priorities will be implemented among the connections according to the type of service. Real-time applications have the highest priority to get a service because real-time applications are delay sensitive applications. This technique uses admission control for resource reservation which determines the flow of applications. In this study we will use different performance metrics of QoS to evaluate our approach such as packet delivery ratio, jitter, end-to-end delay, throughput and packet loss as well. There are some researches which have been done so far to improve QoS, but we found in MANETs there is no reliable mechanism to provide QoS yet.

1.2 Motivation

QoS in MANETs is valuable for better performance of communication system. However, the QoS which have been do so far in different researches particularly in MANETs are not adequate enough to provide better service quality. The motivation behind this research is QoS of AODV routing protocol in MANETs using priority aware with admission control technique. This will help in improving the service quality in MANETs. In addition to this, the problems in QoS enhancement techniques in AODV routing protocol which have been done so far suggested more on QoS enhancement using different techniques motivate to do on this area of the research.

1.3 Statement of the Problem

It is well known that exiting MANETs routing protocols have certain weaknesses in providing QoS [6]. Routing is the mechanism of forwarding a packet towards its destination using the best path and the cost of the path is measured in various metrics like, number of hops, traffic, bandwidth, security, end-to-end delay, packet delivery ratio [7, 8] etc.

In MANETs, QoS is much more challenging than in wired networks, mainly due to node mobility, multi-hop communications, unpredictable link properties, resource constraints, contention for channel access, and lack of central coordination [9]. In MANETs equipping devices required to properly route traffic is more challenging than wired networks. Nowadays, multimedia and real-time applications consume much network resources and as a result it is better to have high flow rates and very small transfer delay.

The performance of MANETs routing protocols depends on the values of its parameters. The researches which have been done so far for AODV protocol in MANETs are not enough to improve all the QoS metrics yet. This is because AODV can lead to heavy control overhead and unnecessary bandwidth consumption [10]. When congestion happens in the network the low priority packets transmit faster than the higher priority packets and therefore, throughput and delay for real-time traffic are affected and QoS in the network decreases.

There are some QoS aware routing protocols that have been proposed by various researchers to improve certain parameters like throughput, delay, jitter and packet delivery ratio. But, at the time of multi-applications in queue, these protocols failed to utilize network resources efficiently.

Therefore, we intend to improve these problems by using priority with admission control mechanism which can efficiently utilize the available resources. After priority have been given to the applications the flow must be determined by admission control. Priority with admission control is used because admission control is the most important resource reservation scheme in MANETs and admission control is used to determine admission of the applications for better delivery of QoS because it makes decision if traffic flow is admitted and resources can be assigned to the applications.

1.4 Objectives

General Objective

The general objective of this research is to design and develop Priority Aware AODV Routing Protocol to enhance QoS in MANETs.

Specific Objectives

To achieve the above general objective, it is essential to go through the following basic tasks.

- Review related research papers which have been proposed so far.
- Investigate the current protocols in MANETs routing protocol.
- Detailed analysis and study of the proposed research.
- Design the required algorithm.
- Implement the Priority Aware AODV Routing Approach on simulation environment.
- Conduct experiments to show how effective the proposed work is.
- Compare the performance with existing normal AODV protocol.

1.5 Methods

The activities to be carried out through the research to accomplish those objectives are as follows.

Literature Review

Exhaustive study and explorations will be made on the areas related to QoS enhancement in MANETs. This will be accomplishing by reading different books, journals or conference papers which have been done so far with different approaches, so as to have sufficient understanding of the problem. Techniques and approaches appropriate for development of a routing algorithm for AODV routing protocol and other routing protocols in MANETs will also be reviewed as well. After deep understanding of the problem we will propose a new model to achieve better QoS in AODV routing protocol.

Design and Implementation

While we do this study, we will use different algorithms to achieve the specified objectives and we use the network simulation toolkit as a working environment. This study involves the development of a new model using priority aware with admission control mechanism to provide a solution to the current QoS problem in AODV routing protocol by adding new improvement technique.

Experimental Evaluation

Experiments will be conducted to test the effectiveness of our proposed Priority Aware QoS enhancement in AODV routing protocol in MANETs, and the performance evaluation of this work will be carried out in comparison to evaluate in terms of its objective and contributions in comparison to what is already done so far which is existing standard AODV routing protocol using a tool called NS-2 simulation environment. Evaluation will be conducted by considering different QoS metrics.

1.6 Scope and Limitations

The scope of this research is limited to:

- Prioritize the data according to the type of service.
- Utilize the available resources by using admission control.
- Test the proposed solution how effective it is by using QoS metrics.

Finally, this work will increase the performance of QoS for AODV routing protocol in MANETs by discovering better routes to avoid congestion and reduce excessive routing overhead based on the priority given to those applications as far as selecting the best route. Since it is beyond the scope of the research work the security of AODV routing protocol in MANETs will not be included or addressed as part of this research.

1.7 Application of Results

This research will significantly contribute to the area of wireless communication in MANETs for effective communication because as long as the QoS is enhanced the user will be satisfied with the service. This work will facilitate the services of MANETs applications and the most important application areas that will benefit from this work are emergency scenarios like military environments, multimedia, and in education.

1.8 Thesis Organization

The rest of this thesis is organized as follows. Chapter Two presents and describes the review of literature related to MANETs. Chapter Three presents related works which have been done on MANET routing protocols and related areas. The Fourth Chapter deals with our proposed system which is the design of priority aware QoS in AODV routing protocol in MANETs. In Chapter Five implementation or prototype and evaluation result analysis is presented. Finally, Chapter Six addresses Conclusion, Contribution and identifies direction for Future Work.

Chapter 2 : Literature Review

2.1 Overview

This Chapter deals with literatures in related to MANETs. Routing protocols are reviewed and discussed briefly. The Chapter covers overview of MANETs and main applications in the field of wireless communication and network routings, challenges and characteristics.

Ad hoc is a Latin phrase which means “for this purpose”[1]. A Mobile Ad hoc Network is a dynamic multi-hop wireless network that is established by a group of mobile nodes on a shared wireless channel [6, 11]. Nodes may be computers or devices such as mobile phones and pocket PCs with wireless connectivity between those devices. The nodes communicate with each other and exchange network information as needed, and network topology changes could occur randomly, rapidly, frequently, and unpredictably. As a host, a node function as a source and a destination in the network and as a router; nodes act as intermediate bridges between the source and the destination giving store and forward services to all the neighboring nodes throughout the communication.

The characteristics of easily deployments, speed of development, and decreased dependency on the infrastructure are the main reasons to use an Ad hoc network. It allows people and devices to seamlessly internetwork in areas without pre-existing communication infrastructure or without any central administration. They have wide applications ranging from military battlefield operations, emergency operations, search and rescue operations in remote areas and other applications such as meeting in a room, etc. Each node is responsible for forwarding a packet it has received from one to another as required as far as the packet reaches to the destination [6, 11].

2.2 Mobile Ad hoc Networks

The emerging of mobile computing and communication devices such as cell phones, laptops, hand held digital devices, and wearable computers are driving revolutionary change in our information society.

[1] https://de.slideshare.net/simemon/manet-14754260, March 24, 2017

Recently, wireless networks and mobile devices gained a wide popularity [11]. This led to the significant increase of mobile Ad hoc networks in the last few years. Due to this, MANETs became one of the most important areas of research. The ability of this type of networks to operate anywhere and anytime made it adaptable in many new applications. MANET is a collection of wireless mobile hosts forming a temporary network without the aid of any stand-alone infrastructure or centralized administration. Due to the mobility of the nodes in the network, these nodes are self-organizing and self-configuring. They do not only act as hosts, but they also function as routers.

Basically, computer networks can be classified into two types such as wired and wireless network [12]. In wired networks, data travels as electrical signals through wires, but in wireless medium, no wires are used and signals travel as electromagnetic waves through air. With a wirelessly connected device anyone can move around and stay connected providing the person to be within the range. In wired network, the speed is fixed but in wireless network the speed is fluctuating and depends on the distance between nearest access point and whatever happens to be in between wireless device and access point itself. Furthermore, wireless network can be classified into two types [11, 12, 13] based on the communication approach for wireless mobile nodes. First, Infrastructure-based which are based on cellular concepts that the mobile nodes can move while communicating with access points such as the base stations being fixed and as the node goes out of the range of a base station, it gets into the range of another base station. Second, in Infrastructure-less or Ad hoc wireless networks the existing wireless infrastructure is expensive and inconvenient to use. It consists of a collection of wireless dynamic nodes that form a network. The nodes exchange information without using any pre-existing fixed network infrastructure.

An Ad hoc network [12, 13] consists of a collection of autonomous mobile nodes formed by means of multi-hop wireless communication without using any pre-existing fixed network infrastructure. Basically, Ad hoc networks can be classified into three categories based on applications such as, MANETs, Wireless Mesh Networks (WMNs) and Wireless Sensor Networks (WSN). These days, MANETs are becoming more popular research area in a wide spectrum of applications.

Mobile nodes self-organize themselves to form a network over radio links and all nodes in MANETs basically function as mobile routers using some routing protocol required for deciding and maintaining the routes [14]. Since MANETs are Infrastructure-less, self-organizing, rapidly deployable wireless networks they are highly suitable for applications involving special outdoor events, communications in regions with no wireless infrastructures, emergencies, military operations, mine site operations, urgent business meetings and robot data acquisitions. An Ad hoc routing is challenged by power and bandwidth constraints as well as by frequent changes in topology, to which it must adapt and converge quickly.

MANETs are collections of mobile nodes and those nodes within each other radio range communicate directly through wireless links and those are apart from each other and uses other nodes as relays or routers [14]. Since there is no central infrastructure in such networks, the control is distributed among all the mobile nodes in the network. As long as the routing functionality in this network will have to be incorporated into mobile nodes, the network is self-configured, decentralized network; where all network activity including discovering the topology and delivering messages are executed by the nodes themselves [15]. Those nodes are provided with wireless transmitters and receivers using antennas, which may be highly directional (point-to-point), omni-directional (broadcast), probably steerable, or combination of these. At a given point in time, depending on positions of the nodes, their transmitter and receiver coverage patterns, communication power levels and co-channel interference levels, a wireless connectivity in the form of a random, multi-hop graph or Ad hoc network exists among the nodes. Mobile Ad hoc networks provide more flexible communication model than traditional wired networks because the user is not limited to a fixed physical location.

The current Internet architecture supports best-effort data delivery by default which has provided satisfactory services for various applications such as email and file transfer [14]. On the other hand, the increase in demand of real-time multimedia applications such as Voice over IP, Audio and Video streaming in the public Internet demands for QoS routing. QoS [14, 16] is usually defined as a set of service requirements that need to be met by the network while transporting a packet stream from source to its destination. It can also be expressed as the ability to provide different priority to different applications, users, or data flows, or to guarantee a certain level of performance to a data flow. Due to the demand of service requirements of those applications in MANETs QoS is the essential feature. Due to dynamic characteristic of MANETs, the wired QoS architecture is not suitable to the wireless mobile Ad hoc networks.

With the increasing needs of QoS [14] provisioning for evolving real-time applications such as audio or video, it is desirable to support these services in wireless mobile Ad hoc networking environments. The network is expected to guarantee a set of measurable service attributes to the user in terms of end-to-end delay, probability of packet loss, energy, and delay variance or jitter. QoS routing is a routing process that guarantees to support a set of QoS parameters during establishing a route and routing in MANETs is needed to support multimedia real-time communications 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.

2.3 Characteristics of MANETs

MANETs have their own characteristics and they are characterized by the following features [13, 17].

- **Dynamically Changing Network Topology:** Nodes are free to move arbitrarily having different speeds and the topology may change spontaneously and randomly at unpredictable time. The nodes are free to move and dynamically establish routing among themselves as they travel around by establishing their own network. In addition, the nodes can join and leave the network. This results in changes in routes and perhaps occurrence of data packet losses.
- **Multi-hop Routing**: In mobile Ad hoc networks, there is no default router available which means no dedicated routers. Every node acts as a router and forwards each packet to enable information sharing between mobile hosts. Single-hop MANETs are simpler than multi-hop in terms of structure and implementation with the cost of less functionality and applicability. When delivering data packets from a source to its destination out of the direct wireless transmission range, the packets should be forwarded across one or more intermediate nodes.
- **Autonomous Terminal**: MANETs do not depend on any established infrastructure or any centralized administration. Each device has an independent node which could function as both as a host and as a router. Which means that besides the basic processing ability as a host, mobile node acts and performs switching functions as a router.

- **Light-Weight Terminals**: In most cases, the nodes in MANETs are mobiles with less CPU capability, low power and small memory size. Those devices need to have optimized algorithms and mechanisms that implement the computing and communicating functions.
- **Distributed Operation**: There is no background network for the central control of the network operations. The control of the network is distributed throughout the nodes. The nodes involved in MANETs should cooperate with each other and communicate among themselves and each node acts as a relay when needed to implement specific functions like routing and security.
- **Temporarily and Rapidly Deployable**: The nodes in MANETs are temporary and there is no base station. Whenever the nodes are within their transmission radius, they form an Ad hoc network because they are rapidly deployable networks.

2.4 Routing Protocols in MANETs

MANET is a kind of wireless Ad hoc network and it is a self-configuring network of mobile routers and associated hosts connected by wireless links which forms an arbitrary topology [15]. Such networks may operate in a standalone fashion or may be connected to the larger Internet. Mobile Ad hoc network is a collection of independent mobile nodes that can communicate to each other through radio waves. The mobile nodes can directly communicate to those nodes that are in radio range of each other, whereas other nodes need the help of intermediate nodes to route their packets. These networks are fully distributed and can work at any place without the aid of any infrastructure and central administration.

The term routing is the process of selecting the best path in a computer network along which to send data [6, 15, 18]. At least one intermediate node within the network is encountered during the transfer of information. This process is used to communicate information about topology and link weights, and a routing algorithm selects paths between those nodes. Basically, two activities are involved in this concept which are determining optimal routing paths and transferring the packets through the network. The transferring of packets through the network is called packet switching which is straight forward, and the path determination could be very complex. Routing protocols use several metrics as a standard measurement to calculate the best path for routing a packet to its destination that could be number of hops, which are used by the routing algorithm to determine the optimal path for the packet to its destination. In the process of path determination, routing algorithms maintain routing tables which contain the total route information for the packet. The information of route varies from one routing algorithm to another. Routing in MANETs is intrinsically different from traditional routing which is found on infrastructured networks. In routing protocols, the routing tables are filled with entries such as IP-Address prefix and the next hop [18]. Destination/next hop associations of routing table tell the router that a particular destination can be reached optimally by sending the packet to a router representing the next hop on its way to the final destination and IP Address prefix specifies a set of destinations for which the routing entry is valid.

Routing is classified into static routing and dynamic routing [18]. Static routing is done manually. It maintains a routing table usually filled by a network administrator which means the routing table does not depend on the state of the network. Dynamic routing is a routing strategy that is being learnt by a routing protocol and this routing primarily depends on the state of the network.

The primary goal of any Ad hoc network routing protocol is to meet the challenges of the dynamically changing topology [11]. Those routing protocols are essential to the performance of wireless networks especially in mobile Ad hoc network scenarios.

In MANETs [19] routing protocols can broadly be classified into three basic categories as reactive, proactive and hybrid. A routing protocol is needed whenever a packet needs to be transmitted to a destination through a number of nodes and several routing protocols have been proposed so far for mobile Ad hoc networks. Those protocols find a route for the packet delivery and deliver the packet to its correct destination, and they have different features regarding the way to exchange routing information [20]. In Ad hoc networks the major problem is the routing protocols. Since nodes in MANETs are all mobile, a routing protocol should be able to find an alternate route quickly and efficiently as well. Many routing protocols have been proposed so far in this area to solve different issues that affect the performance of the network [21]. We discuss routing protocols in wireless mobile Ad hoc networks as follows.

2.4.1 Reactive Routing Protocols

Reactive routing protocols are also called on-demand routing protocols and these protocols do not maintain routing information or routing activity in the network nodes as long as there is no communication between those nodes. Which means the protocol creates routes only when these routes are required [15, 17, 21]. In other words, when a packet is to be transmitted from a source to its destination it invokes the route discovery procedure. The route remains valid till either the destination is reached or the route is no longer needed [11]. When a source node requires a route to a destination it initiates a route discovery process within the network. As long as all the routes are found or all the possible permutations have been examined those processes are completed. After that there is a route maintenance step to keep up the valid routes and to remove the invalid routes as well [21].

In the case of reactive routing protocols, the routing information is collected only when it is desired and route determination depends on sending route queries throughout the network [15, 19]. The main advantage of this routing protocol is that the wireless channel is not subject to the routing overhead data for routes that may not be used [6]. While reactive protocols do not have fixed overhead required by preserving continuous routing tables, they may have significant route discovery delay. Reactive search procedures can also add a major amount of control traffic to the network due to query flooding. There are various popular reactive routing protocols such as AODV, DSR and TORA. We discuss the well-known reactive routing protocols briefly as follows.

a. Ad hoc on-Demand Distance Vector Routing Protocol (AODV)

Ad hoc on-Demand Distance Vector Routing Protocol [11, 22] is the most widely used and it is a reactive routing protocol by its nature, an energy efficient protocol, and it is best suited for large networks. It is an on-demand routing algorithm which means that whenever the node needs to transmit information it builds a route. Which means the protocol starts a route discovery process only when it has to send data packets to another node and has no information about the route to that particular node. This routing protocol uses on-demand approach to discover and identify a specific route [11, 22, 23]. As long as they are needed by the sources the protocol maintains the routes. Nodes maintain route cache and uses destination sequence number for each route entry. In AODV, the fact that a node seeks information about the network only when needed and the use of sequence number ensures loop free route. To distinguish and keep up routing path or to handle route information, AODV uses set of three control packets or route messages in between source and destination such as Route request (RREQ), Route Reply (RREP) and Route Error (RERR). The RREQ packet contains IP address, current sequence number (SN) of destination node and this message will be transmitted through different nodes, routes and finally arrives to the destination node. The path which is followed by the message to arrive at the destination is recorded inside the message. Then after this message is sent from the destination to the source node, a process is known as Route Reply (RREP), the best route will be selected by the source node. In case if there is a link failure then it uses the route error (RERR) which is sent to source and destination. Without source routing AODV relies on routing table entries to propagate RREP back to the source and subsequently, to route data packets to the destination [11].

An important feature of AODV is the maintenance of timer-based states in each node regarding utilization of individual routing table entries. A routing table entry is expired if not used recently [11]. A set of predecessor nodes is maintained for each routing table entry, indicating the set of neighboring nodes which use that entry to route data packets. These nodes are notified with RERR packets when the next-hop link breaks. Each predecessor node, in turn forwards the RERR to its own set of predecessors, thus effectively erasing all routes using the broken link.

The main objective of the protocol is quickly adapting to the changes on the network links [6]. A Hello message in this protocol indicates presence of the nodes, if not received from a particular node then the neighboring node can assume that the node has moved away. This routing protocol 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. This routing protocol favors the least congested route instead of the shortest route and it supports both unicast and multicast packet transmission even for nodes in constant movement. It also responds very quickly to the topological changes that affects the active route.

The advantage of AODV [11] routing protocol is its effectiveness in highly dynamic networks, since the information of stale routes expire after a specific time, requires less space as compared to other reactive routing protocols and supports multicasting. It lacks an efficient route maintenance technique since routing information is always obtained on-demand.

When we compare AODV with respect to DSR, RREQ in AODV carries the destination address where as in DSR RREQ carries full routing information. Because of this reason AODV has less overhead than DSR.

b. Dynamic Source Routing Protocol (DSR)

Dynamic Source Routing protocol is an Ad hoc routing protocol based on the theory of source based routing rather than table-based [11, 24]. This protocol is source initiated and is particularly designed for use in multi-hop wireless Ad hoc networks [11]. DSR does not need any existing network infrastructure or administration. This allows the network to be completely self-organizing and self-configuring. This routing protocol composed of two essential mechanisms such as route discovery and route maintenance. Each node maintains a cache in order to store recently discovered paths. When a node needs to send a packet to another node first it checks its entry in the cache, if it is there then it uses that path to transmit the packet. If the entry does not exist in the cache or if it is expired because of being idle for a long time then the sender broadcasts a route request packet to all neighbors asking for a path to the destination. The sender waits till the route is discovered. As soon as the route request packet reaches any of the neighboring nodes, the latter looks for the destination in its corresponding cache. If the route information to the destination is known, then the neighbor node sends back a route reply packet to the sending node, otherwise the same route request packet is broadcasted.

DSR can be chosen to provide soft QoS guarantees in different areas of MANET applications when better QoS metrics like reliability, packet delivery, overhead, etc. should be taken into account for routing of packets [6]. Due to its source routing DSR has major scalability problem [16, 24, 25]. Nodes use routing caches to reply to route queries [16, 25]. This results in an 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. DSR is not scalable to large networks and even requires significantly more processing than most other protocols [24, 26]. In order to obtain the routing information, each node must spend lot of time to process any control data it receives, even if it is not the intended recipient. In addition, the route maintenance mechanism does not locally repair a broken link [27]. Stale route cache information could also result in inconsistencies during the route reconstruction phase. The connection setup delay is higher than in table-driven protocols and the performance degrades rapidly with increasing mobility.

c. Temporally Ordered Routing Protocol (TORA)

TORA is a distributed highly adaptive routing protocol designed to operate in a dynamic multi-hop network [26]. It uses arbitrary height parameter to determine the link between any two nodes for the given destination. To initiate the route the node rebroadcasts the query packet then broadcasts the update packet which lists its height with respect to the destination. When this packet propagates in the network each node that receives the update packet sets its height to a value greater than the height of the neighbor from which the update was received. This has the effect of creating a series of directed links from the original sender of the query packet to the node that initially generated the update packet. When it is discovered by a node that the route to a destination is no longer valid, it will adjust its height so that it will be a local maximum with respect to its neighbors and then transmits an update packet. If the node has no neighbors of finite height with respect to the destination, then the node will attempt to discover a new route. In TORA route rebuilding may not occur as quickly as possible due to oscillations and during this period this can lead to long delays while for the new routes to be determined.

2.4.2 Proactive Routing Protocols

In proactive routing protocols or table-driven routing protocols each node maintains one or more tables containing routing information to every other node in the network. All nodes keep on updating their routing tables to maintain the latest view of the network [11]. These routing protocols follow the conventional method of finding and maintaining the route between the source and the destination and they maintain up-to-date routing information for all nodes in the network even before they are needed [21].

Every proactive routing protocol usually needs to maintain routing information even before it is needed [15]. This means each and every node in the network maintains routing information to every other node in the network. The routing table is used to keep routing information and is periodically updated as the topology of the network changes. Moreover, these routing protocols maintain different number of tables and these protocols are not suitable for large networks, as they need to maintain node entries for each and every node in the routing table of every node. This causes more overhead in the routing table which may lead to consumption of more bandwidth.

In proactive routing, each node has to maintain one or more tables to store routing information, and any changes in network topology need to be reflected by propagating updates throughout the network in order to maintain a consistent network view [28]. These protocols continuously learn the topology of the network by exchanging topological information among the network nodes. Tables are updated frequently in order to maintain up-to-date routing information from each node to every other node [29]. To maintain up-to-date routing information, topology information need to be exchanged between the nodes on a regular basis, leading to relatively high overhead on the network. The main disadvantage of table driven implementation algorithms is that the requirement for maintenance of a large amount of data at every node and slow reaction on restructuring and failures [24]. Well known routing protocols in proactive routing approach are discussed as follows.

a. Optimized Link State Routing Protocol (OLSR)

Optimized Link State Routing protocol is one of the proactive routing protocols in MANETs [20, 30]. It uses Multipoint Relays (MPRs) a node’s one hop neighbor selected for forwarding packets to reduce traffic overhead [30]. Three kinds of control messages are used in this routing protocol. First, hello messages are sent frequently to all its neighbor nodes containing its MPRs, neighbors whose bidirectional link have not been yet known, node's identifier and list of node's neighbors. Second, Topology Control (TC) messages are periodically sent by a node having a set of bidirectional links between the node and a subset of node's neighbors. The third and the one last is Multiple Interface Declaration (MID) messages as the name indicates these are used to declare that a node is running OLSR on multiple interfaces. In this protocol, large bandwidth and power is required to maintain the routing tables in addition maintenance of routing tables becomes difficult for large networks [31].

b. Destination Sequenced Distance Vector (DSDV)

The Destination Sequenced Distance Vector Routing Protocol presented in [6, 11] is a table-driven algorithm based on the classical Bellman-Ford routing mechanism. The improvements made to the Bellman-Ford algorithm include free from loops in routing tables. Every mobile node in the network maintains a routing table in which all of the possible destinations within the network and the number of hops to each destination are recorded. Each entry is marked with a sequence number assigned by the destination node. The sequence numbers enable the mobile nodes to distinguish stale routes from new ones, thereby avoiding the formation of routing loops [24, 32]. Routing table updates are periodically transmitted throughout the network in order to maintain table consistency.

To help alleviate the potentially large amount of network traffic that such updates can generate, route updates can employ two possible types of packets [24]. The first is known as a "full dump". This type of packet carries all available routing information. During periods of occasional movement these packets are transmitted. Smaller "incremental" packets are used to relay only that information which has changed since the last full dump. Each of these broadcasts should fit into a standard size packet thereby decreasing the amount of traffic generated. The mobile nodes maintain an additional table where they store the data sent in the incremental routing information packets. New route broadcasts contain the address of the destination, the number of hops to reach the destination, the sequence number of the information received regarding the destination, as well as a new sequence number unique to the broadcast. The route labeled with the most recent sequence number is always used. In the event that two updates have the same sequence number, the route with the smaller metric is used in order to optimize or shorten the path. Mobiles also keep track of the settling time of routes, or the weighted average time that routes to a destination will fluctuate, before the route with the best metric is received. By delaying the broadcast of a routing update by the length of the settling time, mobiles can reduce network traffic and optimize routes by eliminating those broadcasts that would occur if a better route was discovered in the very near future [24]. This protocol needs to send out messages to the adjacent nodes periodically as a result its expense is always higher [32]. That means wastage of bandwidth occurs because of unnecessary advertising of routing information if there is node change in the network topology and more bandwidth is required in maintaining the routing table's advertisement for larger network as it requires more bandwidth [27].

2.4.3 Hybrid Routing Protocols

Hybrid routing protocols contain the advantages of those of reactive and proactive routing protocols [33]. The main drawback of hybrid routing protocols is that the nodes that have high level of topology information maintain more routing information, which leads to more memory and power consumption [6]. An example of hybrid routing protocol is the Zone Routing Protocol (ZRP). This protocol 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 [33]. Another weakness of ZRP is that efficiency or effectiveness of the protocol is based on how efficiently the size of the zone is selected.

ZRP is the most distinctive hybrid routing protocol in mobile Ad hoc networks. It is a hybrid routing protocol for mobile Ad hoc networks which localizes the nodes into sub-networks or zones [33]. It is designed to take advantages of both reactive and proactive routing protocols. It composed of Intra-Zone Routing Protocol (IARP), Inter-Zone Routing Protocol (IERP) and Bordercast Resolution Protocol (BRP) along with various Query Control mechanisms [34]. IARP has limited scope which is defined by zone radius. Within this routing zone radius IARP maintains the topology information of its local zone. IERP acts as a global routing component for ZRP. Whenever a node needs to send information outside the routing zone or the route needed by a node is not available in local neighborhood IERP is used to send the data. As the traditional nature of reactive routing protocols route discovery and route maintenance is also performed by IERP. For the reduction of routing overhead Bordercast Resolution Protocol is used. By using the information provided by IARP, it directs the route requests outward. The outward request sent is multicast in nature sent to certain set of peripheral nodes or surrounding nodes. If in case, there is no reply after BRP these set of nodes again perform border-casting to their peripheral nodes.

2.5 Applications of MANETs

According to the works in [11, 13, 28, 35] major examples of MANET application environments are the following.

- **Military Battlefield:** Ad hoc networking can permit army to exploit benefit of conventional network expertise for preserving any network information between those vehicles, armed forces or soldiers and headquarters of military tactical information. In such areas there is no reliable infrastructure that can be easily and fastly deployable.
- **Cooperative Work:** To facilitate the commercial settings necessity for concerted computing is very significant external to office atmosphere and surroundings as compared to inner environment. People want to get outside meetings for exchanging the information on tasks and cooperating with each other regarding any assigned task.
- **Commercial Sector:** Commercial scenarios like ship-to-ship Ad hoc mobile communication for transportation of goods in logistics, needs such a rapid deployment of communication system. In addition, it is used in e-commerce, for example, electronic payments from anywhere like rural areas.

- **Educational Sector:** Arrangement of communication facilities for computer-generated conference rooms or classrooms or laboratories. Therefore, it can ensure effective communication among the nodes and creates collaborative learning environment in educational sectors.

2.6 Challenges in MANETs

Some of the challenges in MANETs according to the works mentioned in [11, 13, 28] are discussed as follows.

- **Routing:** In MANETs the issue of routing is an important challenge of the performance degradation due to unicasting, multicasting and geocasting demanded by the network nodes in contrast to single hope wireless networks. It is because of random movement of nodes, rapid change in network topology and with different mobility speeds.
- **Quality of Service:** In MANETs QoS is an important challenge for the different kinds of quality level demands by the network users. It becomes very difficult to fulfill the different levels or priority demands related to quality of service. So, these networks require best control of QoS specially in case of real-time applications. The need for provisioning QoS in MANETs is becoming important for the requirement of specific applications. Therefore, QoS is essential to meet the requirement for diverse applications.
- **Security:** In MANET security is one of the challenges due to its wireless environment. The data of users from one node to another node must be transferred safely. In addition to the common vulnerabilities of wireless connection, Ad hoc network has its particular security problems due to nasty neighbor relaying packets. The feature of their distributed operation requires different techniques of authentication and key management.

2.7 QoS Routing in MANETs

The term QoS in MANETs can be described as the performance level of services provided and according to RFC 2386, it is a set of service requirements to be met by the network while transporting a packet flow from the source to its destination [16]. The network is expected to guarantee a set of measurable pre-specified service attributes to the users in terms of end-to-end performance such as bandwidth requirement, probability of packet loss, the variation in latency or jitter, route acquisition delay, communication overhead, etc.

One of the key issues in QoS routing is finding a feasible path that satisfies the QoS constraints of a given MANET application [6]. However, in MANETs QoS routing is very challenging due to node mobility, limited resource constraint, multi-hop communications, contention for channel access, and lack of central coordination. In the past decade, several approaches proposed various routing algorithms with QoS support for MANETs. However, none of them is adequate enough to incorporate all the available QoS parameters for an efficient routing of a packet.

QoS can also be defined as a set of constraints such as latency, throughput, packet loss and jitter that need to be met by the network for a specific data flow [36]. Nowadays, the demand to transmit real-time traffic through mobile Ad hoc networks is increasing and essential. Those real-time applications have QoS requirements for example, delay, bandwidth and jitter. Due to the time sensitivity nature of such kind of traffic, it requires the packet to reach its destination within its specified deadline if not those packets become useless or dropped. As such, a mobile Ad hoc network should provide QoS technique to meet the requirements of those applications. However, mobile Ad hoc networks are characterized by their infrastructure-less networks, mobility, power consumption, limited bandwidth and channel sharing, which makes such kind of task more challenging than wired networks. Protocols and frameworks are proposed so far to address the problem of provision QoS in MANETs. The provision of QoS guarantees is challenging in mobile Ad hoc networks compared with that of wired networks because of the frequently unpredictable topology changes of mobility and power depletion in MANETs.

Chapter 3 : Related Work

QoS routing in MANETs has been investigated by researchers and a number of algorithms have been proposed. In this Chapter, we review and discuss published papers that are particularly related to MANETs routing protocols and QoS in MANETs.

3.1 QoS in Reactive Routing Protocols

The work in [37] proposed to calculate the available bandwidth using the ratio between the number of transmitted and received packets. The aim of this work was to propose QoS enabled routing protocol in Ad hoc networks and compare it with AODV routing protocol using NS-2. The results show that although the sessions are paused when the QoS objects change, the average packet delay in the proposed work is shorter than in actual AODV protocol. The available bandwidth is enhanced as it is calculated by minimizing the unnecessary signaling and stopping the sessions that cannot meet the QoS requirement. Hence, the message overhead is decreased while increasing the data rate. The work also analyzed the effect of hello messages when it carries QoS object information instead of using link layer information in control routing messages. But the delay based QoS routing is not included as part of the work because hello messages should be used for the link delay measurement, and it is necessary to incorporate a time stamp in hello messages and the first hop neighbors would know the link delay by comparing the current time with the time stamp in the hello message received. In addition, even though the technique supports significant utilization of resources when the ongoing traffic session is paused during links congested may result in low packet delivery ratio.

In [38] the authors proposed AODV with Sufficient Bandwidth Aware (AODV+SBA) routing protocol which significantly improves the performance of on-demand routing protocols by discovering better routes to avoid congestion and reducing excessive routing overhead. In this work, a light-weight mechanism is used to determine network congestion and the parameters for measuring local network congestion around a node depend largely on the MAC layer based on IEEE 802.11 distributed coordination function (DCF). To achieve their objective, they analyzed the proposed work using the NS-2 network simulation tool and the analyzed result was the improvement of network performance and stability by reducing data packet delay and routing overhead and increasing packet delivery ratio under high traffic load. Moreover, in case of low-to-medium traffic load its performance is close to the popular AODV routing protocol. Generally, the proposed work outperformed the original AODV in terms of average delay and confidence interval period especially when the network traffic is heavily loaded. It performs the same as the original AODV in terms of normalized routing overhead because route re-discovery is not required in the steady network. In comparing their routing overhead, the proposed work was better lightweight than the original AODV routing protocol. They tried to improve network performance by reducing routing overhead but in this work the type of service to have a priority is not taken into consideration.

In [39] node location information is used as a means of reducing overall communication overhead for packet forwarding in MANETs. It fetches the node location information using GPS for reducing the computation and communication requirement to select the next node for packet forwarding. The proposed work fetches the node location information using GPS and follows the robust, adaptive and efficient routing algorithm to ensure communication occurs with minimum number of hops and computations. Routing overhead can be reduced, efficiency of routing protocols can be improved and tried to confirm packet delivery. Performance of geographic Location Aware Adaptive routing (GLAAR) is analyzed using NS-2 and the performance of GLAAR is evaluated by analyzing throughput of sending and receiving packet and jitter effect of packets sent and received over the network and the obtained simulation results enhance the performance analysis of GLAAR in terms of throughput and jitter tolerance for the packet transmission over the network. Finally, the authors concluded that evaluation of GLAAR meets the requirement and is efficient in terms of bandwidth, scalability, and throughput and tolerable to jitter effect. But the network resources are not utilized according to the type of service which means packets are forwarded based on location information instead of utilizing the appropriate path to the intended receiver.

In [40] an on-demand delay based QoS routing protocol (AODV-D) is proposed for QoS routing to ensure that delay does not exceed a maximum value. MAC layer channel contention information and number of packets in the interface queue are considered in addition to minimum hop criteria for route discovery. The proposed protocol provides more accurate estimation of end-to-end delay. They used GloMoSim for the experimental evaluation. The result analysis is observed in terms of effect of node mobility and effect of traffic load. From their analysis using different QoS metrics AODV-D is considerably performing well than AODV and it is able to meet the QoS requirements efficiently up to 20 sessions and above 300 seconds pause time. If the traffic increases, i.e., the number of sessions increases more than 20 the average end-to-end delay exceeds 400 ms. It has provision to avoid a congested path by keeping track of accumulated delay value extension field. The work focuses on reducing the network delay but does not consider the bandwidth requirements of real-time applications.

In [41] an Efficient Power Aware Ad hoc on-Demand Distance Vector (EPAAODV) routing protocol is proposed. This is a modification of AODV. The objective of this work is to increase network lifetime of a MANET. An energy consumption analysis is performed on the proposed work. The proposed EPAAODV routing protocol differs from the AODV in the way intermediate nodes process an incoming RREQ. From the results obtained from analysis, it has a low energy consumption compared to AODV. The performance parameters such as packet delivery ratio and throughput are also analyzed using NS-2.

The packet delivery ratio of the proposed work is higher as compared to AODV. This could be due to the stability of path in the proposed protocol. Since the proposed protocol prolongs network lifetime, it means there are less link breakages, and the proposed protocol guarantees that most of the packets sent are delivered. The throughput of the proposed work is slightly higher compared to AODV. But when they used 50 nodes for simulation the case becomes different for about 70 seconds AODV outperforms the proposed protocol. The reason could be because the performance of AODV in medium density environment is poor, hence less energy is used in AODV. The work did not consider the service quality.

In [42] the authors focused on the two popular algorithms AODV and DSR. They analyzed and compared the performance through simulation using NS-2. From this work, they assessed metrics like packet delivery ratio, average time delay and routing load overhead by varying network size and transmission range of the respective nodes. The general observation from the simulation is that in QoS metrics such as average delay and packet delivery ratio, DSR outperforms AODV in less dense situations. However, AODV outperforms DSR in more dense situations. Moreover, DSR consistently generates less routing load than AODV. It is also observed that the packet loss is very less in case of AODV initially, but it increases substantially as simulation time increases. In case of DSR, the packet loss is very high initially, but it decreases substantially as the simulation time increases. They concluded that if the MANET has to be setup for a small amount of time then AODV should be preferred due to low initial packet loss. But, in this work they did not use any kind of QoS improvement technique for the provisioning of QoS in those protocols and the experiment must be performed by varying different network parameters to know more about the behaviors of the two protocols.

In [43] probability based broadcasting technique for routing protocol is proposed to trim down flooding problem. It uses node's current remaining energy and threshold random delay to generate rebroadcast probability dynamically for the efficient broadcasting in route discovery. This technique is analyzed over reactive AODV routing protocol. The RREQ packet of AODV is modified to gather energy information of nodes. The main objective of this work is by using probability based broadcasting technique to find an efficient probabilistic based broadcasting protocol which controls the rebroadcasting of received broadcast packets. The experiment is conducted to measure the performance of the modified protocol and is analyzed over broadcast packets sent and end-to-end delay using NS-2 simulator. Simulation results are observed to reduce redundant transmission by 19 to 28 percent and hence improve network performance. The improved end-to-end delay in case of probability based broadcasting technique is reduced by 11 to 22 % in comparison to AODV. The average end-to-end delay in comparison to rebroadcast of RREQ packets in AODV, the RREQ packets of probability based broadcasting technique are controlled while rebroadcasting using dynamic probability the traffic load of the network is reduced. The IEEE 802.11 Distributed Coordination Function(DCF) is used as the MAC layer protocol. In the scenario, UDP connection is used with Constant Bit Rate (CBR) data traffic between source and destination. The proposed work enhances broadcasting performance significantly and incurs much less overhead in network control and hence it can be more adaptive to the MANET environment. But it doesn't fulfil the QoS requirement in MANETs.

In [44] the authors proposed an algorithm to balance energy consumption among all participating nodes that will extend the network lifetime of the nodes. It is a dynamic distributed load balancing approach that balances energy consumption among nodes and chooses paths that are easily loaded. For experiment comparing to AODV and Local Energy Aware (LEA-AODV) protocols they used NS-2. At first the nodes are moving in a fixed speed and alternative pause time. The pause time is fixed at 20 seconds, but the maximum speed is set respectively as 5m/s, 10m/s, 15m/s, 20m/s, 25m/s, 30m/s to carry on the simulation separately. They evaluated LEA-AODV protocol by comparing its performance with AODV protocol to obtain the minimum energy consumption and prolong the network's lifetime. A square field of 500m×500m is taken where 10 nodes are randomly deployed, simulation time is 900s, and the maximum speeds for nodes is 20 m/s, with a total of 10 nodes. The pause time is respectively: 0, 20, 120, 600, 900 seconds. The traffic sources are CBR (Constant Bit Rate), 512-byte as data packets, and the sending rate is 4 packets. The use of CBR is for the purpose of a fair comparison. But since the bit rates vary, data packet traffic load will become unpredictable and the proposed work does not consider the type of services.

3.2 QoS in Proactive Routing Protocols

In [45] the authors proposed an approach to improve the quality of service in the optimized link state routing protocol. This approach proposed to perform at each node an estimation of the bandwidth fair share between all adjacent nodes and tends to ensure the selection of a path with all Multi Point Relays (MPRs) that provide a higher bandwidth along the path. They tried to find the path that ensures the highest bandwidth among all possible paths between the source node and the destination node. To evaluate the efficiency of the proposed algorithm they conducted an experiment and the results analyzed from the experiment using OPNET Modeler 14.0 show that the proposed approach achieves a higher performance than the standard OLSR routing protocol used in wireless mesh networks. But as the number of MPR nodes increases in the proposed work it might lead to higher routing overhead.

In [46] the authors proposed to support QoS routing in OLSR routing protocol. The goal of the work is to achieve finding of an optimal bandwidth path. They proposed heuristics that allow OLSR routing protocol to find the maximum bandwidth path and showed through simulation that these heuristics do improve OLSR and finally, they showed that for the Ad hoc network model, two of the heuristics are indeed optimal that means guarantee that the highest bandwidth path between any two nodes is found. But the impact of node movement and bandwidth change is not included in the proposed work. The flow of applications according to their sensitivity based on their priority did not involve in the work.

3.3 QoS in Hybrid Routing Protocols

In [47] a new Virtual Base Station (VBS) election technique is proposed to help in QoS provisioning in MANETs. This VBS election technique is based on the mobile node’s Signal-to-Noise Ratio and has been applied on hybrid zone routing protocol. The objective of the work was to improve the performance of ZRP and make the MANETs virtually cellular by implementing the Virtual Base Station technique. The developed routing protocol is referred to as SNR-VBS ZRP

(Signal to Noise Virtual Base Station Zone Routing protocol). In order to study the impact of the SNR-VBS ZRP on the main QoS metrics such as throughput, end-to-end delay and energy consumption, simulation results were derived from the QualNet simulator tool. The SNR-VBS ZRP performance was compared to the standard ZRP to highlight its effect on QoS provisioning in MANE. But it needs to be enhanced at higher traffic load and at longer pause time in mobility scenario in order to reduce and measure the end-to-end delay.

3.4 Summary

The main essence of a mobile Ad hoc network is to provide communication among users in different application areas such as military environments, emergency scenarios like Earthquake and flooding, education, and commercial sectors, etc. In such application areas, we believe that the information should be delivered as fast as possible depending on the sensitivity of the application.

Generally, the following are the problems on routing protocols that are reviewed in this chapter.

- Do not handle congestion efficiently.
- Routing overhead.
- Demand of more bandwidth.

Routing protocols are proposed to purely function on a best effort basis with no attempt to provide QoS whatsoever [37]. Lots of works should be done on providing more efficient QoS on routing protocols in MANETs environment. Though many different works have been tried, there is no work on priority with admission control mechanism for provisioning of QoS. So, this research work presents a new technique to provide QoS in AODV that is able to satisfy users based on priority of service types with admission control technique.

Chapter 4 : Design of The Proposed Architecture

4.1 Overview of The Architecture

In this Chapter, the architecture of the proposed priority aware QoS in AODV protocol is designed and described. The proposed solution applies priority mechanism and admission control technique for better routing computation with respect to QoS metrics. The detailed description about the proposed solution is presented. QoS mechanism can decrease packet delay and improve efficiency in the proposed system. The aim of the proposed solution is to improve the overall network efficiency or performance in order to reduce packet delay and packet loss by considering the idea of the higher the priority the earlier the transfer.

The proposed work targeted to achieve the QoS provisioning during communication and the aim is to increase the performance of mobile Ad hoc networks in order to satisfy the requirement of different traffic transmission. As long as the quality of the communication system is determined by the QoS parameters, we believe that the future of wireless communication systems will depend on guaranteeing the provisioning of QoS. To solve the problem of QoS in MANETs we used best QoS provisioning schemes such as prioritization scheme using scheduling technique and admission control technique together. The priority is managed using scheduling technique to handle better the classes of services. This admission control helps in deciding new incoming data flows in such a way that determine the state of the network resource and utilizing the resource as well and accept the appropriate flow.

Mobile Ad hoc network is a technology which those nodes in the entire communication system inherit the characteristics of mobility nature, self-administration and connected wirelessly. As per the description in Chapter Three there are lots of problems in QoS provisioning in mobile Ad hoc networks and those problems need to be addressed using different QoS provisioning mechanisms. Having this assumption in mind we come up to contribute on the QoS in this area of this thesis. In this Chapter, all the techniques and the algorithms for the proposed solution are discussed. The general architecture of the research is illustrated in Figure 4.1 on the network protocol stack.

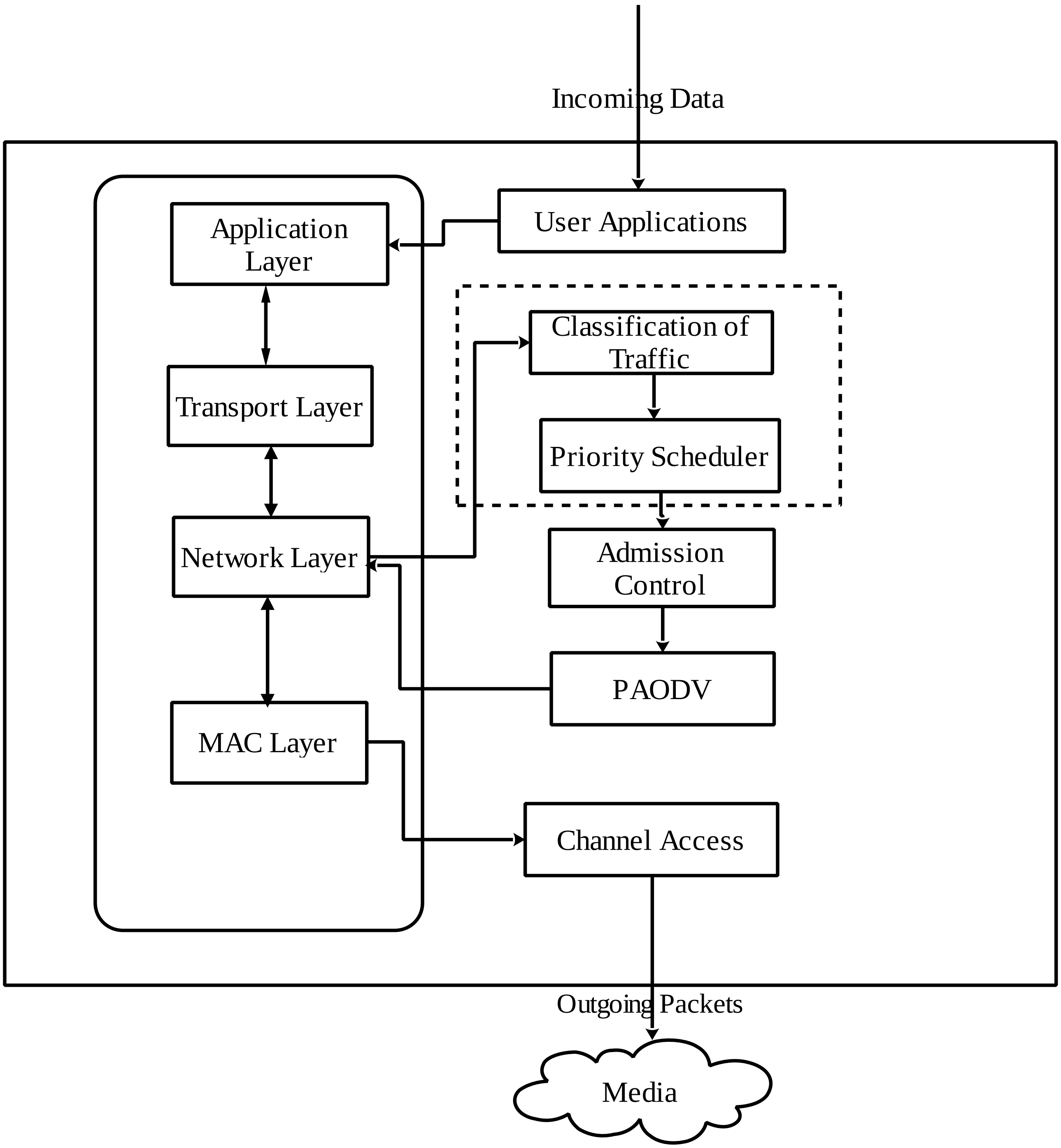

Figure 4.1: *The Proposed Priority Aware QoS Architecture*

The goal of this work is to prioritize the traffic in accordance with the sensitivity of the services. Scheduling is the key function we use in the research to improve the QoS in mobile Ad hoc networks and it also reduces bad channel situation in the communication system. So, delay sensitive applications like real-time applications have higher priority than non-sensitive or no-real-time traffic for delay and jitter.

To offer QoS the proposed solution is able to classify traffic information and prioritize those classified traffic and schedule them using WRR (Weighted Round Robin) scheduling that is used to schedule the incoming packets based on their priority level. As such, our proposed solution offers stable QoS which means packet delay of real-time traffic is reduced. Applications are classified based on ToS field in the IP header information.

The proposed priority aware QoS architecture shows the structure which we apply for QoS technique in order to improve those QoS metrics. The designed proposed system decreases delay of packet transmission and performance of routing will be increased when packets are scheduled according to their priority. Hence, the transmission packets are classified, scheduled and congestion is also being reduced. The major components of the proposed solution are described below.

4.2 Description of Major Components of the Architecture

4.2.1 User Applications

Applications which come from the outside or inputs to the wireless mobile Ad hoc nodes are called user applications. User applications are applications which are generated as a traffic to help us further classification based on their class. The traffic is generated and pass through the application layer and the application layer helps in generating traffic. This contains the information about the traffic generated and application agents. From this, the generated traffic are prepared for classification part. Which means this traffic is an input for the classification part. For example, when a user wants to communicate with another using mobile the audio is an input for the mobile node. Like that in our case input applications are applications used as an input to the node and generated as a traffic. Hence, the incoming input applications should be created as traffic application packets and those traffic are transported with an agent. To generate traffics we use a built-in Constant Bit Rate (CBR) traffic generator in NS-2.

4.2.2 Classification of Traffic

In order to classify applications to different classes of traffic we need to have a way to differentiate traffic. Such a classifier module helps the system to determine what kind of priority has been provided for final scheduling. Classifier is used to classify applications according to their service classes. The classes of the traffic should be classified to perform queueing according to their sensitivity just like real-time and non-real-time or data traffics are classified and as a result the scheduler schedules those to be transmitted according to their respective prioritized level of flow. This classification process is used to prepare classified packets and forward them to the priority scheduler to be discussed in Section 4.2.3.

The traffic should be classified regarding the characteristics of the applications which means that the application that needs better QoS needs to have higher priority than those applications that are not that much sensitive to delay. To provide QoS in mobile Ad hoc networks giving priority is not sufficient if we have multi-classes of services as long as the traffic is not differentiated. The classifier can be able to differentiate classes of services easily and efficiently. It is the process of categorizing packets into different QoS classes.

Classifying network traffic has a capability to organize traffic into traffic classes based on whether the traffic matches a certain criterion [48]. Classifying a network traffic is the foundation for enabling many QoS features on the network and the goal is to group traffic according to defined criterion so that the resulting groups of network traffic can then be subjected to specific QoS treatments.

Blake *et al.* [49] classify network traffic into different classes. The traffics entering into the network are classified at the boundaries of the network by marking a special differentiated service field in the IP packet header in the Type of Service (ToS) field. It maps multiple application flows into few service classes.

To classify traffic, packet classifier selects packets in a traffic stream based on the content of the part of the packet header. To identify the type of application for classification purpose we use the IP header information in which the values will determine the per-hop behavior received by each classification of traffic class that is able to identify the type of service [49].

The packet classification policy identifies the subset of traffic which may receive a differentiated service by being conditioned and/or mapped to one or more behavior aggregates by differentiated service codepoint re-marking within the differentiated service domain [49]. The incoming traffic should be classified and marked based on the service type. The packet contains information to be scheduled. Based on the defined IP header information, the application is classified and ready to be buffered into the priority scheduler which means the classified packets are used as an input for the priority scheduler. In this work DiffServ is modified in such a way that it is to be used to classify flows into different classes in NS-2 based on the dynamic characteristics of mobile Ad hoc networks. Therefore, it is suitable or adaptive for MANETs because it divides traffic into a small number of classes to be convenient for the scheduler.

To avoid the need for a signaling protocol the class is marked directly on the packet in the Differentiated Service Code Point (DSCP) value. The DSCP in differentiated service field is part of the original Type of Service (ToS) field in the IP header. It provides treatment of forwarding traffic for QoS in different flows of traffic [49]. This ToS information helps in mapping packets to proper category of access. It also determines the QoS behavior of packets at a node throughout the network. Different classes of traffic have different level of priority and after this classification is performed, the scheduling algorithm should ensure the higher priority packets are transferred before lower priority packets.

The differentiated service is an approach to provide QoS and it depends on the type of service classes. Which means applications are classified according to QoS traffic classes and those traffic are mapped into priority queue in order to be treated accordingly. During classification the corresponding entry of the queue is assigned and then after queued into the queue scheduler. To clarify more the classified packets are scheduled using scheduler and determined by the admission controller and finally after route is established those scheduled packets are sent. The classification mechanism is modified to be adaptive in mobile Ad hoc networks.

Generally, the classification module helps to meet the requirements of applications to be marked and ready to be buffered into the queue and forwarded by the priority scheduler. Algorithm 4.1 shows how the classification technique in the proposed solution works.

```
Input: New Incoming Packets
While Packet Classified Do:
   New Packet has Arrived
     If type of Packet = real-time Then
          Insert the Packet into First Priority Queue
     Else if type of Packet = non-real-time Then
          Put the Task into the Second Priority Queue
          Check Queue Size
           If Queue Overflow
                Reject new Insertion into the Queue
           End if
     End if
```

Algorithm 4.1: *Classification Algorithm*

The packets are found to be real-time and non-real-time based on the information contained in the ToS IP header which helps to identify the service type.

4.2.3 Priority Scheduler

In our real-life environment to achieve whatever any kind of work or task, scheduling is very important aspect to perform the works properly in accordance with the work's level of priority. It plays a very important role in our day-to-day activity because it enables us to easily determine the next eligible work flow. Likewise, scheduling algorithms play an important role for designing efficient communication systems in mobile Ad hoc networks to be able to enforce those transmitted packets to flow with their level of service priority. It is a proper way to manage the resource in accordance with the requirement of the application. As long as the packets are treated separately in the network during communication network congestion is reduced due to the use of packet scheduling algorithm technique.

After packets are classified they should be scheduled based on the class of service identified in the classification phase. To do this we need to have scheduling mechanism for proper management of packets in the queue.

WRR (Weighted Round Robin) priority scheduling is a mechanism we use to prioritize traffic in the proposed system. It is the mechanism used to ensure the treatment of certain packets to have higher transmission priority over other lower priority packets and determine which packets should be served next regarding fairness. Higher priority packets should get higher precedence than other lower priority ones. The priority may be updated based on the traffic QoS requirement. This technique is adaptive for occurrence of congestion. The way of ordering and distribution of different applications QoS characteristic is determined by the scheduler in order to achieve the desired service quality in the communication system. The scheduler schedules with fairness that treats all the traffic flowing in the entire MANETs. Therefore, this scheduler adjusts the transmission of classes of services in fair manner that helps to realize QoS. Which means the end-to-end delay and packet loss ratio for different packets in the communication system are better because the resource consumption is prevented using this mechanism in such a way that schedules service classes waiting for scheduling. Furthermore, packet loss and end-to-end delay occur due to congestion which is not properly managed by the QoS mechanisms. Therefore, scheduling can prevent the network from being congested as far as managing the traffic properly for QoS requirement.

We use WRR scheduling technique in order to prevent low priority packets from resource starvation. As long as MANETs are used in different applications, whichever application are in the communication system it should be realized that those diverse applications should use the resources fairly without being starved.

The scheduling technique should be utilized in mobile Ad hoc networks to provide QoS. After the packet classification phase, packets are distributed in priority scheduling depending on the type of traffic classes separately in the queues. Packets that entered into the queue should be scheduled regarding the nature of the sensitivity of the service type after classification.

The packet priority scheduler prioritizes the incoming classified traffic according to their nature of sensitivity for delay. That means regarding the application types real-time traffic should get higher priority than non-real-time traffic. The scheduler uses queuing and scheduling mechanisms for the flow of traffic classes between those traffic accordingly. It is essential for MANETs to have efficient routing and QoS mechanism to support different applications. Apply priority scheduling enable us for queuing management mechanism to gain QoS guarantees [49].

The scheduling does play an important role in the QoS provided by the network. It is only effective if there is sufficient queue space to contain incoming packets. Because queues are not of infinite size, they can fill up and overflow to contain all the new incoming packets. When a queue is full, packets cannot be allowed to enter into the queue and will be dropped. The issue is that the node cannot prevent those packets from being dropped even if the packet is a high priority packet. So, the purpose of queue management is to make sure that the queue does not fill up. Therefore, there is space for high priority packets [50].

Scheduling real-time and non-real-time packets is significantly essential in reducing overhead, bandwidth consumption, communication power consumption, and end-to-end delay [51]. Likewise, scheduling packets in mobile Ad hoc networks improves QoS metrics. The scheduling schemes can determine which packet should be dropped when congestion occurs during transmission which means the algorithm has the power to enforce high priority packets should be forwarded before lower priority packets [51].

Generally, after the applications are differentiated using the classification technique then those traffics are scheduled and for our study we use the WRR scheduling technique to manage and forward packets due to its simplicity as well as its low computational cost. It has better QoS for real-time applications.

WRR is a scheduling technique that is designed to handle traffic classes with different service requirements fairly [48, 52, 53]. Therefore, we can say that this technique manages and prioritizes packet transmission process and we believe that prioritizing packets increases the performance of the routing process. The packets waiting at the queue are served according to their level of priority during transmission and weighted round robin is a scheduling technique in the proposed solution we used. This algorithm is a mechanism that accepts the input classified traffic and allow to forward those traffics according to their weight. In our proposed solution, the weight for each queue is computed and each class of queue is determined by this scheduler.

In WRR scheduling each classified queue is checked to know which class of traffic is served first in order to give higher priority traffic classes without starvation of non-real-time traffic classes.

Therefore, each queue has weight as a result, the higher the queue weight the greater is the bandwidth reserved. WRR scheduler operates in the form of a Round Robin fashion and in each round the scheduler checks each queue starting from the first queue.

Weighted round robin scheduling technique is efficient to help the delivery of class of traffic flows avoiding starvation for low priority packets. That means class of traffic having different service requirements are better handled using this scheduling technique [48].

The aim of QoS in MANETs is to minimize the transmission delay of packets, serving packets based on their priority.

There is a technique to treat contention of network resources using scheduling and manage the available resource during the design of network service for widely varying types of traffic [54]. Each node as part of the resource allocation mechanisms must implement the queuing algorithm that governs how packets should be buffered while waiting to be transmitted in the queue. The queuing technique also affects the packet latency by decreasing the time that packets are waiting to be transmitted. In order to distinguish the services priority, it is essential to use a scheduling algorithm which would be appropriate for providing QoS.

We modified WRR scheduling technique to be adaptive for our work and it is better in computational load and this technique supports classified packets for scheduling. The modification is done in a way that the classified packets are mapped into the queue in such a way that real-time traffic hold high priority and non-real-time traffic have low priority and after that the scheduler performs forwarding those queued packets.

In a priority scheduling multiple queues are assigned to a network interface and each queue have been determined by the scheduler [55].

WRR scheduler determines the number of packets dequeued from each queue with the proportion of their weight and forwards packets until all packet have been sent. In each round of the scheduler the weight of the queues should be updated in order to help the next round to effectively determine the next weight.

The priority to applications can ensure network stability during congestion by allowing us to assign routing protocol and other types of network control traffic to the highest priority queue. It serves one class of traffic different from other class of traffic and allows to organize buffered packets [53].

Algorithm 4.2 shows the WRR scheduler that helps to manage classified packets by computing service weight of each class.

```
Input: Classified Packets
While each queue is not empty
   For each queue in each round
     Check current queue weight of high priority queue
     and low priority queue
     Check traffic priority
     Compute queue weight from each queue
     If queue weight is maximum
       Serve traffic
     Else
       Serve traffic based on their priority
     End if
     Reset weight for each service class
   End for
End while
Output: Forward Packets
```

Algorithm 4.2: *Priority Scheduling Algorithm*

4.2.4 Admission Control

The purpose of admission control is the admission of only as many new users in the system that can maintain QoS promised to applications already admitted along the route [56]. Admission control mechanism restricts the access to the network based on resource availability in order to prevent network congestion, service degradation, connection failures, etc. for a new incoming data flow [57]. A new request is accepted only if there are enough resources to meet the QoS requirements without violating the QoS of already accepted requests. Admission control implements the decision algorithm that a router or host uses to determine whether a new flow can be granted the requested QoS without impacting the earlier guarantees [58].

Admission control is used when the resource in the communication system is limited [59]. When a new request comes, this mechanism should determine whether the resources of the system meets the requirement of the new incoming request. The admission of the new request should not decrease the performances of the accepted request. If the resources of the system can meet the requirement, the new task or request will be admitted, otherwise it will be rejected. In order to maintain a high quality of service, good admission control should accurately decide the acceptance or rejection by the resources of the system, which will maximize the utilization of the resources in the system.

We can also define admission control in such a way that it is the process of regulation of the network flow which is used to limit the flow on the network. Which means if there is no path that could not meet the requirement of the QoS, it will be rejected else accepted. When the source node receives a request, it will first determine the resource consumption of this requested flow to accept or reject.

Nowadays the need to use applications in wireless communication system specially in mobile Ad hoc networks become increasing in a higher demanding rate. As such, congestion may occur during communication or transmission. As a result, admission control should be an alternative in such kind of environment for utilizing resources and to handle the imbalance between the available resources and the resources requested by the application. This technique is used to prevent the classes of services being overloaded.

Admission control is a key component for QoS delivery in IP networks because it determines the extent to which network resources are utilized and whether the contracted QoS characteristics are delivered [60].

In our proposed solution, to provide QoS for a certain traffic flow, admission control is used. Admission control is used to estimate the available bandwidth to be able to utilize the network resources available in the channel for those applications based on the state of the network. Therefore, the estimation of the available resources allows those intermediate nodes to know the resources along the path.

The available resources in admission control should be more than the amount of data that is going to be transmitted and such kind of criteria is handled by this admission control technique which means the threshold value of the network should be greater than or equal to the requested amount of data. It is not possible to use beyond the threshold value of the available resources. It is known that congestion may occur during imbalance of the available resources and the demand for the resources. Therefore, this mechanism is used to determine whether admitting or rejecting the flow based on the available resources.

When the number of channels used exceeds the threshold then new flow from low-priority will not be admitted [61]. In order to guarantee QoS, specially in the case of voice, the capacity of the network should not be exceeded, and this condition may not be satisfied when we apply traffic differentiation. It is essential to provide admission control which should be responsible for the entry of new network flows. As a result, the required QoS will be met [62].

In mobile Ad hoc networks resource capacity is limited, and it is difficult to provide service beyond the capacity of this limited resource in different class of services. If the available resource is not estimated by considering the transmission amount of the data which means how much bandwidth will consume the data supposed to transmit, the flow may become useless due to the occurrence of congestion on the network.

The new incoming flows in admission control are not allowed for transmission if the threshold is less than the amount of flows. This kind of problem should be handled by the admission control to manage the traffic in a precise manner. Generally, real-time and non-real-time packets are differently treated from the resource available in the channel. Hence, the resource is the most important factor in determining QoS to prevent admitted traffic from delay. The algorithm for admission control is shown in Algorithm 4.2 [59].

```
Input: Flow of Packet

For all the incoming flows Do:

     If Incoming Flow of Traffic <= Threshold

       Admit the Incoming Flow

     Else

       Reject the Requested Flow

     End If

End For

Output: Accept/Reject the Flow
```

Algorithm 4.3: *Algorithm for Admission Control*

4.2.5 PAODV Routing

As mentioned in the literature review in Chapter Two AODV is a reactive routing protocol or on-demand routing protocol that initiates route discovery to locate the destination node when the source node needs a route to a destination. In this protocol, the source node requests a route request message to be set up to the destination and a route reply is sent back directly to the source node either by the destination itself or any other intermediate node that has a current route to the destination. On the receiving side, intermediate nodes update their routing table for the reverse route to the source. The forward route to the destination is updated on receiving a route reply packet. AODV uses sequence numbers to determine the timeliness of each packet and expire timers are used to keep the route entries fresh. Link failures are propagated by a route error message from the node of a link break to the source node for that route. When the next hop link breaks RERR packets are sent to a set of neighboring nodes that communicate over the broken link with the destination.

PAODV is just a name we gave for the modified version of AODV. In our proposed approach, some extensions are added to the route discovery mechanism of AODV based on the priority of those application's traffic types and we give this modified AODV a name PAODV. The rout request mechanism is controlled by using admission control technique and the priority of the applications is done by using WRR priority scheduler as mentioned earlier.

Figure 4.2 shows the original RREQ message format for AODV that uses hop count.

Type (8bit)	Flags and Reserved (16 bit)	Hop count(8bit)
RREQ ID		
Destination IP Address		
Destination Sequence Number		
Originator IP Address		
Originator Sequence Number		

Figure 4.2: *Route Request (RREQ) Message Format of original AODV*

Route Discovery Mechanism in the Proposed Solution (PAODV)

In this proposed system, the route discovery procedure is modified to support QoS in such a way that the node should do an admission control procedure to check the resources that applications require for admitting the flow or to establish the route request message. As long as we want to have safe communication or transmission of packets the route stability is essential and mandatory. Therefore, the route discovery mechanism of the protocol should be safe.

In this research the route discovery process has been completed after admission control has made decision on the flow. The prioritized packets are scheduled with their corresponding service type using priority scheduler and then admission control admits those traffics to be routed as we can see on Figure 4.1.

As described in Chapter Three there are several QoS routing solutions based on mobile Ad hoc routing protocols. In this research the routing performance is improved and the QoS becomes better. In the protocol we modify the RREQ header in the routing table to hold the information about the bandwidth information for applications. The modification we made on the RREQ affects the route discovery process. In our system whenever the source node wants to communicate with another node it depends on the QoS extension made on RREQ on the routing table. After admission control is done the path is discovered using this RREQ that contains bandwidth information. If overflow occurs new incoming packets will be dropped by considering the state of the network resource available on the channel. In this research, the routing table contains entries composed of the information about the message to be transmitted through the transmission channel.

Real-time applications require QoS metrics like low packet loss, higher packet delivery ratio, low jitter and high throughput than non-real-time applications that is why bandwidth information taken into consideration. The modified version of the original AODV shaded to hold the bandwidth information is shown on Figure 4.3. This information helps in estimating the available resources. In order to make the protocol convenient for QoS, AODV is extended by adding additional field to contain bandwidth information. The bandwidth information added to the RREQ message format enables the protocol to know the maximum and minimum bandwidth currently available to perform.

Type (8bit)	Flags and Reserved (16 bit)	Hop count (8bit)
RREQ ID		
Destination IP Address		
Destination Sequence Number		
Originator IP Address		
Originator Sequence Number		
		Bandwidth Information

Figure 4.3: *Modified Route Request Message Format*

This information helps the system to know the current node's bandwidth information that enables the protocol to support QoS.

4.2.6 Channel Access

MAC layer plays an important role in coordinating channel access among the intermediate nodes in the transmission system [63]. It is essentially important especially for mobile Ad hoc networks. Because of broadcast nature of the radio medium in mobile Ad hoc networks, MAC protocols for allocating the multi-access medium and resolving potential collision among various stations have great influence on the performance of the network.

The channel access is used to access the scheduled packets and transmit those packets towards the wireless transmission media in order to help those nodes to communicate with one another in such a way that the order of transmission in packets is accessed through this component. Those prioritized packets transmitted to the wireless channel are extracted according to the order of their level of priority. This helps other nodes to collaborate and to be accessed by the other nodes using the MAC layer and the collision will be reduced because of the proper packet transmission. The

MAC layer performs the channel access to the medium and reliable data transmission. As long as the scheduled packets are not empty the buffered packets should be fetched and transmitted with the help of the channel access.

The MAC forwards to the channel during transmission and it arranges those packets for transmission to another node. MAC uses IEEE 802.11 protocol stack to perform the entire task. The channel is sensed when the source is ready to transmit or broadcast the packets to another node. Each node acts as a router to perform the communication between those nodes. As such, the MAC channels should cooperate among themselves to forward the packets to the appropriate channel based on the state of the channel.

Chapter 5 : Implementation and Analysis of Experimental Results

5.1 Overview

MANETs are popular telecommunications technology that can be applied to almost any environment having fast deployment configuration and no need for any underlying support of infrastructure [64]. Nodes communicate among themselves to accomplish the objective of the intended mission in the entire communication system.

MANETs can also be expressed as ubiquitous wireless communication systems which can communicate anytime and anywhere. QoS provisioning in MANETs is a challenging task due to self-organized, infrastructure-less organization, nature of distributed, and contention to channel access in competition between multiple applications.

In this thesis to address QoS in MANETs, we designed an approach to improve and provide suitable QoS technique for MANET applications as discussed in Chapter Four that would be an effective QoS solution. The proposed system is able to support QoS requirement for real-time applications considering their level of importance regarding serving low-priority packets fairly. Therefore, it is essential to develop and simulate such kind of QoS supported systems which will be able to serve high and low priority service classes to make the communication system more affordable for adequate preferential treatment for delay sensitive applications.

Applying the traffic priority and admission control technique helps in improving the routing performance in mobile Ad hoc networks. When we compare priority across multiple applications, for instance, when we take real-time and non-real-time applications, real-time applications have restriction on packet delay and loss during communication of nodes. For example, voice is real-time applications and file transfer is non-real-time applications have different properties as well as needs on network resources. Those diverse applications need efficient QoS traffic monitoring by using priority between those scheduled packets in order to reduce packet loss and delay. It ensures fair distribution of resources among real-time and non-real-time packets to achieve priority as well as fairness regulation on resource in the communication system. The delay allowed for those different flow of applications should be considered. In our proposed solution we used specific routing protocol called AODV routing protocol with modifications to support QoS in mobile Ad hoc networks.

This Chapter deals with the implementation of the proposed solution on a simulation environment, and the tools we have used during prototype implementation of the proposed system are described in detail. The performance of the proposed system is evaluated and compared with AODV using QoS performance measuring metrics and analytical discussion on the results from our point of view. The goal of the simulation is to design, simulate and analyze the performance of the proposed system by comparing it with AODV using QoS metrics. The empirical study of the performance results is analyzed from experimental analysis using the trace file generated during simulation run time. This trace file contains the events which occur during communication between nodes when we run the system.

The general conclusion on the performance is drawn from the analytical observations obtained from the simulation. The proposed system is evaluated by using various QoS metrics such as packet delivery ratio, end-to-end delay, throughput, jitter, and packet loss to evaluate the effectiveness whether achieving the objectives.

5.2 Simulation Tools and Development Languages

In this Section simulation environment and development languages that we used in implementation and evaluation of the proposed solution are described in detail.

It is known that simulation plays an important role in mobile Ad hoc networks to design, implement and evaluate real-world communication scenarios that help us to evaluate the performance of the communication system in a scientific way. It is an important technique used to realize and show how the real-world communication system operates.

Simulation is widely used in exploring and modeling different communication systems for many application areas like military applications, education, videoconference, etc. It used to deploy real network communication systems as well as reducing the cost of building and testing any proposed model by doing experimentation.

There are lots of different network communication simulators that have been developed with their own powerful features that cover different characteristics of MANETs. Among the major network communication system simulation tools are NS-2, GLOMOSIM, OMNET++, QUALNET, J-SIM, OPNET, and TOSSIM [65, 66].

All these aforementioned simulation tools have their own characteristics that should be considered to make simulation for MANETs environment. Therefore, selecting the proper simulator by assessing which one will provide optimum performance and suitability of network for implementing and evaluating the proposed work is the critical factor that should be considered in simulation of many communication systems specially in MANETs.

According to the survey which has been made on those simulation tools, NS-2 is better in simulation of wireless mobile Ad hoc networks and we select this for our simulation purpose [66].

5.2.1 NS-2

NS-2 is an event-driven simulation tool which is proved to be useful in studying the dynamic nature of network communication systems. It is used in simulation of wireless as well as wired network communication systems. This is a very important tool which provides users with a way of specifying network protocols and simulation of their corresponding characteristics and analyze their efficiency. It has gained popularity in the network communication system research community starting from its foundation in 1989 due to its flexibility and modular nature. It is developed at the University of California and Cornell University [67].

NS-2 involves various modules to help test several network components and it is implemented using two types of languages, namely C++ and OTCL (Object Oriented Tool Command Language). OTcl script is used to manage parameters of protocols as well as assembling network objects and C++ is used to implement modules and algorithms of the protocols. Although there are several network simulators with different features in different aspects, NS-2 is the most popular simulator in academic research for its advantages of open source and useful library of different network components [68]. It is advisable to use these C++ classes to set up a simulation using Tcl script. However, advanced users may find these objects insufficient and they need to develop their own C++ classes and use OTcl configuration interface to put together objects instantiated from these class [67].

NS-2 has advantages over other network simulators because it runs on various operating systems such as Linux, Sun Solaris, MacOS X, and Windows if a package called Cygwin has been installed. One great benefit of using Tcl in NS-2 is that there is no need to recompile the simulator between different simulations because it allows setting up topology, link bandwidth, traffic sources, etc., from the OTcl scripts [69].

5.2.2 AWK

To process and extract important information from huge amount of data or text, a scripting language is necessary and essential. From those scripting languages for our research we prefer to use AWK programming language because it is suitable for processing huge amount of network trace files to produce performance results.

The trace file is meaningless unless the analysis is done in such a way that meaningful result is obtained from the output file. For each QoS metrics we wrote AWK script that obtains the performance information from the trace file. The analyzed results obtained for each QoS metrics are recorded using Excel and finally plotted as a graph. We wrote AWK script to find QoS metrics values by obtaining network communication information from the trace file. The sample AWK scripts we wrote for QoS metrics for our analysis is included in Appendix B.

5.3 Prototype Implementation and Simulation Models

a. Prototype Implementation

This Section contains the detailed explanation of the prototype implementation and the simulation scenarios. To show the communication we use mobile nodes and the application service discipline on each mobile node is based on priority to ensure low delay for sensitive traffic class. Simulation of this work also considers the fundamental elements that may affect the performance of the system.

The goal of the proposed model is to decrease packet loss and delay for real-time traffic by monitoring priority on the network resource. To generate the scenarios to assess our proposed system we used Tcl scripting language with different number of mobile nodes. Those mobile nodes exchange information with each other during the simulation. Network simulation scenarios help us to design the network topology, and the traffic flow model between mobile nodes. The simulations created are used to evaluate the performance of the system from different perspectives. The simulation is created in such a way that different number of mobile nodes are randomly generated in different scenarios (10, 20, and 30) to observe the combined impact on those number of nodes in the performance evaluation of experimental results. This scenario helps us to analyze and know the performance of the system in varying number of nodes. The area size of mobile nodes is 1800m by 840 m based on the random waypoint mobility pattern for each scenario generated for communication between those intermediate nodes. The number of packets transmitted through the network is 1000 bytes and the threshold value of 50 packets per second.

The simulation for mobile nodes are randomly generated by considering the application areas that the system will be implemented randomly as far as achieving the QoS with respect to the mobility nature of MANETs. In the simulation the movement of each node is determined randomly and starts communicating to a destination node that has been randomly selected. We believe that randomness is the best way that helps to analyze the impact of the network mobility and it is the best way to know the performance of the communication system. Furthermore, the unpredictable and irregular mobility nature of MANETs is better controlled in using the mobility model. The sample simulation model which has been written to show the scenarios in our work is presented in Appendix A.

In MANETs lower priority packets may take higher precedence than high priority packets which may create congestion on the network as far as transmission unfairness and impact on delay sensitive high priority traffic. Therefore, it is crucial for many of the communication systems in managing such kind of diverse traffic applying priority by classifying them with respect to their nature of sensitivity that will minimize network congestion as well as fair distribution of resources among different service classes. As a result, delay on sensitive information will be reduced in MANETs. To do so the following brief information shows how the prototype for the entire simulation has been developed.

NS-2 provides traffic generation mechanism that helps for simulation and create traffic related to an OTcl function. The traffic generator is a built-in function in NS-2 that helps to create traffic for an experiment. The traffic generation object is defined and connected with the UDP agent. Applications are created using CBR traffic which operates on top of transport layer of UDP agent and passes for classification. The agent helps as a traffic generator for simulation.

The prototype is done based on the assumption that each connected mobile node in MANETs performs and serves the tasks based on the Type of Service among packet class. In this thesis classifying traffic is the basis to enable QoS in MANETs to treat class of traffic in simplified and organized manner. Algorithm 4.1 of Chapter Four is applied to classify the generated traffic in terms of first high priority and second low priority class based on the IP header information called ToS field and put in the related queue. Which means real-time traffic class is assigned as first priority and non-real-time traffic class assigned as second priority and scheduling is done by using weighted round robin scheduling algorithm. Voice data is real-time information which get higher precedence than non-real-time data and the real-time information is identified by using Differentiated Service Code point (DSCP) defined header information in the ToS. Each mobile node is capable of configuring itself dynamically because of its self-administrative property and enabled to traffic classification and identify packets on the basis of this DSCP which indicates the class of category in type of service. The service requirement of real-time traffic is higher than non-real-time traffic and real-time high priority traffic is distinguished from non-real-time low priority traffic in separate queue which is determined by the traffic classification.

The queues are handled using the scheduler which determines and ensures fair resource sharing among real-time and non-real-time traffic for robust QoS operation regarding the information provided at the packet header by computing weight for each traffic class that realizes real-time packets to get better quality.

The mode of Weighted Round Robin (WRR) scheduler expressed in Algorithm 4.2 of Chapter Four is applied to schedule service class which effectively balances the network resource in each separate queue. The weight of each queue is checked in each round to ensure the superiority of the real-time traffic keeping fairness for non-real-time traffic for QoS. The weight of service class is acquired from each separate queue in each service round for QoS transmission until the queues are empty. The packet delay is reduced, and network throughput is increased due to the proper packet scheduling. The proposed approach helps in managing traffic so as to meet QoS requirement of low delay for real-time traffic. The level of fairness characteristics of this thesis is capable of ensuring to minimize congestion on the traffic flow in the entire network maximizing the packet delivery and preventing starvation of low priority packets.

To enable the traffic for routing the service has admitted with admission controller. The use of this mechanism benefits the traffic from congested which means, if the capacity of the network resource is beyond the entire traffic being transmitted, the traffic will be rejected that helps to prevent the network from congestion.

Besides the classification and scheduling, the routing protocol in MANETs is the most fundamental part to provide QoS and the routing protocol is modified to help the routing functionality in such a way to have information about the available bandwidth on paths which creates stable route for packets. This information is added to the packet header in RREQ as discussed in Chapter Four. The mechanism for route construction is the same as normal AODV but RREQ is modified. The information is added to recognize where the specified header belongs in the entire RREQ header of the protocol that defines the structure of the protocol header. When modification is done to hold the attribute of packet membership, variables for the new field are defined. The protocol uses different message formats in order to discover the route and from those messages discussed in the Literature review RREQ is the most important message for route computation. Whenever route is needed, RREQ is disseminated to get the path to the destination and after the route discovery process is performed, the transmission stars to send packets on the available links. The modified AODV protocol is used for routing packets according to the bandwidth information in RREQ which is specified to disseminate the packets through paths which is suitable for QoS constraint. This information contains the maximum and minimum bandwidth requirement for applications. The bandwidth information in the routing path is checked for packet being transmitting which satisfies the desired QoS requirement. Whenever a mobile host starts to communicate, it disseminates RREQ message regarding the desired QoS requirement for the traffic flow. In addition to use the former sequence number AODV identifies which route is free and available for transmitting packets through the routes, the protocol uses the minimum and maximum bandwidth capacity to carry the traffic is an important information capable of supporting QoS requirement in MANETs.

The connection information on each mobile node is provided by hello message broadcasted by active nodes on the entire network. The choice of this protocol in this thesis is its special feature in providing better routing in such a way that reduces routing load as far as its wide acceptance and used by researchers in different mobile Ad hoc networks application areas. In addition to that the quality of the communication system in MANETs entirely depends up on the type of protocol selected.

The packets are transmitted to intermediate nodes via channel access which regulates the channel usage and every node uses this feature to share the channel. Therefore, the standardized MAC employed in our proposed solution is IEEE 802.11b which is adopted in MANETs that is capable of operating in multi-hop network communication systems. We use this channel access mechanism because it helps the performance of our proposed solution which is explicitly considered to mitigate contention of accessing the channel in mobile Ad hoc networks. Each mobile host listens to the channel in order to help the protocol to track the path to the intermediate mobile nodes with the help of channel access mechanism. Therefore, each mobile node is capable of communicating with each other.

Figure 5.1 shows mobile nodes created before starting to communicate with each other. Figure 5.2 shows the entire simulation model in communication among intermediate mobile nodes for 20 mobile nodes. It shows the relationship between organization of mobile nodes. Every node has its own transmission range. The circles indicate the range of transmission among nodes which means that when the mobile nodes are in the same transmission range they can exchange packets with each other; otherwise, they communicate via other nodes indirectly. When the developed system is run, the mobile nodes are displayed and ready to communicate among themselves. In addition to communication of nodes among themselves, a trace file is created when communication starts, and the trace file contains all the information about the events and characteristics every second which helps to study the performance of the system. The network setting for nodes is dynamically adjusted by themselves because of their nature of self-administrative.

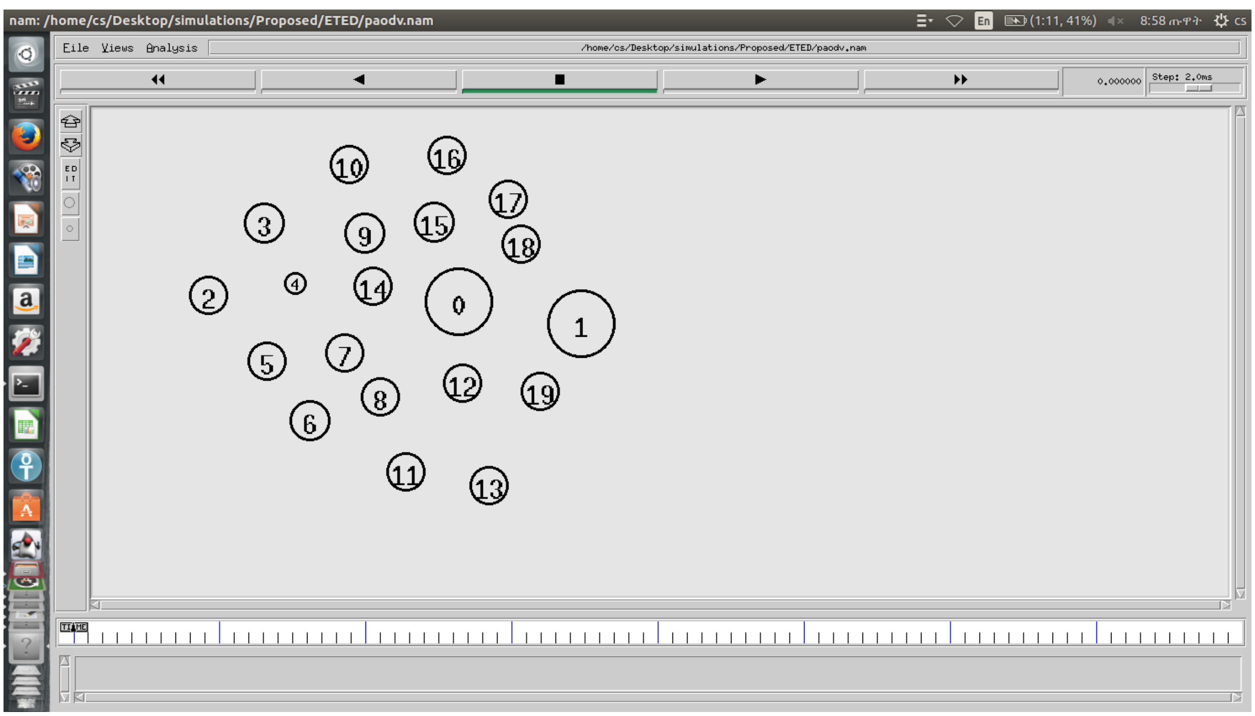

Figure 5.1: *MANET Initial Node Position*

For better communication between those intermediate nodes the most important thing we have been targeted to implement is management of resource in each node in such a way that priority is given for those applications based on their sensitivity to delay regarding starvation of applications that are non-sensitive to delay. Every node transmits packets from source to destination based on the applications classified, scheduled, and admitted for routing using MANET protocol.

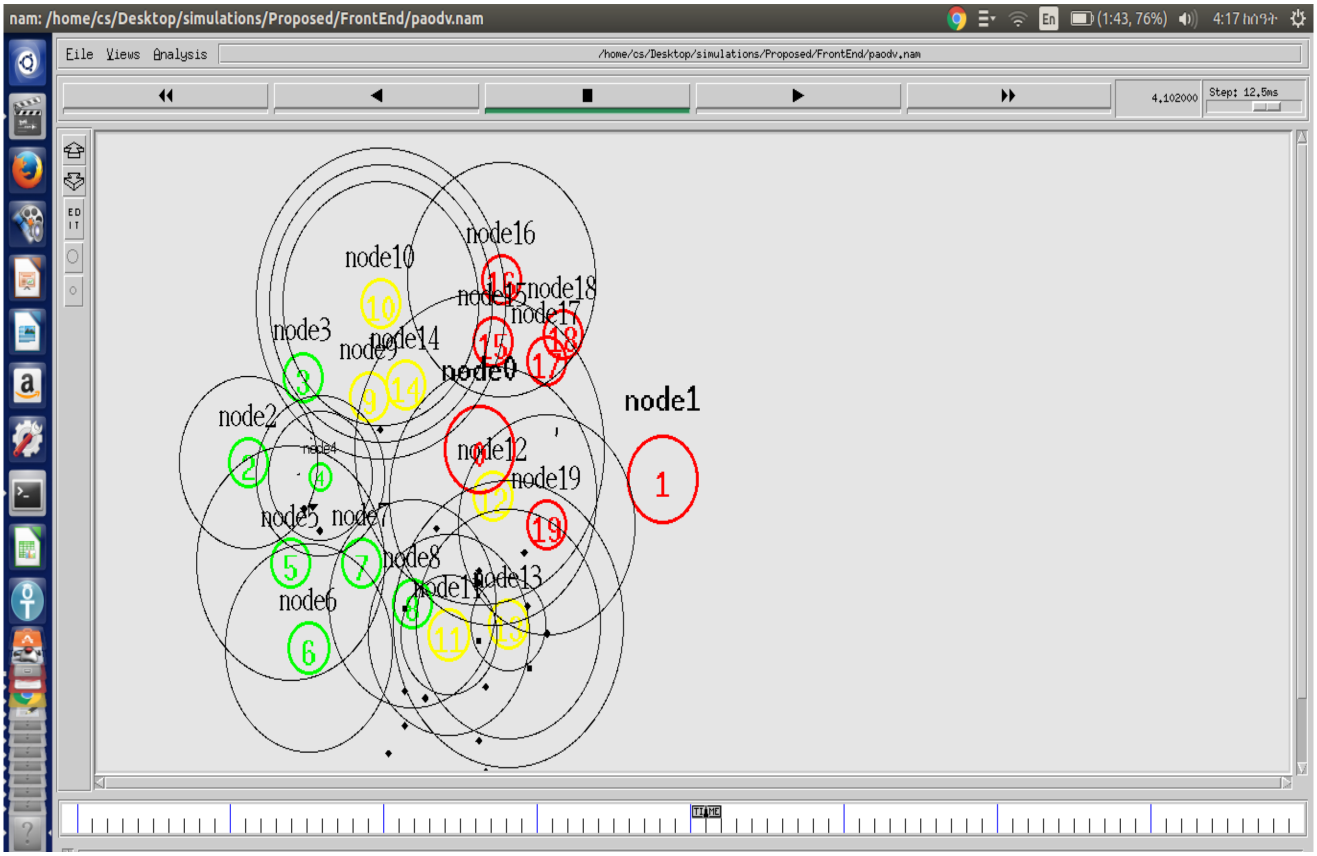

Figure 5.2: *Snapshot from the Simulation*

The packet scheduler determines the transmission priority order in such a way that real-time packets get special treatment over non-real-time packets along with fairness among this diverse traffic. After priority scheduling on application is performed and admitted for transmission, the route discovery mechanism is formulated using MANET routing protocol. The classified and scheduled packets on each node that are allowed to be transmitted are forwarded to the intermediate mobile nodes based on their priority in order to deliver packets that sensitive to delay. The priority level of each service class considers fairness and each node forwards those packets regarding the traffic behavior criterion for the purpose of increasing throughput and reduce delay when congestion occurs on the entire network communication system. Mobile nodes route the packets from the source to the destination through the entire nodes.

Each mobile node supports QoS defined for each traffic class of service with level of priority in organized treatment of network resource usage. Therefore, each node may have real-time and non-real-time traffic and traffic is treated based on their priority. Classified services are adjusted by the scheduler which controls the order in which packets are fairly served by enforcing better QoS priority for high priority traffic over low priority traffic class. The resource sharing among high priority and low priority traffic is fair.

Generally, after traffic classification and scheduling are computed, admitted traffic are routed using MANET protocol that dynamically distribute packets towards other nodes among paths. The path is determined by the MANETs protocol. This is the general transmission procedure on the entire communication system. The route discovery process of the protocol starts whenever communication is needed on the network because of its on-demand characteristics of the protocol. The scheduled packets are disseminated towards the intermediate nodes whenever communication starts, and the principal objective of the thesis is transition of packets on the basis of priority.

b. Simulation Models

Mobility is the determinant factor that differentiates MANETs from other network communication systems. The mobility model in the communication system determines the movement of nodes. Therefore, in MANETs simulation analysis should be supported with appropriate mobility model that better fits and enables to help QoS provisioning. From various mobility models in wireless communication system, in this research we use random waypoint mobility model.

All mobile nodes are generated using random waypoint mobility model for the movements of mobile nodes and this random waypoint mobility model is widely used by the community of researchers in MANETs [70]. In this model the movement of nodes is random that means the movement is determined by random waypoint model where each node is distributed randomly in the simulation area, and then moves towards the destination due to the special characteristics of MANET nodes in spatial independence and not restricted geographically. In addition, the most important reason to use random waypoint mobility model is because it is the most widely used mobility model which helps the research community to evaluate network communication systems in MANETs [71]. This random waypoint mobility model is also followed widely in mobile ad hoc network and it represents the motion of nodes in any direction and speed for a real-world scenario [72]. Therefore, node connectivity in MANETs is dependent on the mobility model.

Antenna model also has a special benefit on QoS in MANETs. Therefore, the antenna model we used in this simulation is omni-antenna which has better antenna model for QoS in MANETs and most preferred antenna model on this area of research. The major simulation parameters in the simulation scenarios are illustrated in Table 5.1.

Table 5.1: *Setting Parameters of the Simulation*

Simulation Parameter	**Value**
Type of Channel	Wireless
Network Interface	Phy/WirelessPhy
Mobility Model	Random Waypoint
Channel	IEEE 802.11b
Antenna Model	Omni antenna
Number of Mobile Nodes	10, 20, and 30
Traffic Model	CBR Traffic
Number of CBR connections	13
Speed of mobility	2-12.5 m/s
Simulation time	30s
Packet rate	8-350 Kbps
Packet size	1000 bytes
Area of Deployment	1800m*840m

c. Development Environment

The experimental setting of the development environment that is used in the simulation of our proposed system is carried out on Ubuntu operating system. Our system is developed and tested on laptop computer. The Laptop Computer we used is Intel Core (TM) i3-4005U processor with 1.70GHz speed, 4.0GB RAM, 500GB hard disk capacity, with Ubuntu 16.04 and Windows 10 operating systems installed in parallel.

5.4 Analysis of Experimental Result and Performance Evaluation

To investigate and measure the performance of the proposed solution, extensive simulation experiments have been performed on various simulation scenarios. Analyzing the result is the most important final step in simulation. Therefore, the performance of the proposed system is observed in terms of different QoS metric described in detail below.

To observe the effect of random mobility nature for each varying number of scenarios we run three times during simulation and the average of the values obtained is taken as the result for our analysis and finally plotted as a graph. The analysis of the result is based on the average of three runs with those set of parameters in order to obtain the average simulation results in the proposed solution as well as in AODV protocol. Working simulation on NS-2 contains processes like design simulation, running simulation, and finally post simulation process. Therefore, in this Section post simulation process analysis has been made that we collect relevant performance results from the entire experiment. The reason to run three times during simulation is because the mobility nature of mobile nodes, running the system three times and take the average is the best way to get average representative quality result on the proportion of varying network density. The main goal of this experiment is to make evaluation analysis on the performance comparison between the proposed system and the normal AODV protocol to show the effectiveness of our proposed solution in terms of different QoS metrics.

5.4.1 Simulation Results and Discussion

QoS metrics are base parameters for measuring the quality or performance of network communication systems. To demonstrate the effectiveness of the proposed solution there must be a metrics to measure the effectiveness of communication system. QoS metrics are the performance evaluation metrics for the proposed system. Generally, the proposed solution is measured using the execution set of realistic QoS measurements in order to realize how the communication system is efficient and effective using important QoS metrics discussed below. This Section presents results of analytical expressions depending on adopted QoS metrics simulated under different number of mobile node network scenarios and plotted graphically to show the obtained result comparably clearly.

In order to know the performance of MANETs that QoS support achieves the desired result, we have evaluated the performance of the proposed solution and AODV along with different network scenarios. On each QoS metrics we use Priority Aware QoS in AODV (PAQoSAODV) to express and show the proposed solution on the plotted graph. The result is analyzed based on the trace file obtained.

5.4.2 Trace File Analysis

Whenever we want to measure the performance of certain communication system there should be an information obtained during simulation that helps to analyze the performance in accordance with the characteristics of QoS metrics and trace file is a common information obtained during simulation to perform performance measurement tasks in MANETs. We obtained trace file from the traffic being transmitted during simulation which contains information about the events occurred on the entire network communication system and this trace file has its own format to process. The detailed format is described in Table 5.2.

Trace file is a text file which contains all relevant network information for each event occurred in the entire simulation period which is used for further performance analysis and this step is called post simulation analysis. The transmitted and dropped packet information are recorded between those nodes during simulation and obtained as output file to be processed further.

Table 5.2: *Trace File Format*

Symbol	**Description**
+	An event for packet enque
-	An event packet deque
R	An event for packet reception
D	An event for packet drop
T	What time tracing the packet is created

Based on this important information we wrote AWK script to calculate the performance of the network communication system. Figure 5.3 shows how the QoS result (PDR and end-to-end delay) looks during result analysis.

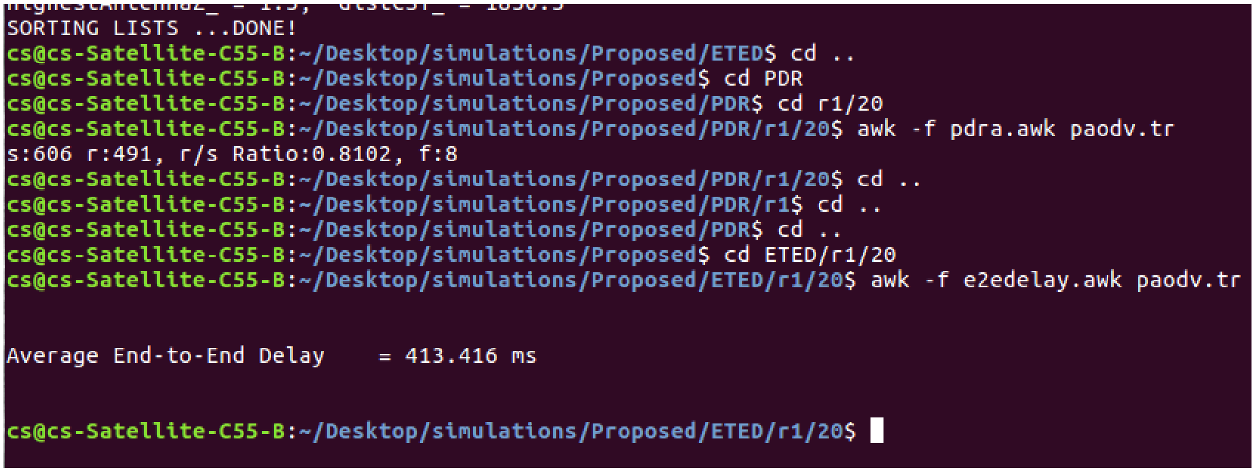

Figure 5.3: *Sample QoS Results*

a) Packet Delivery Ratio (PDR)

Packet delivery ratio is the ratio between the total packets successfully received by the receiver to the total packets sent by the sender. This metric shows the level in which how much data have been delivered to the destination from the packets sent from the source. This metrics shows how the system is effective in delivery of sent packets since as the number of dropping packets increases the packet delivery ratio decreases. The performance may have decreased due to congestion and dynamic mobility nature of the MANET nodes in the network. In the reverse, as the number of packets sent to the destination increased the packet delivery ratio also increases which means the system is better.

Figure 5.4 shows the performance of the network tested as a function of number of mobile nodes. The mobile Ad hoc network has been modeled with varying number of mobile nodes ranging from 10, 20, and 30. The simulation represented by running three times and each point on the line depicted on the graph represents an average of three runs in each number of mobile nodes then the average has been extracted for better performance analysis.

As we observed the obtained result from the comparison depicted on the graph, it indicates that the proposed approach has higher packet delivery ratio than AODV which means the proposed solution has better QoS performance than AODV. This is because the resource in the entire communication system has been utilized using QoS mechanism which is able to provide intended services effectively in the proposed solution by reducing packets being dropped. Whereas, in the standard AODV protocol congestion of traffic occurs because QoS techniques are not included which degrades performance. As more number of packets reach to the destination the ratio between sent packets and received packets reaches to one. Generally, in this thesis, we can conclude that the proposed system has better QoS performance in PDR.

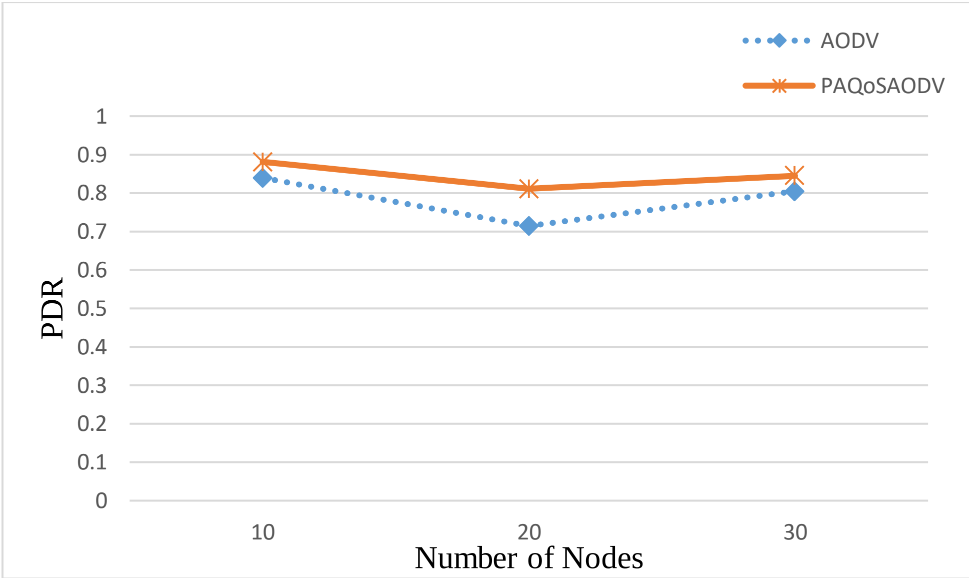

Figure 5.4:*Result for PDR QoS parameter with respect to Varying Nodes*

b) End-to-end Delay

End-to-end delay is a QoS metrics which indicates the average time taken for a packet from source to destination. This delay occurs during the route discovery process and it is measured in seconds.

Figure 5.5 shows the analysis of average end-to-end delay which indicates the efficiency of both AODV and the proposed solution. As we can observe from the graph the prosed solution has less end-to-end delay than AODV. As the number of node density increases the end-to end delay of the proposed solution becomes better. The end-to-end delay of AODV has increased because it has no QoS support and could not be able to handle the occurrence of high congestion during communication. It means that when AODV is used delay is observed due to congestion in the communication system.

Mobility affects the efficiency of both the proposed system and AODV but QoS mechanism in the proposed solution allows to reduce the effect of mobility over the service flows on the entire network. At the very beginning on the graph the end-to-end delay is almost the same and as the number of nodes increases the performance becomes different for both scenarios.

So, the proposed solution reduces the end-to-end delay which improves the performance. Therefore, comparatively the proposed QoS solution has lowest end-to-end delay and better performance than the normal AODV protocol.

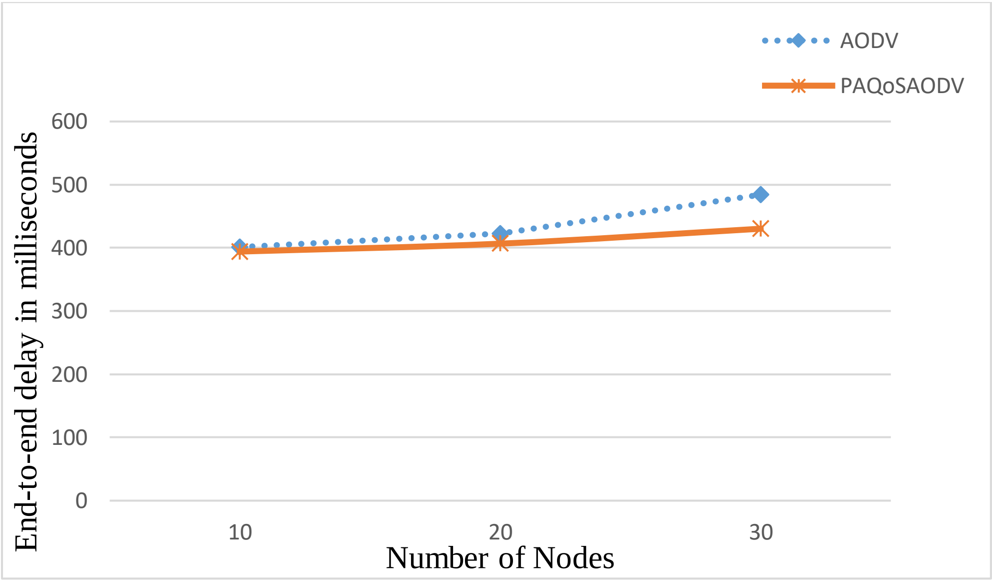

Figure 5.5: *End-to-end delay Evaluated over Number of Nodes*

c) Throughput

Throughput is described as the rate of processing packets and it is a measure of how many packets are processed by a system over the simulation time which is measured in Kbps. The higher the throughput the better the performance of the communication system.

Figure 5.6 illustrates the average throughput with respect to different number of nodes. It is observed that the proposed solution has higher throughput than AODV and as the number of nodes increases the throughput value also increases. Based on the observation we also noticed that the throughput increases when the density of nodes increases. Therefore, the overall performance of network throughput is better in our proposed solution for all number of mobile nodes.

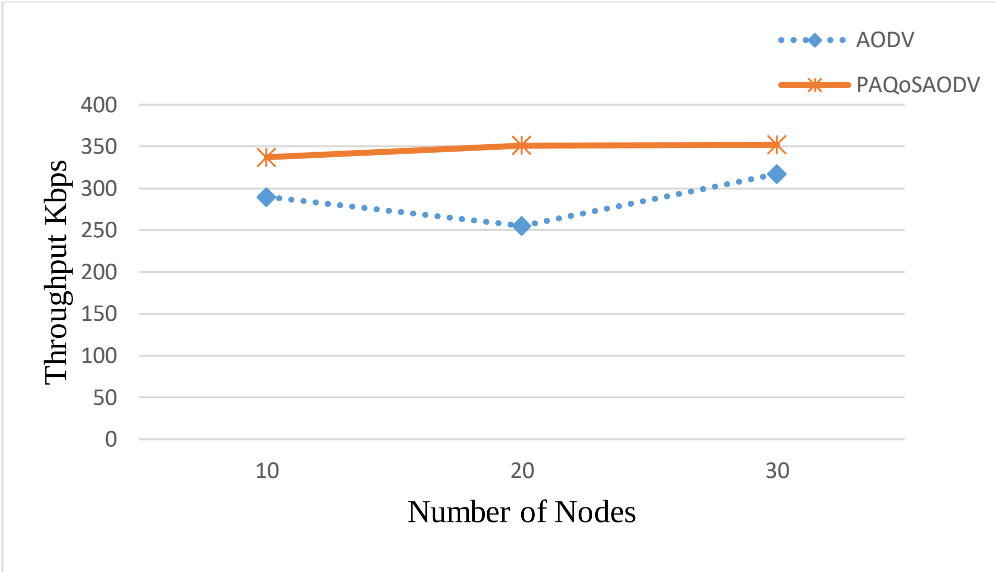

Figure 5.6: *Throughput Comparison Evaluated over Number of Nodes*

d) Jitter

Jitter is a metrics which measures the variation of arrival time between consecutive packets. We can also define jitter as delay variation of packets in the communication system. Instead of remaining constant the delay between packets may vary which may occur due to congestion of traffic.

Figure 5.7 is a comparison between the average jitter of the proposed solution and AODV. From the figure, it is observed that the variation in the delay of received packets is lower in our proposed solution than AODV. Therefore, performance in terms of jitter is better in the proposed solution.

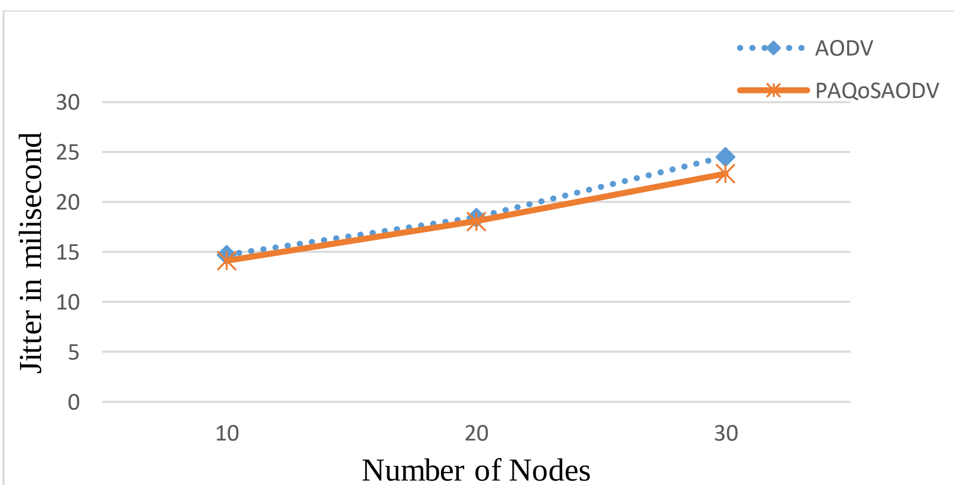

Figure 5.7: *Jitter Comparison Result Evaluated over Number of Nodes*

e) Packet Loss

Packet loss is the metric to know the total number of lost packets in the network. This metric is the most important QoS metric which demonstrates the effect of durable and stable approach on total number of lost packets in the network. Packet loss is the term used to define the packets that do not arrive along the path at the intended destination due to overloading. It may occur due to network congestion. Therefore, the lower packet loss rate, the better the delivery of packets sent.

As we observe in Figure 5.8 the proposed system has better performance in this QoS metrics. As far as we know, when the number of mobile nodes increases the computational load on the entire network also increases which may affect the coordination among the intermediate mobile nodes. So, under this circumstance the proposed system reduces the number of lost packets because of the QoS techniques applied to be adaptive on the system.

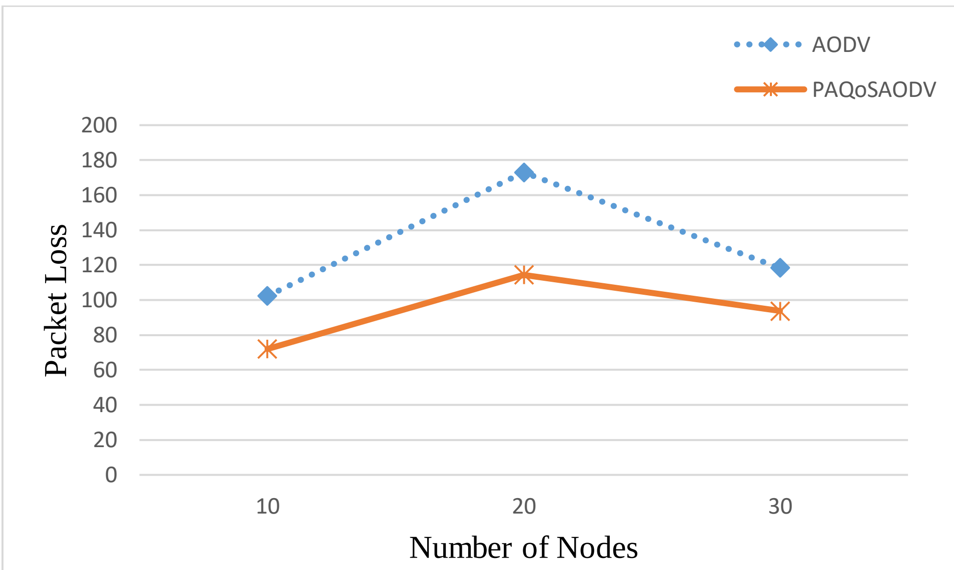

Figure 5.8: *Packet Loss Graph Evaluated Over Number of Nodes*

5.5 Summary

The proposed solution has been analyzed through experimental simulation to test its effectiveness in achieving the objectives of better QoS in MANETs. We have used NS-2 simulation tool as a platform for simulation using 10, 20, and 30 number of mobile nodes with in the area size of 1800m by 840m. The performance evaluation QoS metrics we used are PDR, end-to-end delay, throughput, jitter, and packet loss. The comparative analysis of the conducted experimental evaluation we made is between the proposed solution and AODV. Finally, it has been demonstrated that in each of the QoS metrics the proposed solution performs better.

From our analysis, QoS requirement on type of traffic class has a significant impact on the performance of the communication system in MANETs as far as preventing the network communication system from being overloaded by different traffic flow that may result in resource consumption.

Chapter 6 : Conclusion and Future Work

6.1 Conclusion

This Chapter comprises of conclusion, contributions and the future works.

Nowadays, with the growing need of mobile devices as well as progress in wireless communication systems, mobile Ad hoc network is widely used in different application areas. Wireless mobile Ad hoc networks are distributed systems in which those wireless mobile nodes are dynamically configured. MANETs are constructed dynamically in the absence of infrastructure and each node acts and operates as a host and as a router to forward traffic to destinations. This technology is the core component and important in wide variety of application areas. The characteristics of easily deployments, speed of development, and reduced dependency on the infrastructure are the main reasons to use mobile Ad hoc networks. It enables the mobile nodes to interconnect without any pre-existing communication infrastructure or without any central coordination. MANETs are composed of its own protocol and network management mechanism. In this research applications, challenges and characteristics of mobile Ad hoc networks are discussed as far as providing the detail analysis on protocols in MANETs studied so far.

QoS is an important solution to increase the performance coverage of wireless communication systems in MANETs in such a way that important information requires more service quality. MANETs are used in enormous application areas like military battlefield, education, emergency operations like earthquake, and on ship to ship communication at logistics. Due to this importance, research on QoS in MANETs is growing. It is the most important factor in this wireless communication system area of research to optimize network resource and decrease unnecessary packet overload avoiding unnecessary packet delay.

QoS is a measure of the performance of the communication system in wireless mobile Ad hoc network communication in order to provide better services to required applications. It provides guaranteed service for different QoS metrics. It is a technique which can be expressed in such a way that manages network resources to satisfy application requirements in the communication system. So, it is an important aspect that should be considered in mobile Ad hoc networks to improve the performance of the communication system.

As mentioned above the aim of QoS in MANET communication systems is to provide guaranteed service for diverse applications. There are various research attempts which have been made to enhance QoS in MANETs, but yet there is no appropriate QoS in MANETs because, QoS provisioning is challenging task due to MANET's nature of self-administration, node mobility and dynamic topology change, multi-hop communications, unpredictable link properties, limited resources, contention for channel access, and lack of central coordination.

To provide a guaranteed QoS different applications should be controlled using a certain QoS mechanism for the purpose of communication between nodes in MANETs. For example, voice is the most important communication we prefer in emergency scenarios than low priority applications like non-real-time applications. It should be supported with a certain priority to help real-time coordination and monitoring high priority traffic scenario over non-real-time traffic. However, congestion may limit the effectiveness of this voice communication when we use it with non-real-time applications. Therefore, service priority is beneficial and necessary to serve the applications based on their sensitivity to delay providing QoS.

In our study Priority Aware QoS Based on AODV over MANETs is proposed and the ultimate goal of this research is to schedule packets according to the requirement of applications in order to preserve the real-time traffic over non-real-time traffic. We have investigated different ideas on this research area so as to achieve our objectives. The existing QoS in MANETs support or provide services without taking into account of the service type as well as resource which means real-time applications will not be guaranteed for priority. Differentiating those traffic using QoS improvement mechanisms and schedule in proper way is the main goal of this research. We can realize that real-time applications are characterized by their nature of delay sensitivity than non-real-time applications which means high priority packets need to have high throughput and low end-to-end delay.

The traffic is classified using the classification mechanism that classifies traffic according to the service type and enables those applications to be scheduled by the scheduler based on their level of priority by considering which class of service the flow of packets belongs to. This scheduler performs all the packet scheduling work and forwards the packets based on their weight of priority. Scheduling is a mechanism which performs packet priority which reduce the delay for sensitive services. Hence, one of the most important aspect for QoS is to optimize the resource for applications based on the state of the network and determine which traffic should be processed first.

This research work attempts to realize QoS in mobile Ad hoc networks. The proposed solution improves QoS metrics which improves the entire network performance and fulfil the delay requirement of diverse applications. The reason for obtaining better results is because applications are treated independently according to their priority applied on the services when congestion occurs in the network.

Finally, in order to assess the performance of our proposed approach an extensive simulation has been conducted and examined on NS-2 by considering number of mobile nodes. The statistical data for performance evaluation is extracted from the trace files using AWK script and depicted on graphical representation. The analysis of performance comparison has been made by varying number of nodes and the simulation result observed indicates that the proposed approach significantly improves the performance from the analyzed facts identified during simulation in terms of sets of execution QoS metrics.

6.2 Contribution

The overall study of this research has the following contributions:

- ❖ Prioritize traffic to adapt the process of routing better in mobile Ad hoc networks and provide delay requirement of those delay sensitive applications by managing traffic effectively in such a way that the properties of traffic are specified.
- ❖ During route computation the work reduces resource consumption as far as serving service priority. In addition to this because of using scheduling congestion is decreased and packet delay also reduced.
- ❖ More adaptive in transmitting real-time applications without starving non-real-time application and the most significant feature of our proposed solution is able to maximize the number of packets arrived at the destination due to the treatment of traffic regarding their QoS requirement.
- ❖ An extensive simulation study has been made showing significant improvement in reducing end-to-end delay encountered by different traffic applications.

6.3 Future Work

Although the performance of the proposed solution is better, there are further research works that need extra investigation. The following are promising research directions beyond the scope of this study recommended that help to realize more robust QoS in MANETs.

- Integrate the proposed solution with security mechanisms by using advanced cryptography techniques and ensuring as well as improving security of the communication system between those intermediate mobile nodes in MANETs. The malicious nodes should be detected before attack has been done on the entire communication system using advanced security mechanisms to ensure the cooperation among mobile nodes. Furthermore, malicious attackers may hijack nodes in MANETs and may complement normal mobile nodes which generate unwanted traffic. Therefore, suspicious activities that may interrupt the entire communication should be managed by intrusion detection system and distributed key management system in order to protect the group of nodes connected in the communication system from intruder.

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Appendix A: Sample Source Code of the Simulation

```
set opt(chan)           Channel/WirelessChannel    ;# channel type
set opt(netif)          Phy/WirelessPhy       ;# networkinterface type
set opt(mac)            Mac/802_11b                 ;# MAC type
set opt(ant)            Antenna/OmniAntenna        ;# antenna model
set opt(ifqlen)         50                        ;# max packet
set opt(nn)             10                    ;# number of mobilenodes
set opt(rp)             PAODV                      ;# routing protocol
set opt(x)              1800          ;# X dimension of topography
set opt(y)              840           ;# Y dimension of topography

### Setting The Simulator Objects

      set ns_ [new Simulator]
      #create the nam and trace file:
      set tracefd [open paodv.tr w]
      $ns_ trace-all $tracefd
      set namtrace [open paodv.nam w]
      $ns_ namtrace-all-wireless $namtrace  $opt(x) $opt(y)
      set topo [new Topography]
      $topo load_flatgrid $opt(x) $opt(y)
      create-god $opt(nn)
      set chan_1_ [new $opt(chan)]

      set dist(5m)  7.69113e-06
      set dist(9m)  2.37381e-06
      set dist(10m) 1.92278e-06
      set dist(11m) 1.58908e-06
      set dist(12m) 1.33527e-06
      set dist(13m) 1.13774e-06
      set dist(14m) 9.81011e-07
      set dist(15m) 8.54570e-07
      set dist(16m) 7.51087e-07
      set dist(20m) 4.80696e-07
      set dist(25m) 3.07645e-07
      set dist(30m) 2.13643e-07
      set dist(35m) 1.56962e-07
      set dist(40m) 1.56962e-10
      set dist(45m) 1.56962e-11
      set dist(50m) 1.20174e-13
      Phy/WirelessPhy set CSThresh_ $dist(50m)
      Phy/WirelessPhy set RXThresh_ $dist(50m)
                  $ns_ node-config -adhocRouting $opt(rp) \
                   -llType $opt(ll) \
                   -macType $opt(mac) \
                   -ifqType $opt(ifq) \
                   -ifqLen $opt(ifqlen) \
                   -antType $opt(ant) \
                   -propType $opt(prop) \
                   -phyType $opt(netif) \
```

```
                 -topoInstance $topo \
                 -agentTrace ON \
                 -routerTrace ON \
                 -macTrace ON \
                 -movementTrace ON \
                 -channel $chan_1_
      set n0 [$ns_ node]
      set n1 [$ns_ node]
      set n2 [$ns_ node]
      …
      set n9 [$ns_ node]
      set opt(seed) 0.1
      set a [ns-random $opt(seed)]
      set i 0
      while {$i < 5} {
      incr i
      }
###  Setting The Initial Positions of Nodes
      $n0 set X_ 513.0
      $n0 set Y_ 517.0
      $n0 set Z_ 0.0
      $n1 set X_ 1445.0
      $n1 set Y_ 474.0
      $n1 set Z_ 0.0
      ….
      $n9 set X_ 334.0
      $n9 set Y_ 647.0
      $n9 set Z_ 0.0
      $ns_ at 0.75 "$n2 setdest 379.0 349.0 20.0"
      $ns_ at 0.75 "$n3 setdest 556.0 302.0 20.0"
      $ns_ at 0.20 "$n4 setdest 309.0 211.0 20.0"
      $ns_ at 1.25 "$n5 setdest 179.0 333.0 20.0"
      $ns_ at 0.75 "$n6 setdest 139.0 63.0 20.0"
      $ns_ at 0.75 "$n7 setdest 320.0 27.0 20.0"
      $ns_ at 1.50 "$n8 setdest 505.0 124.0 20.0"
      $ns_ at 1.25 "$n9 setdest 274.0 487.0 20.0"
      ## Setting The Node Size
      $ns_ initial_node_pos $n0 125
      $ns_ initial_node_pos $n1 125
      $ns_ initial_node_pos $n2 70
      $ns_ initial_node_pos $n3 70
      $ns_ initial_node_pos $n4 40
      $ns_ initial_node_pos $n5 70
      $ns_ initial_node_pos $n6 70
      $ns_ initial_node_pos $n7 70
      $ns_ initial_node_pos $n8 70
      $ns_ initial_node_pos $n9 70
```

```
      #### Setting the Labels For Nodes
      $ns_ at 0.0 "$n0 label n0"
      $ns_ at 0.0 "$n1 label n1"
      $ns_ at 0.0 "$n2 label node2"
      $ns_ at 0.0 "$n3 label node3"
      $ns_ at 0.0 "$n4 label node4"
      $ns_ at 0.0 "$n5 label node5"
      $ns_ at 0.0 "$n6 label node6"
      $ns_ at 0.0 "$n7 label node7"
      $ns_ at 0.0 "$n8 label node8"
      $ns_ at 0.0 "$n9 label node9"
      $n2 color green
      $ns_ at 0.0 "$n2 color green"
      $n3 color green
      $ns_ at 0.0 "$n3 color green"
      $n4 color green
      $ns_ at 0.0 "$n4 color green"
      $n5 color green
      $ns_ at 0.0 "$n5 color green"
      $n6 color green
      $ns_ at 0.0 "$n6 color green"
      $n7 color green
      $ns_ at 0.0 "$n7 color green"
      $n8 color green
      $ns_ at 0.0 "$n8 color green"
      $n9 color yellow
      $ns_ at 0.0 "$n9 color yellow"
      $n0 color maroon
      $ns_ at 0.0 "$n0 color maroon"

      $n1 color maroon
      $ns_ at 0.0 "$n1 color maroon"

      ## SETTING ANIMATION RATE
$ns_ at 0.0 "$ns_ set-animation-rate 12.5ms"

   #  COLORING THE NODES
$n9 color blue
$ns_ at 4.71 "$n9 color blue"
$n5 color blue
$ns_ at 7.0 "$n5 color blue"
$n2 color blue
$ns_ at 7.29 "$n2 color blue"
$n6 color blue
$ns_ at 7.59 "$n6 color blue"
$n9 color maroon
$ns_ at 7.44 "$n9 color maroon"
$ns_ at 7.43 "$n9 label TTLover"
$ns_ at 7.55 "$n9 label \"\""
#### traffic generation and Establishing Communication between mobile
nodes
      set udp0 [$ns_ create-connection UDP $n0 LossMonitor $n9 0]
```

```
$udp0 set fid_ 1
set cbr0 [$udp0 attach-app Traffic/CBR]
$cbr0 set packetSize_ 1000
$cbr0 set interopt_ .07
$ns_ at 0.0 "$cbr0 start"
$ns_ at 4.0 "$cbr0 stop"
set udp1 [$ns_ create-connection UDP $n0 LossMonitor $n8 0]
$udp1 set fid_ 1
set cbr1 [$udp1 attach-app Traffic/CBR]
$cbr1 set packetSize_ 1000
$cbr1 set interopt_ .07
$ns_ at 0.1 "$cbr1 start"
$ns_ at 4.1 "$cbr1 stop"
set udp2 [$ns_ create-connection UDP $n8 LossMonitor $n9 0]
$udp2 set fid_ 1
set cbr2 [$udp2 attach-app Traffic/CBR]
$cbr2 set packetSize_ 1000
$cbr2 set interopt_ .07
$ns_ at 2.4 "$cbr2 start"
$ns_ at 4.1 "$cbr2 stop"
set udp3 [$ns_ create-connection UDP $n0 LossMonitor $n7 0]
$udp3 set fid_ 1
set cbr3 [$udp3 attach-app Traffic/CBR]
$cbr3 set packetSize_ 1000
$cbr3 set interopt_ 5
$ns_ at 4.0 "$cbr3 start"
$ns_ at 4.1 "$cbr3 stop"
set udp4 [$ns_ create-connection UDP $n0 LossMonitor $n6 0]
$udp4 set fid_ 1
set cbr4 [$udp4 attach-app Traffic/CBR]
$cbr4 set packetSize_ 1000
$cbr4 set interopt_ 5
$ns_ at 4.0 "$cbr4 start"
$ns_ at 4.1 "$cbr4 stop"
set udp5 [$ns_ create-connection UDP $n7 LossMonitor $n8 0]
$udp5 set fid_ 1
set cbr5 [$udp5 attach-app Traffic/CBR]
$cbr5 set packetSize_ 1000
$cbr5 set interopt_ 5
$ns_ at 4.0 "$cbr5 start"
$ns_ at 4.1 "$cbr5 stop"
set udp6 [$ns_ create-connection UDP $n5 LossMonitor $n7 0]
$udp6 set fid_ 1
set cbr6 [$udp6 attach-app Traffic/CBR]
$cbr6 set packetSize_ 1000
$cbr6 set interopt_ 5
$ns_ at 4.0 "$cbr6 start"
$ns_ at 4.1 "$cbr6 stop"
set udp7 [$ns_ create-connection UDP $n4 LossMonitor $n2 0]
$udp7 set fid_ 1
set cbr7 [$udp7 attach-app Traffic/CBR]
$cbr7 set packetSize_ 1000
```

```
$cbr7 set interopt_ 5
$ns_ at 4.0 "$cbr7 start"
$ns_ at 4.1 "$cbr7 stop"
set udp8 [$ns_ create-connection UDP $n4 LossMonitor $n3 0]
$udp8 set fid_ 1
set cbr8 [$udp8 attach-app Traffic/CBR]
$cbr8 set packetSize_ 1000
$cbr8 set interopt_ 5
$ns_ at 4.0 "$cbr8 start"
$ns_ at 4.1 "$cbr8 stop"
set udp9 [$ns_ create-connection UDP $n4 LossMonitor $n3 0]
$udp9 set fid_ 1
set cbr9 [$udp9 attach-app Traffic/CBR]
$cbr9 set packetSize_ 1000
$cbr9 set interopt_ 5
$ns_ at 4.0 "$cbr9 start"
$ns_ at 4.1 "$cbr9 stop"
set udp10 [$ns_ create-connection UDP $n4 LossMonitor $n2 0]
$udp10 set fid_ 1
set cbr10 [$udp10 attach-app Traffic/CBR]
$cbr10 set packetSize_ 1000
$cbr10 set interopt_ 5
$ns_ at 4.0 "$cbr10 start"
$ns_ at 4.1 "$cbr10 stop"
set udp11 [$ns_ create-connection UDP $n4 LossMonitor $n5 0]
$udp11 set fid_ 1
set cbr11 [$udp11 attach-app Traffic/CBR]
$cbr11 set packetSize_ 1000
$cbr11 set interopt_ 5
$ns_ at 4.0 "$cbr11 start"
$ns_ at 4.1 "$cbr11 stop"
set udp12 [$ns_ create-connection UDP $n5 LossMonitor $n6 0]
$udp12 set fid_ 1
set cbr12 [$udp12 attach-app Traffic/CBR]
$cbr12 set packetSize_ 1000
$cbr12 set interopt_ 5
$ns_ at 4.0 "$cbr12 start"
$ns_ at 4.1 "$cbr12 stop"
#ANNOTATIONS DETAILS
$ns_ at 0.0 "$ns_ trace-annotate \"MOBILE NODE MOVEMENTS\""
#$ns_ at 4.59 "$ns_ trace-annotate \"PACKET LOSS AT NODE10\""
$ns_ at 4.71 "$ns_ trace-annotate \"NODE10 CACHE THE DATA\""
### PROCEDURE TO STOP
proc stop {} {

                  global ns_ tracefd
                  $ns_ flush-trace
                  close $tracefd
                  exec nam paodv.nam &
                  exit 0}
puts "Starting Simulation........"
$ns_ at 25.0 "stop"
```

```
        $ns_ run
} }
```

Appendix B: Source Code of AWK Script

AWK Script for calculating of End-to-End Delay

```
BEGIN {

    seqno = -1;

#    droppedPackets = 0;

#    receivedPackets = 0;

    count = 0;

}

{
    if($4 == "AGT" && $1 == "s" && seqno < $6) {

          seqno = $6;

    }
#    else if(($4 == "AGT") && ($1 == "r")) {

#            receivedPackets++;

#    } else if ($1 == "D" && $7 == "tcp" && $8 > 512){

#            droppedPackets++;

#   }

    #end-to-end delay

    if($4 == "AGT" && $1 == "s") {

          start_time[$6] = $2;

    } else if(($7 == "cbr") && ($1 == "r")) {

        end_time[$6] = $2;

    } else if($1 == "D" && $7 == "cbr") {

          end_time[$6] = -1;

    }
```

```
}

END {

    for(i=0; i<=seqno; i++) {

          if(end_time[i] > 0) {

              delay[i] = end_time[i] - start_time[i];

                  count++;
        }

            else

            {

                  delay[i] = -1;

            }

    }

    for(i=0; i<=seqno; i++) {

          if(delay[i] > 0) {

              n_to_n_delay = n_to_n_delay + delay[i];

        }

    }

   n_to_n_delay = n_to_n_delay/count;

     print "\n";

#    print "GeneratedPackets = " seqno+1;

#    print "ReceivedPackets = " receivedPackets;

#    print "Packet Delivery Ratio      = "
receivedPackets/(seqno+1)*100
#"%";

#    print "Total Dropped Packets = " droppedPackets;
```

```
    print "Average End-to-End Delay    = " n_to_n_delay * 1000 "
ms";

    print "\n";}
```

AWK script for Packet Delivery Ratio

```
BEGIN {
        sendLine = 0;
        recvLine = 0;
        fowardLine = 0;
}
$0 ~/^s.* AGT/ {
        sendLine ++ ;
}
$0 ~/^r.* AGT/ {
        recvLine ++ ;
}
$0 ~/^f.* RTR/ {
        fowardLine ++ ;
}
END {
        printf "s:%d r:%d, r/s Ratio:%.4f, f:%d \n", sendLine,
recvLine, (recvLine/sendLine),fowardLine;
}
```

Declaration

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other university, and that all source of materials used for the thesis have been duly acknowledged.

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