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INVESTIGATING MULTIPLE QoS METRICS FOR THE IMPROVEMENT OF AODV PROTOCOL IN MANET

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Approval sheet

This Independent Research entitled as "INVESTIGATING MULTIPLE QoS METRICS FOR THE IMPROVEMENT OF AODV PROTOCOL IN MANET" has been read and approved as meeting the preliminary research requirements of the School of Computing in partial fulfillment for the award of the degree of Master in Computer Networking,

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List of Figures and Tables

Acronyms, abbreviation and Terminology

Acronyms

MANET…………....	Mobile Ad hoc NETwork
AODV……………..	Ad hoc On demand Distance Vector
DSR………………...	Dynamic Source Routing
TORA………………	Temporarily Ordered Routing Algorithm
VANET…………….	Vehicular Ad hoc NETwork
QoS………………...	Quality of services
NAV	Network Allocator Vector

Terminologies

Routing……………...	The process of selecting the best path and forward packet
Link………………...	Connection between two nodes
Path…………………	Route between two nodes (source and destination) a collection of Links

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Abstract

Mobile ad hoc network is a type of wireless network known by their characteristics such as infrastructure less, node mobility, frequent topology change, lack of central coordination and hence along. They are an aggregation of nodes capable of wireless communication. During the communication, node acts as sender, receiver or as a relay between the source and destination. Hence the node acts as both end devices and routers. These characteristics make it hard routing in MANET. Providing routing based Quality of Services needed by applications is more challenging due to instability of links between those nodes. In this paper, we have proposed QoS enabled AODV protocol, which selects a path based on residual bandwidth, delay and jitter on the path. To calculate the residual bandwidth we used hello bandwidth estimation. Delay and jitter on the path also calculated from hello message and putted on RREQ messages during the route discovery process. Finally, route reply part of AODV will make the decision of route selection based on the value of path cost; which in turn calculated from the value of bandwidth, delay and jitter. In case two paths have equal path cost, the selection will be based on hop count. We simulate our proposed approach on NS2 simulator. We have evaluated the efficiency of our protocol based on the packet loss ratio, throughput, end to end delay, and overhead. We have also compared original AODV and our QoS enabled AODV using the above mentioned parameters (packet loss ratio, throughput and end to end delay) and achieved competitive result; yet our approach showed little bit overhead.

CHAPTER ONE

INTRODUCTION

1.1 Background and Justification

Wireless communication is one of engineering success of twenty first century. Today, due to wireless communication we are visioning anywhere, any time communication system; which allows any person to communicate with others from anywhere at any time. Many systems today depend on wireless communication. In some application wireless is the only means of communication. As an example, in the place affected by natural disaster where all communication infrastructure is destroyed the only easily and immediately deployable network will be wireless communication network. Such type of wireless network which can be deployed without pre-installed infrastructure is called Ad hoc networks. There are different types of such networks, but the widely known is Mobile Ad hoc Networks (MANET). MANET is a type of Ad hoc networks, which contains nodes (which can be any mobile devices) which are connected to each other in peer to peer mode. In MANET a given node can be source, destination or intermediate node. The intermediate node acts like router for a reason that they are responsible of forwarding packets to the next node. So the nodes can act as normal end devices or as a router. This means such networks contain mobile router which makes routing a difficult task to achieve a better result in MANET. Creating a routing protocol as well as providing quality guaranteed services are the main challenges and hot research issues in MANET today. The challenges came from MANET characteristics; such as mobility which results in frequent topology changes; also limited resources of mobile nodes participated in the networks and so on.

As a result the first attempts to create a routing protocol for MANET focused on providing best effort services [1].Best effort service means delivering a packet to destination without considering the quality of the link, it only considers distance or number of hops to select the path. However, minimum hop count may not always be the best path for they may be congested. MANET protocols broadly categorized into reactive and proactive. In proactive protocols, route is discovered and maintained in the table. Whether the node has data to transmit or not, the route will be discovered and updated frequently. Due to frequent changes of their topology such protocol must update their route table frequently, which leads to control signal overhead and computational complexity. Unlike to proactive protocol reactive protocols discover routes on demand. A route discovery process started whenever nodes have data deliver. This makes reactive protocols to have less control signal overhead and less computational complexity [2].

One example of reactive routing is AODV protocol. AODV is developed to provide best effort services; it is on demand protocol, which is based on a table. Hence it has a capacity of caching routes whenever they are discovered. An author of [3] performed performance analysis for AODV, OLSR, GRP and DSR and stated that AODV is the best among all by average performance. Also in paper [4] the researchers compared AODV and DSR performance and argued that AODV is better than DSR. However, both AODV and DSR select the best route based on hop counting only [4]. Yet, routing protocols relying on hop count only might not select the optimal path for application such as multimedia application; as routing can also be significantly affected by such factors as bandwidth, delay, jitter, node mobility, residual energy of a node and so on.

Taking the above drawbacks of routing protocols based on hop count into account, quality of services (QoS) provision is required in MANET. According to John A et al [30], Quality of services (QoS) can be defined broadly as network capability that resulted in the user or application satisfaction. According to the authors QoS can be provided by resource reservation on the router. In resource reservation QoS approach defined quality needed by different application and send to the router then the router classify application based different QoS class and reserve resources for each class. This method is used in infrastructure based network and is difficult to apply to network like MANET since it needs more resources. For example, in MANET link is not stable so it is difficult to reserve resources on such networks. The other reason why they are not appropriate for MANET is that this approach adds much control traffic overhead. Since QoS determination and routing uses different control traffic. The other QoS method uses QoS routing which select route based on quality demand of a given application. QoS routing is selecting path during routing which satisfy QoS requirement of application. QoS routing is the most widely used QoS provision in MANET. It integrates the process with routing. In our paper we are going to use this approach. In this paper we enhanced AODV protocol to include QoS; which selects path based on bandwidth, delay and jitter.

In original AODV quality of service is not considered at all. But there are different proposed mechanisms by researchers to incorporate QoS in this protocol. In the paper [6] AODV enhanced to include alternate best path to the destination as back up route. If the first route is broken, the second route will be used. They called this protocol as backup route AODV (BR-AODV). This protocol did not consider any additional QoS parameters other than the number of hops. In the paper [7] maximum delay and minimum bandwidth requirement added as metrics to select the route. In the paper [8] residual node energy of a node is considered as a QoS parameter so AODV is extended to include this. Also in paper [9] multipath concept is added to AODV, in this extension of AODV multiple routes is discovered in a single Route Discovery process. This multiple route can be used as an alternative during route maintenance.

The most popular improvement of AODV is Qos-AODV explained in [10], in which bandwidth is estimated from the hello messages of AODV. After the bandwidth is calculated it is added to the RREQ packet of AODV along with the number of hops. According to the paper if two paths have equal hop count; the one with high bandwidth will be selected.

1.2 Statement of the problem

As explained section 1.1 above AODV was first coined to provide best effort services. As the application of mobile Ad hoc Network increased in different areas, it is necessary to improve the quality of the path selected in order to provide Quality services. Applications such as multimedia streaming needs quality link which has good bandwidth, less delay and jitter. For traditional networks, we have a different provision mechanism, for example, differentiated services and integrated services are used widely. Both work on the method of reserving resources for different applications. Reserving resources for QoS services needs additional overhead, and hence consume more energy; and it is not appropriate for energy constrained devices in MANET networks.

The widely used QoS approach in MANET is routing based on the quality of the link: i.e. the path is selected not only because it has a minimum hop count but also fulfill some quality metrics such as bandwidth and delay. In other words, we should look also to the link quality in addition to its distance. As already described in section 1.1 most of QoS routing available in MANET today is only by taking bandwidth or delay in to consideration individually. In this paper, we proposed QoS enabled AODV protocol, which selects best paths based on available bandwidth, delay and jitter. Here we put into consideration on how to determine those QoS metrics. We proposed hybrid approach in which QoS metrics are determined proactively by using hello messages yet route discovery is on demand as it is in the original protocol. We followed this to decrease potential initial route discovery delays.

1.3 Objectives of the research

1.3.1 General objection of the research

The general objective of this research is to investigate QoS metrics for enhancement Ad hoc Network On demand Vector (AODV) routing protocol to incorporate Quality of services needed by Application.

1.3.2 Specific objectives

- Doing Literature review on QoS routing in MANET and QoS routing metrics for different application in context of MANET.
- Identify an appropriate QoS metrics
- Integrate the identified QoS metrics in AODV
- Design algorithm for computing the routing path by considering QoS metrics.
- Implement the prototype using simulation software
- Evaluate the performance of the improved protocol with already exist one.
- Conclude and state future direction.

1.4 Methodology

To complete this study the following phase followed thoroughly:

a. Literature review

- We reviewed of relevant literature from different books, journal articles, conference papers and resources from internet on:
  - ✓ The detail concept of QoS Routing in MANET is reviewed
  - ✓ Related works QoS enabled AODV protocol with different metrics are critically reviewed.
  - ✓ We also reviewed in detail QoS metrics gathering techniques used in different paper.

b. Design

- Based on the finding from literature review we developed QoS enabled AODV protocols
  - ✓ Adopting QoS gathering techniques we reviewed in literature
  - ✓ We have enhanced AODV protocol by incorporating QoS metrics identified so that route selecting decision will be based on the value of these QoS metrics.

c. Implementation and evaluating results

- ✓ We Simulated the enhanced AODV on NS2 simulator
- ✓ We compared it with an original AODV protocol to evaluate its performance.
- ✓ We evaluated our new protocol with the original in terms of packet loss ratio, throughput, and end to end delay

1.5 Expected output/outcome

The outcome of the research will be Quality of service optimized AODV protocol. This outcome has two significances. The first one is for industry; the prototype protocol on simulator can be upgraded to full software product and can be incorporated into mobile devices. Second academician or researchers interested in the area of MANET routing can use this paper to know the future trends in QoS routing of MANET. The other significance of our research is if it is implemented it, may play a significant role to create networks at disaster and emergency area. On the application level in disaster area using the outcome of this research enables people around the disaster to communicate efficiently.

1.6 Thesis organization

The thesis was organized as follows: in the second chapter, we are going to present a literature review to elaborate MANET and QoS concepts. In the third chapter, we have presented works related to our work. In chapter four we have presented our architecture of our enhanced protocol and describe each component in detail. An algorithm that is executed by each component also explained in this chapter. We have also elaborated our works by presenting different scenario in this chapter. Then chapter five is about simulation of our work and result. Finally, in chapter six we have presented the conclusion and recommendations.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Wireless technology is a big technological advancement of mankind. It enables communication from anywhere at any time. Wireless communication can have two forms. The first one is infrastructure mode the second one is infrastructure less. The first one uses dedicated network equipment, while the second one is the form of wireless network in which end devices usually called nodes create a direct communication line to each other. Usually nodes are mobile so we call such networks as Mobile Ad hoc NETwork (MANET). According to [2] MANET is in use starting from early internet revival during ARPANET project. Their use increased as we use them in many application environments and do not need any infrastructure support. Collaborative computing and communications in smaller areas (buildings, organizations, conferences, computer lab, etc.) can be set up using MANETs. Communications in battlefields and disaster recovery areas are other examples of application environments.

Similarly, another potential application of MANET is communications using a network of sensors or floats over water. As different application and devices now widely start using MANET another challenge starts; that is, providing Quality of Services (QoS) for those applications. Supporting Quality of Services (QoS) in a MANET environment is a big challenge because of the characteristics of such networks, such as mobility of node, frequent change of topology resource limitations of nodes and soon [11]. QoS support in MANETs encompasses issues at the application layer, transport layer, network layer, medium access control (MAC) layer, and physical layer of the network infrastructure [1]. Our paper focuses on QoS at network layer, i.e. selecting the best path during routing based on QoS metrics. So in this chapter, we are going to review some of the concept and work related quality of service in MANET. Different QoS metrics, and the way of acquiring them is going to be discussed.

2.2 Mobile Ad hoc NETwork (MANET)

Ad hoc network is one flavor of wireless networks. The wireless network can be defined as a network of devices that have the computing power and connected to each other with wireless communication modules. The communication between the devices can be infrastructure based or infrastructure less. Infrastructure based network always uses central management devices which control the communication between this end device. Such devices can be a router, access point or base station. In the infrastructure less network devices are connected and share resources based on some purposes and we call such network ad hoc networks. Ad hoc is a Latin phrase for "for this purpose" indicating that this network has some specific purposes during their creation.

The concepts of wireless or mobile network is not new; rather when packet switching technology was introduced with the ARPANET in 1969, the department of US defense immediately understood the potential of packet switched technology to interconnect mobile nodes in the battle field. It is the DARPA packet radio project, which starts in the early 70's that helped to establish the notion of mobile ad hoc networking. This is a technology that enables untethered, wireless environments where there is no wired or cellular infrastructure such as battlefield, disaster recovery and soon. [12]

Ad hoc networks have different types. In the following section we presented different categories of ad hoc networks shortly, then after we focused on mobile ad hoc networks (MANET) and discuss the challenge and early approach for the challenge.

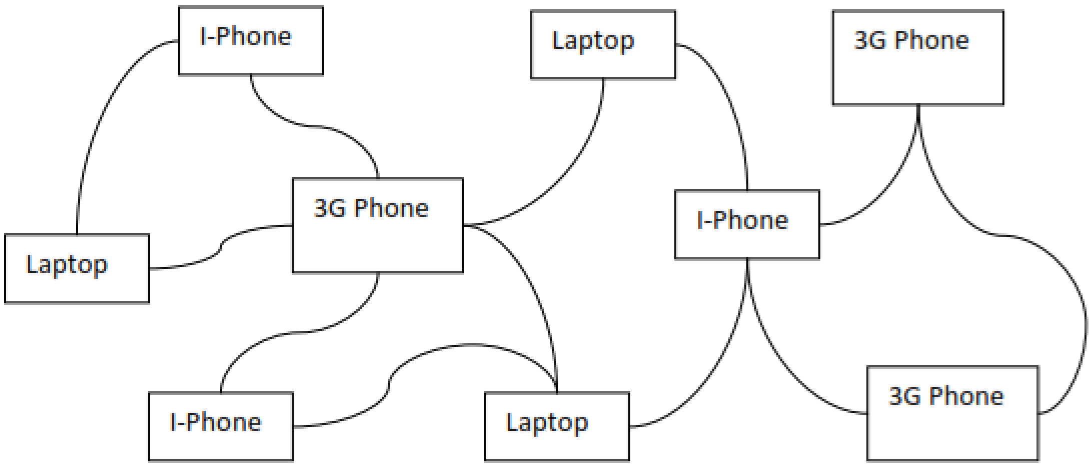

Figure 2 1 *Overview of Ad hoc network [13]*

Types of ad hoc networks

Vehicular ad hoc networks (VANET): this type of ad hoc networks contains a group of vehicles that have wireless communication modules. They are mobile at car speed so any routing for such network must consider about the speed. They have the capability of sharing messages to each other's while they are traveling along the road. Most the messages exchanged by the vehicles are safety messages so there must be minimum delay and high reliability in their communication. [13]

Intelligent vehicular ad hoc networks (InVANET): the same as VANET but in such network nodes can intelligently make the decision and sent important messages to their fellow vehicles by observing data around them; in order to prevent accident or collision.

Internet based mobile ad hoc network (IMANET): in such types of ad hoc networks one node act as a bridge between mobile nodes and fixed internet gateways. The routing method used in these networks is different from normal ad hoc networks. [13]

Today computer network is highly dependent on wireless communication. Without wireless communication paradigms of computing, such as pervasive computing, ubiquitous (everywhere, every time computing) is unthinkable. Due to wireless communication now the world visions about Internet of Things (IoT). IoT is the discipline dealing with establishment of pervasive system in which all electronic devices can talk to each other by web technologies [12]. Wireless networks have two modes of operation. The first one is the infrastructure based mode, which uses an access point (in case of local area network (LAN)) or base station (in the case of cellular networks) as a coordinator. All functions related to routing, mobility management and others are controlled by those central devices (access point or base station). End devices in such networks communicate with each other through an access point or base station. That means there is no direct communication between end devices and the communication traffic and the end devices, mobility is controlled by this central device. The advantages of using these central devices are the following:

Central coordination: access point or base station controls communication between end devices like switch or router in wired networks. Also error detection and correction system can be applied to these devices.

Routing: the second most important things of these central devices are that they are used as a communication relay between end devices. They can buffer data or write it on best path according to the application [14].

The second mode of wireless is infrastructure less mode. This mode is used where there is no central devises such as access point or base station. In such networks; end devices usually called nodes directly communicate to each other's without intermediate devices. They need no infrastructure to communicate. Using their wireless communication module device directly communicate. In case they (the source and destination) are far apart they use intermediate nodes as a relay which itself is mobile end device. Different variants of such networks are available today. Among them VANET (vehicular ad hoc network) is a self-organizing and infrastructure less networks, i.e. used to provide communication between Vehicle-to-Vehicle and Vehicle to Road Side Units (RSUs). It is one of the influencing research areas that have been used in wireless communication for the better improvement of Intelligent Transportation Systems (ITS) because it has tremendous potential to provide a safe and comfortable environment for the driver and passenger along with allied services in the cases of emergencies. The primary purpose of VANET is to support vehicular safety, passenger security, traffic monitoring and other commercial application.

The other variants are called Mobile Ad hoc networks (MANET) which are multi-hop wireless networks without an explicit backbone, lifting the restriction and the expenditures of an unmovable infrastructure. In MANETs, all stations combine the functionality of clients and routers. The network topology is continuously tracked, and routing paths are constantly updated, as stations freely roam about. MANETs can be set up quickly without effort and used to connect mobile devices [40]. A Mobile Ad hoc Network is a collection of independent mobile nodes that can communicate with each other via radio waves. The mobile nodes that are in radio range of each other can directly communicate, whereas others need the aid of intermediate nodes to route their packets. Each of the nodes has a wireless interface to communicate with each other. These networks are fully distributed, and can work at any place without the help of any fixed infrastructure as access points or base stations. Figure 1.1 shows a simple ad-hoc network with 3 nodes. Node 1 and node 3 are not within range of each other; however the node 2 can be used to forward packets between node 1and nodes 2. The node 2 will act as a router and these three nodes together form an ad-hoc network.

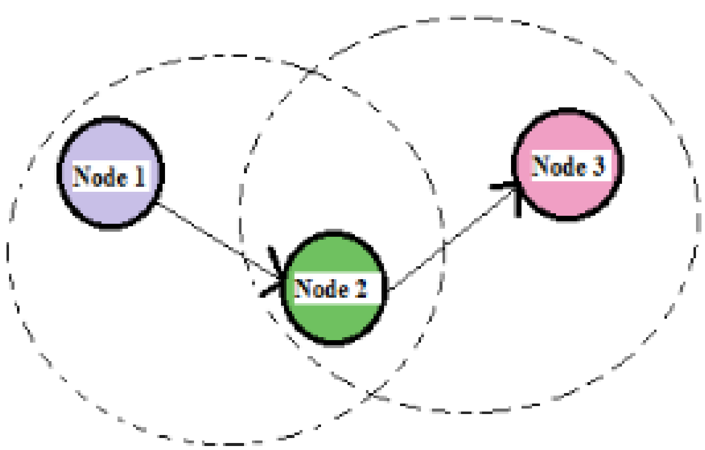

Figure 1.1 Example of Simple MANET [15]

2.2.1 Characteristics of MANET

According to paper [15, 32] MANETs exhibit the following characteristics:

1. **Distributed operation:** There is no background network for the central control of the network operations; the control of the network is distributed among the nodes. The nodes involved in a MANET should cooperate with each other and communicate among themselves and each node acts as a relay as needed, to implement specific functions such as routing and security.
2. **Multi hop routing:** When a node tries to send information to other nodes, which is out of its communication range, the packet should be forwarded via one or more intermediate nodes.
3. **Autonomous terminal:** In a MANET, each mobile node is an independent node, which could function as both a host and a router.
4. **Dynamic topology:** Nodes are free to move arbitrarily with different speeds; thus, the network topology may change randomly and at unpredictable times. The nodes in the MANET dynamically establish routing among themselves as they travel around, establishing their own network.
5. **Light-weight terminals:** In maximum cases, the nodes at MANET are mobile with less CPU capability, low power storage and small memory size.
6. **Shared Physical Medium:** The wireless communication medium is accessible to any entity with the appropriate equipment and adequate resources. Accordingly, access to the channel cannot be restricted.

2.2.2 Advantages of MANETs

According to [15] MANETs have the following advantages:

- They provide access to information and services regardless of geographic position.
- Independence from central network administration. Self-configuring network, nodes are also act as routers. Less expensive as compared to other infrastructure based wireless networks.
- Scalable: any nodes can be added while the networks in operation.
- MANETs is flexible because of their self-configuration nature.
- The network can be set up at any place and time.

2.2.3 Application of MANETs

MANETs have many applications today than before; they are the only means of communication in a disaster area for emergency relief. In the following we have listed some common application of MANET [16, 32, 48].

1. **Collaborative work:** For some business environments, the need for collaborative computing might be more important outside office environments than inside and where people do need to have outside meetings to cooperate and exchange information on a given project.
2. **Local level:** Ad-Hoc networks can autonomously link an instant and temporary multimedia network using notebook computers to spread and share information among participants at a e.g. conference or classroom. Another appropriate local level application might be in home networks where devices can communicate directly to exchange information.
3. **Military battlefield:** Ad-Hoc networking would allow the military to take advantage of commonplace network technology to maintain an information network between the soldiers, vehicles, and military information head quarter.
4. **Rescue Operations**: It provides Disaster recovery, means replacement of fixed infrastructure network in case of environmental disaster. Ad hoc can be used in emergency/rescue operations for disaster relief efforts, e.g. in fire, flood, or earthquake. Emergency rescue operations must take place where non-existing or damaged communications infrastructure and rapid deployment of a communication network is needed.

2.2.4 Challenges of MANETs

Besides their advantages and applications they have the following challenges due to their characteristics [32].

1. **Routing is challenging due to node mobility.** As we have mentioned earlier MANET uses multi hop communication in which mobile devices relay communication. If the relay node moves the connection will be disconnected.
2. **They are resource constraint, they use limited bandwidth,** energy and computing power since the node act as router their computing power is consumed by routing process, their memory is used to buffer packets routed on the network and so on.
3. **Providing Quality of Services is also difficult:** Since the link quality in MANET is not stable due to node mobility providing QoS is also challenging task in such type of networks.

However the usefulness of MANET increased as they widely used in a place where there is no infrastructure like military area, in disaster, even sometimes to create ad hoc lab in a classroom for student and so on. The big challenge of MANET is to create a robust routing algorithm which selects the optimal route with necessary link quality.

A mobile ad hoc network (MANET) is infrastructure less networks used especially in disaster area where there are no other means of communication. Devices participated in such networks have capability of wireless transmission for some given radius. Communication between two devices may be point to point or if they are outside of communication range of each other they communicate through other nodes which we call multi hop communication [16]. The main challenge in mobile ad hoc networks is routing this is because of that there are no dedicated router which is static between source and destination, rather the end devices which is mobile by themselves act as a router. So there is frequent topology change and route disconnection in such type of networks.

There are different routing scheme proposed in a literature to overcome this challenge, however, all routing protocols works in specific situations [17]. These routing protocols can be generally categorized as reactive or proactive: reactive means route is going to be selected whenever there is data to be transmitted, while proactive store and update possible paths always regardless of whether there is data to transmit or not. Reactive and proactive protocols have their own pros and cons as an example, reactive minimize protocol overheads and conserve energy while introducing initial delay. On the other hand, proactive protocols introduces network overhead and consume more energy while minimizing delays [18]. AODV is one example of reactive protocols under IETF consideration for standardization. AODV select paths on demand, however it maintains the state of each link by the periodic hello message. So it balances the pros and cons of the reactive and proactive protocol. AODV as other protocols have its own pros and cons. It is on demand protocol, which start route discovery reactively this introduces delay in the protocols. In order to minimize initial delays AODV uses periodic Hello messages to monitor connectivity between nodes. [19].

2.3 Routing approach in MANET

Routing is one of challenging task in MANET as we already stated in the first chapter due to the characteristics of MANET such as mobility, topology dynamicity, dynamic configuration (node can be added or leave the network dynamically) and soon. Generally speaking routing can be reactive (on demand) or proactive. Reactive protocol means the path is going to be discovered if and when there is a data to transmit from a given node. Unlike reactive protocols; proactive protocols search for feasible path regularly whether there is data to transmit or not from a given node. In the following section we shed light on both approach by taking their example.

2.3.1 Reactive approach

Reactive approach always introduces initial path finding delay but minimize energy consumption and network overhead since there are no frequent update unless there are data to be transmitted. There are popular MANET protocol fall under this category. We have summarized some of popular reactive protocol as follows.

a. Dynamic source routing (DSR)

DSR is one of reactive protocol which finds source to destination hop by hop route using route request (RREQ) packet. Every node accepts RREQ broadcasts it unless it is destination or have links with destination. Then the destination reply routes reply (RREP) messages which contains complete path information. Then these paths are stored in route cache. If route is broken the source is notified by RERR message. The main problem in this protocol is there is no route update at higher rate. Since it lacks topology track scheme route broke difficult to detect early. Also there is no means of knowing link quality prior to route discovery. [20]

b. Temporarily ordered routing algorithm (TORA)

TORA is on demand distributed routing protocol. A separate copy of TORA runs on each node in networks. Whenever a node needs path to any other nodes it generates query containing the destination node address. Then the request propagates in entire networks until it reaches the destination or any node linked with the destination. And the node receives the query reply by updating its distance from the destination.

The main problem of TORA it needs strong coordination between all nodes which is difficult in MANET because all nodes are on mobility always [21].

c. Ad hoc on demand Distance Vector (AODV)

AODV is another on demand distance vector protocol under IETF consideration for standardization. It selects path only by hop count as metric. When source node wants a route to some destination it disseminates route request message over network until it reaches destination or node linked to destination. Then the route is replied by using route reply message from the node. AODV maintain the link state by using periodic hello messages so that route break can be detected early. AODV minimize energy consumption by selecting route on demand. However in AODV the path quality can be known before path is selected by using hello messages in which any node checks the status of its neighbor node [19].

AODV is reactive protocol for MANET networks which developed as a best effort service provider. Here we are going to show AODV protocol structure before we discuss the proposed architecture. To explain AODV protocol let consider two nodes communicate to each other. AODV have four processes

1. Local connectivity management

Local connectivity management is part of AODV which monitors connectivity between adjacent nodes. To do this AODV broadcast hello packets with time to live equal to 1. This enables the packets only to propagate to the node’s one hope neighbors. In other words if hello packets did not come from given nodes in a defined hello interval; it means that the nodes is disconnect due to different reason. When the node know its neighbor is disconnected it will generate route error to its proceeded nodes.Then another path discovery will be initiated if the path is still needed. Hello message is can be used for different purposes; such as bandwidth estimation over the link between two nodes, and generally to measure the quality of the link.

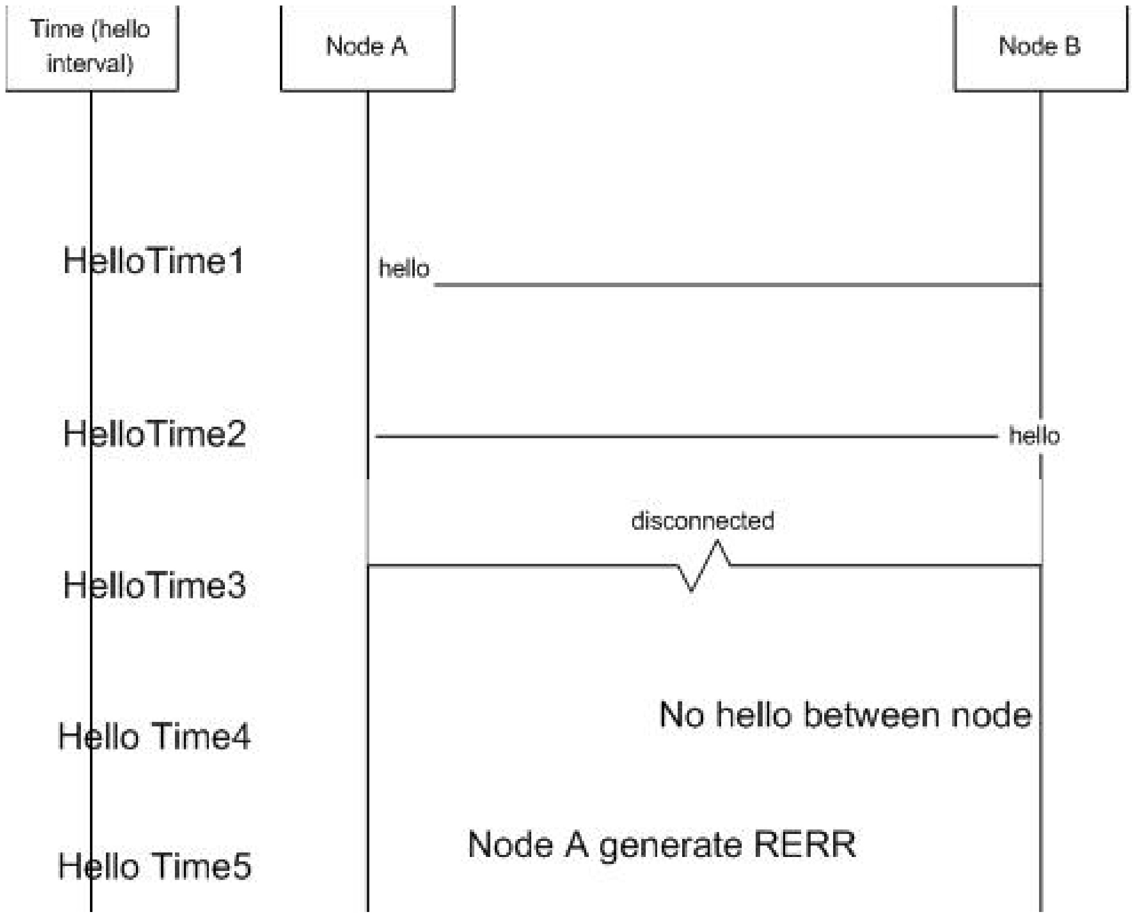

Figure 2 2 Hello Message Flow

2. Route Discovery process

Route discovery process starts when any node wants to transmit data to the other nodes on demand. When nodes wants to transmit data to other nodes it first check its own route table entries; if the path to destination exists in its route table entries it will use that; else it will start route discovery processes. To discover route to new destination AODV broadcast (flood) RREQ messages across the networks. When the network reaches the intermediate nodes those nodes creates reverse path pointers to the source. Then RREP will be generated based on fulfillment of one of the following condition.

I. If the intermediate routes have fresh route to the destination.

II. If the node itself is destination node it will generate RREP

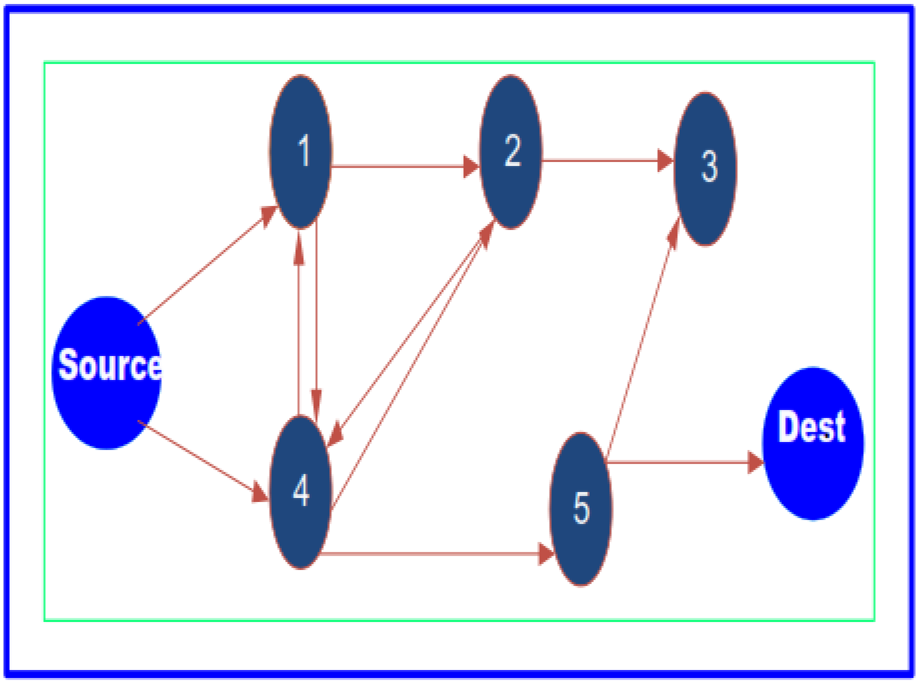

Figure 2 3 route request process [49]

RREP or route reply messages are unicasted to the source nodes through selected nodes. As we already stated the criteria of selecting node is simply by distance or hope count.

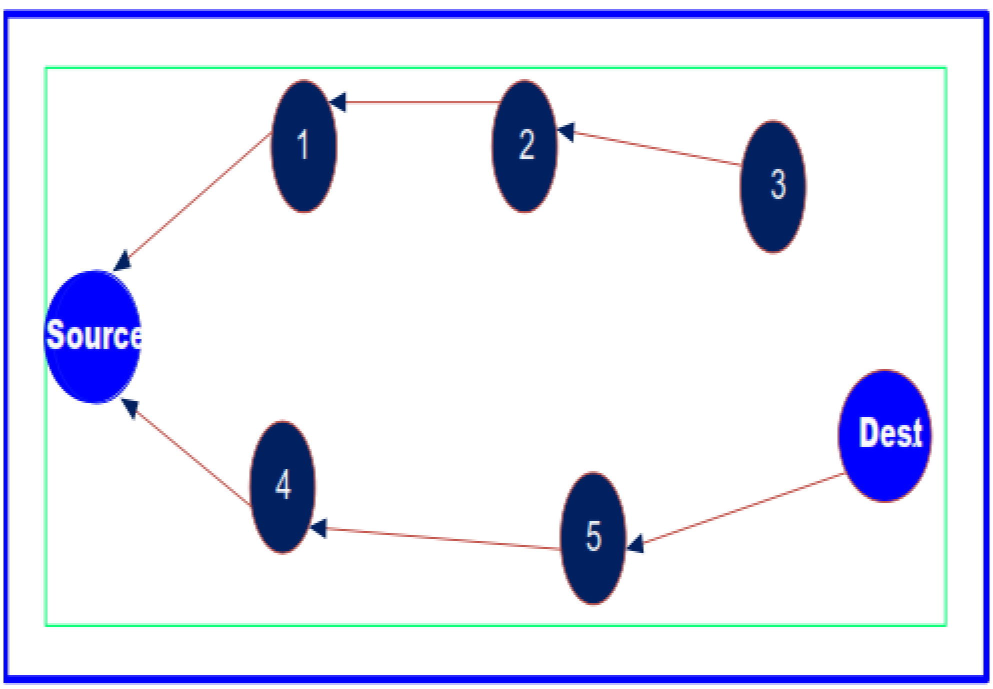

Figure 2 4 route reply process [49]

3. Route maintenance

Route maintenance is done for active route in AODV if one of the nodes on the path failed. The failures of the node can be known by the hello messages of local connectivity management to the adjacent node. As soon as the adjacent node informed about the disconnection it immediately sent RRER messages to the nodes above it which uses the path. Then new route discovery process starts based on:

a. If the route life time is not expired
b. If the route is still needed

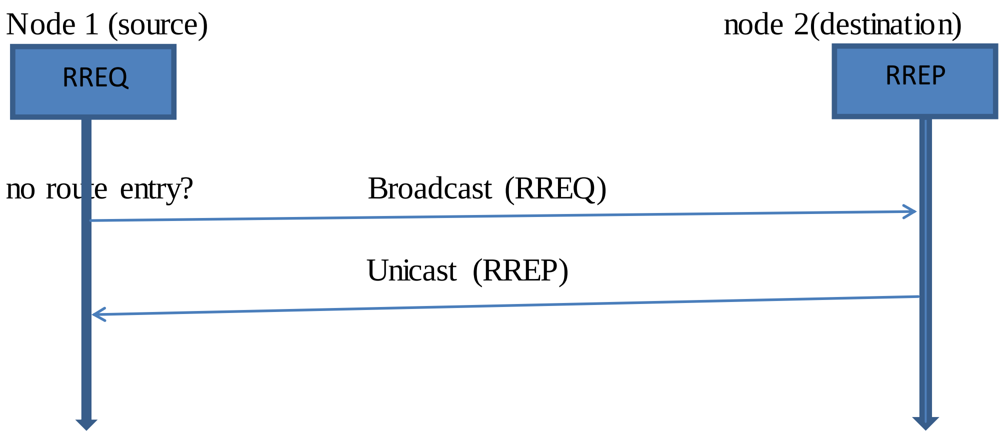

Figure 2 5 Route discovery process

2.3.2 Proactive approach

The proactive routing approach is a routing scheme directly derived from traditional routing protocol in which all routes are frequently updated and stored in table whether there is data to transmit or not. Proactive approach is good in that it can minimize initial delay, but severely affected by energy consumption and network overhead. [18]

One example of a proactive routing protocol is Optimized Link State Routing protocol (OLSR). In this protocol all routing information between 2-hop neighbors are transmitted using UDP (user datagram protocol) [22].

As we have mentioned above routing scheme in MANET can be reactive or proactive, in addition to that MANET routing scheme can be flat or hierarchal.

2.3.3 Routing Based on Node Hierarchy

a. Flat routing

Flat routing approach considers all nodes in the network as one level the main problem with this approach is scalability. On the other hand it does not have complexity. AODV is an example of flat routing. [18]

b. Hierarchal

Hierarchal approach use clustering algorithm to divide the entire topology in to different hierarchal zone (cluster). By clustering different routing approach can be implemented in different cluster. As an example zone based routing: which divides the nodes in to zone. Each zone have cluster or zone head. There are two types of communication inter zone which is reactive and intra zone which is proactive. According to Humayun B et al [18] the main problem of hierarchal approach is that it adds more network overhead i.e there will be another computational issue that is cluster formation.

2.4 Quality of Services

Quality of Services (QoS) is the capability of networks needed for the given application or services. According to Prasant M, et al [11] the wide spread use of MANET in battle field and disaster area initiates the need of QoS in MANET. According to them the main challenges to provide the quality of services in MANET is that there are limited resources and variable resource over the links. Also, they have stated that the issue of providing QoS is the issue of all layers. One way of providing QoS in MANET is by using QoS aware routing. QoS aware routing is routing scheme in which different QoS metrics are put into consideration and the best path is selected if it provides that metrics. As an example lei ch et al [10] proposed QoS aware routing protocol based on estimated bandwidth. There are plenty of such approach in literature, most of them consider delay and bandwidth as QoS metrics [1].

2.4.1 Different QoS provision approach

According to [11] paper QoS can be categorized as hard QoS and soft QoS. Hard QoS is used in mission critical application such as air traffic controller application. Also, it guarantees parameters such as jitter, bandwidth and delay. According to the paper this type of QoS is not feasible in MANET; since the network itself is not reliable. While soft QoS is aimed to provide QoS needed by the application, but not guarantee QoS parameters. Loss in QoS only degrades application, but not cause disastrous consequences. For traditional router based network there are different model for QoS provision as explained in [14]. We will discuss two of them in this section

2.4.1.1 Integrated services (IntServ)

The core idea of this model is to make router reserve resources to guarantee QoS needed by a specific packet stream [14]. The model combines the advantages of datagram networks and circuit switched networks. Datagram networks forwards packet's data's based destination information provided in the packet header. It even doesn't know the actual path at first. On the other hand circuit switched networks are connection oriented networks, which create dedicated channel between source and destination before actual communication is started. This channel will be unavailable for others until the channel is released by the previous users. In IntServ RSVP (resource reservation protocol) is used to setup virtual channel which fulfill the QoS requirement and router uses this to apply QoS management schemes. Generally IntServ is flow based end to end resource reservation.

2.4.1.2 Differentiated services (DiffServ)

According to [14] differential services model also offers a method to guarantee QoS on large networks. It is applied in bulk of data not only single flow as in IntServ. It maps multiple flows into few service levels. The differentiated services architecture is based on a simple model where traffic entering a network is classified and possibly conditioned at the boundaries of the network, and assigned to different behavior aggregates by marking a special DS (Differentiated Services) field in the IP packet header. Each behavior aggregate is identified by a single differentiated service code point. Then the packet is forwarded based on their per hop behavior (PHB) [23].

These two ways of providing QoS is not suitable for Mobile Ad hoc Networks for simple reasons. First, there is no dedicated router; which is static and used to reserve routes. Also applying signaling protocols such as RSVP increase network over head in MANET which may decrease overall performance of the network. Thirdly MANETs are highly flexible network so it is impractical to reserve resources while node they are mobile.

2.4.1.3 Flexible QoS Model for MANET (FQMM)

As described in the paper [43] Flexible QoS Model for MANET is Quality of service model for MANET as an attempt to create a QoS model for MANET which is equivalent of Differential services of that of wired networks. It was aimed at creation of a flexible QoS provision mechanism for MANET. In this approach feature of IntServ and DiffServ is combined. Per flow QoS for higher priority flow and aggregate QoS for lower priority flow. A source node has had unique responsibility it shapes traffic flows. Even if it is flexible it is still not appropriate as it needs separate QoS reservation packets.

2.4.2 QoS in MANET

As mentioned in [11] at an early stage of MANET, people worry only about best effort delivery of data over such networks. Due to this many of early stage protocols are do not consider the quality of services needed by the application. But as the application of such networks increased in different areas such as disaster recovery area in which disaster recovery workers wants to communicate using voice as an example; the need of QoS provision mechanism increased. QoS is the capacity of networks needed by some application. As an example the well-known computer scientist and author Tanenbaum in his book listed different application with their quality metrics. Among them email messages can work low bandwidth, delay, jitter, while another application such as real time audio telephony (voice over IP) needs can work in low bandwidth but they are highly delay sensitive. [14].

MANET todays used in many areas such as disaster relief, fire areas and also in entertainment for example in interactive games. In this, all areas we need a real time voice or video communication. Due to these many emphases are given for QoS in MANET in literature.

2.4.2.1 Routing protocol and QoS (QoS aware routing)

As mentioned in the above section one way of ensuring QoS provision for different application is to select path based on different metrics during route discovery. At an early stage Routing protocols in MANET only focus on best effort delivery. However to expand the application of MANET in entertainment and multimedia transmission, which highly need special QoS provision, many research starts to explore how to include QoS in MANET routing protocol. According to a survey done by Lajos Hanzo et al [1] most of routing protocols consider throughput and delay as metrics. But these metrics are not sufficient for application such as real time video or audio streaming. For example, jitter is very important metrics for real time video or audio streaming. In the following section we will explore some of the important metrics in literature.

Different authors try to review the state of the art on QoS routing protocols in MANETs. Among them, we are going to review two of them. The first paper is the paper written by Lajos H et al.[1] they start by mentioning the problem faces during QoS provision in such types of networks. These problems are unreliable wireless channel, node mobility, lack of centralized control, channel contention, and limited devices resources. The main use of identifying these problems is that they can play important role in protocol adjustment to provide QoS provision. As an example, since one of the problems is limited devices resources they protocols developed must be not resource intensive. The second paper is by Humayun Bakht, [18]. In this paper the authors try to compare popular by mentioning their criticizing their strength and weakness. Their main target is to simply provide an overview about routing protocol without focusing specifically on QoS provision in these protocols. As discussed in the above papers QoS metrics can be considered at different layers, however, since we are focused on the network layer QoS provision in our research we present some of them as follows.

2.4.2.2 QoS metrics

Metrics are application requirements which can be provided by networks. In other words, it is a capacity of networks. Different application has different requirements. Here are some examples of metrics used in the network layer. Available bandwidth is considered as metrics in [24]. In this paper the residual bandwidth is checked and the path is selected based on the residual bandwidth available on the links. In paper [42] end to end delay on the path is measured and the one with minimum delay will be selected. Another way of checking delay is by measuring the node buffer space. In paper [35] node buffer space is considered as a metric to determine delay due to the data in a buffer.

Another important metric for real time voice and video streaming is jitter or delay variation. Jitter is the difference between delays of packets of the same stream [14]. Paper [25] considers energy expended per packet as a metric. Other metrics imposed by mobility of nodes such as route life time are also used in some protocols [26]. Aarti B et al [31] considers mobility index of nodes as route selection parameters. Mobility index in their paper is the availability of the node whenever it is required, if the index is low it indicates that the node is instable, so the path on which that node is found have less chance to be selected. Also, these researchers consider the maximum neighbors of the node as a criterion of selection. They argued that if the nodes have a high number of neighbors it indicates that the node is more stable and information disseminated on this node can reach more nodes.

2.4.2.3 Bandwidth estimation techniques

Bandwidth is shared medium used by neighbor nodes in mobile ad hoc network communication. It is very important metrics for path selecting decision. Paper [27, 28] describes available bandwidth as a concave metric. When we select the path based on available bandwidth we will check bandwidth bottleneck found on the link which is found on a given path as stated in the literature. So the path with largest bandwidth bottleneck will be the best path. As stated in literature estimating the available bandwidth for wireless communication is the challenging task. As stated in paper [28, 29] Bandwidth estimation techniques can be generally divided into three: active bandwidth estimation and passive bandwidth estimation. We will explain each of them as follows:

a. **Active bandwidth estimation:** This technique applies active measurement to estimate the available bandwidth on a given link. There are different tools to measure bandwidth; however, most of them uses probe sending model between the two ends. Using an extra probe for the sake of bandwidth estimation is one drawback of this approach as explained in [28]. The two main examples of active bandwidth estimations are:

    I. **The probe gap model (PGM):** as explained in **[**29] In Probe gap model uses two consecutive probes sent from source node to receiver node and estimate the bandwidth based on the time gap of arrival time at the receiver side. PGM calculates the available bandwidth on the path, to calculate available bandwidth it only assumes single bottleneck on the path. In this model two consecutive probes will be sent at the given gap at a sender side and it may reach to the destination by another time gap. Then the available bandwidth will be calculated from those time gaps (time gap during transmission and time gap during reception). PGM only two probes unlike Probe rate modelling which use a stream of probes in this case it is better; but can under estimate the available bandwidth in multi hop communication as stated in.

    II. **The probe rate model (PRM):** As explained in [29] probe rate model is based on the probe rate between the sender and receiver to estimate the amount of available bandwidth. In PRM if a source node sends probe at a rate less than that of available bandwidth; the rate at receiver side will match that of the sender; in opposite to that if the source node sends probe at a rate above that of available bandwidth then the rate at receiving side will be less than that of the sender. So the available bandwidth can be known at a point when the sender rate starts turning that of receiver rate. By using this approach the probe packet itself can congest the network at some time during bandwidth measuring and this is the drawback of this approach.

In general, inactive bandwidth estimation techniques, probing packets at different rates are used to measure the bandwidth available in the network. These probe packets will cause additional traffic overhead in the wireless network, which affects the performance of ongoing flows.

b. **Passive bandwidth estimation:** as we stated above active bandwidth estimation always uses a probe sending to measure bandwidth which add overhead; and adding over head on MANET traffic is maybe not good for MANET has limited resources already. Because of this the second way of bandwidth estimation is proposed by many researchers; and that is a passive bandwidth estimation. Passive bandwidth estimations do not generate additional traffic rather utilizes Mac layer protocol such as 802.11 Mac. Passive bandwidth estimation has the following categories.[29]

I. **Listen bandwidth estimation:** Here the nodes utilize the 802.11 MAC physical carrier sensing or virtual carrier sensing to identify the channel idle and busy time. The MAC identifies the channel as idle when below given criteria holds true:

- ✓ Network Allocation Vector (NAV) is less than or equal to the current clock time.
- ✓ Receiving state is idle.
- ✓ Sending state is idle.

Although the method is straightforward, the problem starts once the route is broken the corresponding sender will never know whether any node has changed its position until a new data transmission begins.

II. **Hello bandwidth estimation:** the drawback of listen bandwidth stated above is overcome by researcher by using HELLO packets, used by most of routing protocols. These HELLO packets are emitted periodically and can be utilized for exchanging the local information. The few advantages we can derive are: They help in maintaining list of one hop neighbors. They help in exchanging the bandwidth information up to two hops. They avoid sending any other control messages for carrying the information.

III. **Hybrid approach:** paper [47] presents a hybrid approach of estimating bandwidth by using listen bandwidth and hello bandwidth estimation. As we stated above listen bandwidth cannot know if the path is broken when it listens. So the nodes can actually listen to the channel estimates its bandwidth and disseminates this information to its neighbors by using hello messages that is used by many routing protocols. In our paper we have utilized this approach to for bandwidth estimation

In conclusion, hybrid of listening and hello bandwidth estimation is good for the following reason:

- ✓ It is a passive bandwidth estimation; the nodes utilizes MAC layer protocol for bandwidth estimation, therefore there is no additional traffic added unlike the active bandwidth estimation.
- ✓ The second reason is it overcomes the disadvantages of listening bandwidth; i.e the listen bandwidth always tricked when the path is broken it has no knowledge to detect the broken path so it do not release the path even if it is broken. So here when listens bandwidth estimation is used in conjunction with hello bandwidth estimating the broken path can be detected and released by hello messages which is used by many routing protocols. In our paper, since we enhance the AODV protocol we utilizes hello messages of the AODV protocol for this purpose.

2.4.2.4 How/when to determine QoS state

Another important question next after we identify QoS metrics is how and when to determine QoS state. As we have discussed above we have proactive and reactive protocols which have their own trade off. We have said also since reactive protocols save energy and reduces network overhead by minimizing the frequency of route update which are big issues in Mobile ad hoc networks; they are more appropriate for MANET. The same to path discovery, determining QoS state can be proactive or reactive. Both have their own pros and cons. According to the paper [34] if the QoS state is determined proactively session establishment time will be minimized, however, it may add large network overhead since update must be occurred frequently.

Due to this proactive approach can be difficult in high mobility and dense nodes. The second approach is reactively determining. This approach reserve network capacity and energy by ignoring to discover route and QoS state when they are not needed, but add initial discovery delay. The third approach is a hybrid approach, which have different forms. As an example in the paper [36] MANET nodes are divided into the zone and routing is divided as inter zone which is proactive and intra zone which is reactive. Another hybrid form is discovering route proactively and QoS state is determined to demand if the application needs it, this was explained in [33, 37].

2.4.2.5 Voice over IP and QoS metric

Voice over IP (VoIP) is among emerging technology on which voice communication is transported on data network as a packet. Sometimes it's also called IP telephony. Today, many platforms can provide VoIP. According to Eric T et al [38] MANET can be a good platform for the applications of VoIP. As we already said in first chapter MANET can be used in disaster areas and emergency cases, in this disaster area for example, workers in fire department can communicate using voice and that voice can be routed among devices as a packet. As our research focuses on providing Quality of services for real time voice and video transmission let see some of QoS metrics important for such applications.

Authors of paper [39] mentioned two important metrics needed for voice traffic on MANET networks. The first one is Delay. According to them delay can be introduced due to different reason; among them processing delay, network delay and algorithm delay. According to them delay up to some threshold can be acceptable. The second metrics mention in this paper is the packet loss ratio (PLR). According to them packet loss up to 5 % in transmission could be visible to the users. In addition to this according to author Tanenbaum jitter is important factor which affects voice traffic. [14].

In the next chapter we are going to present what we got in literature related to our works focusing on how to provide quality of service routing for voice streaming over MANET. Particularly, we focus on the AODV protocol, which we proposed to enhance to include QoS to support real time voice traffic over MANET.

CHAPTER THREE

RELATED WORKS

3.1 Introduction

This chapter presents some of the papers related to our work. There are a number of works in the literature which try to incorporate different QoS metrics in AODV. As we already stated AODV is first developed with the notion of delivering packet data by using best effort services. I.e no QoS metrics is used while making route decision.

Ad hoc on demand Distance Vector protocol is one of the popular protocols widely deployed in the MANET and also one of the protocols under IETF consideration [18]. It is first developed by Charles E and Elizabeth M [19] as an improvement of DSDV protocol. The main notion of this protocol is to minimize the number of broadcasting to advertise routes between nodes, which is a big problem in DSDV. According to these authors they develop this algorithm so that route - acquisition time (the initial delay) is minimized. AODV contains three main operations. The first one is RREQ in which the source node broadcast RREQ messages to its neighbors. Then the neighbors themselves rebroadcast the messages if it is not the destination or have no links to the destination. The second operation is RREP in which the destination or the node which have links to the destination returns the route to the source. According to their paper the only metric they consider is the distance (number of hops). The third operation is route maintenance in which broken links detected and the route is rediscovered. As they mention route broke down can be detected by the periodic Hello messages between nodes and their neighbors. AODV also uses a table to store active routes. This table have special field called “route caching timeout” which determine the validity of the route for the specified time.

As we have tried to emphasize in the previous chapter that AODV is among the first attempt to provide best effort services for MANET. So it only considers the only number of hops as the route selection parameter. However; a lot of researchers try to incorporate QoS in AODV by taking different QoS metrics such as available bandwidth, delay, energy, and so on. Here in the following section we are going to cover some of the works done to incorporate QoS in AODV protocol by different researchers. We have covered the work done, which considers available bandwidth, energy, delay and jitter. Finally, we have summarized all the work we covered in one table for easy reference.

3.2 AODV enhancement based on available bandwidth as QoS metric

One of the works done to incorporate QoS in AODV protocol is the work done by Lei chen et al [10]. In this paper AODV algorithm is restated to include available bandwidth as QoS metrics in addition to the number of hops. Their work is mainly focused on how to estimate available bandwidth and incorporate the bandwidth information in the route discovery process. For available bandwidth estimation they have used both listen bandwidth and hello bandwidth estimation; and compare the result. Information of available bandwidth is incorporated in Hello messages of AODV. Hence the hello messages now have two fields: The first field includes <host address, consumed bandwidth, timestamp>, and the second field include <neighbors' addresses, consumed bandwidth, timestamp>. In this case the hello message id utilized to distribute the bandwidth information. Each node getting this available bandwidth information then stored in neighbor management table.

Then, during the route discovery process; they incorporated these metrics in a route discovery packet (RREQ) messages. In this case the RREQ header is modified to contain additional fields :< model-flag, bandwidth request, min-bandwidth, AODV RREQ header>. They have simulated their modification of the protocol and concluded that packet delivery rate of the QoS aware AODV is much better than the normal AODV. They have simulated their enhanced protocol in two types of topology scenario; static topology and low mobility topology. In the static topology and low mobility scenario. Their enhanced protocol shows better performance than that of the original AODV. As they stated in high mobility the performance of their protocol is not guaranteed.

The other work we have reviewed is the work done by Ali ch, et al [45] which also focused on based on current bandwidth routing for MANET. In this paper the author stated that they have modified the original AODV protocol so that it will include a minimum bandwidth requirement in their route request of the source node; i.e the source node include the minimum bandwidth requirement of the application. Then the intermediate nodes, checks their current bandwidth and the minimum bandwidth requirement; if their current bandwidth is less that the minimum Bandwidth requirement, then the node will drop the request, else it will be forwarded. Finally the path which contains the node that satisfies the bandwidth requirement of the application is selected. They have modified the original AODV protocol to first estimate the current bandwidth of each node found in the network. Also they have included bandwidth information in the route discovery process. They have presented their results; that their new enhanced AODV protocol performs better than the original one.

3.3 Energy as QoS metrics

Other work done by X.Jing et al [25] considers energy as a quality of service metric and modify AODV algorithm. The authors argue the importance of energy aware protocols for MANET networks for network lifetime extension. According to them energy aware routing metrics are used to select the path to the destination in addition to hop count. They incorporate battery power information in hello message and route discovery messages. They utilize the reserved bit field in the message to convey energy parameter between nodes. The metrics are comprised of run time battery power and a real time propagation loss obtained from sensing the received signal power. Cost for path selection is based on suggested power metric calculated using the run time battery power and real time propagation loss. Low battery alert is on critical battery loss is one improvement of their work from the on previous work.

They have simulated and presented their results; according to their reports the network lifetime is increased for both static and mobile network scenarios they have simulated. Also, they have mentioned that Low battery alert results in affecting the overall throughput. The energy consumption is balanced among the network and the limited battery resources are utilized efficiently.

The same as the previous work we have mentioned in this paper the author uses the hello messages for energy information distribution among the nodes; and they have modified the RREQ and RREP packets of AODV.

Another work we have reviewed is paper [44]. This paper presented the works which control link failure and the energy consumption of each node. As the authors stated in large and highly mobile networks link failure and energy consumption by nodes are more. According to them link failure in AODV is identified when the packet data are on transmission from source to a node.

As a solution they have provided the way to remove the stale path from the route table after certain timeout. They make this time out adaptive according to hop count of the given path. For energy consumption, they have utilized energy awareness methods which they have implemented as load balancing and transmission power control approach. This paper actually does not focus on specific QoS metrics, but by providing a different mechanism they able to improve performance metrics. The reason why we have presented this paper is to show that there are many papers like this which provides the necessary performance metrics without explicitly using QoS metrics in their route discovery process.

3.4 Delay as QoS metrics

There are numbers of work on AODV which considers route selection based on delay. As we already said the delay can be considered as average delay or end to end delay. Or it can also be the sum of queue delay, computation delay, propagation delay, and so on. In this section we will see some examples of AODV enhancement based on delay.

The work presented in paper [33] is one example in which delay is used as a QoS metric. The author extends AODV protocols path discovery process by adding delay and bandwidth as best path selection criteria in addition to hop count. However, in their work they did not consider the dynamicity of the MANET networks. Another work done by R.Asokan et al [41] is focused on AODV QoS extension; by adding delay and energy as quality of service metrics. Both minimum energy on the path and maximum delay was added to routing table entry AODV routing table. Also during the route discovery process the source node sends its RREQ messages with the extension of minimum energy and maximum delay requirements. The result, they have presented also shows good performance.

The other paper related to our work is the work done by Bouchama N et al [46]. This paper mainly focused only quality of service provision in AODV for voice over IP application. In their paper they have identified three QoS metrics as important metrics for VOIP application. These metrics are end to end Delay, jitter and packet loss ratio.

The work we have reviewed in this chapter focused mostly on one metric as a quality of service metrics, however the quality of services needed for application like multimedia streaming including audio and video is more than that. For example, to efficiently stream video on some given networks one need good available bandwidth, low or no delay and low or no jitter. So these three metrics are important, that is why we focus on them on our research.

In our research, we also used the cross layer approach in which available bandwidth; link delay is gathered from lower layer from wireless channels and used to calculate the cost of the path which in turn used for route selection decision during routing.

3.5 Summary

The summary of related works we have covered above is summarized in the following table. The work and the metrics covered is shortly explained in the table.

Author	Title	QoS metrics considered
Lei Chen and Wendi B. Heinzelman	QoS-Aware Routing Based on Bandwidth Estimation for Mobile Ad Hoc Networks,	Bandwidth in addition to hop count
Ali Ch, Feraoun M, Doumi N, KhaterM	Integration of dynamic current bandwidth capacity calculation for existing AODV	Current bandwidth: minimum bandwidth required by application is compared with current bandwidth of nodes.
X.Jing and M.J.Lee	Energy-aware algorithm for AODV in Ad hoc networks	Minimum energy requirement is considered for path decision
M. Tamilarasi and T.G. Palanivelu	Adaptive Link Timeout With Energy Aware Mechanism For On-Demand	Dynamic timeout based on number of hop. energy consumption control by load balancing and transmission power control

	Routing In MANETs	
E. B.-R. C. E. Perkins	Quality of Service for Ad hoc On-Demand Distance Vector Routing	Delay and bandwidth are considered as QoS metrics.
R. Asokan and A. Natarajan	Performance Evaluation of Energy and Delay Aware Quality of Service (QoS) Routing Protocols in Mobile Ad hoc Networks	Energy and delay are considered a QoS metrics
Bouchama N, Nouli T, Nadia A, Djamil D	extending the AODV protocol to provide Quality of Services in Mobile Ad Hoc Networks	End to end delay, jitter and packet loss ratio is considered as QoS metrics. For VOIP application

Table 3 1 summary of related works

CHAPTER FOUR

ENHANCED AODV DESIGN AND ARCHITECTURE

4.1 Introduction

Mobile ad hoc network is composed of nodes. Nodes are end devices capable of wireless transmission. Nodes communicate by using different wireless communication standards; however, in our case we assumed all nodes communicate using 802.11 wireless channels. Those end devices are mobile devices and they are used as a relay of the other node during data transmission. Due to this it is difficult to provide Quality of services in MANET. As we proposed in the chapter one (section 1.2) we are going to design the enhanced AODV algorithm in this chapter. As we have already stated, our main objective is to design the protocol, which considers quality of services. These QoS is described by different metrics. In our research, we focus on three metrics which include bandwidth, delay and jitter. We are going to discuss how to acquire and calculate these metrics in detail.

The MANET network into consideration contains *n* numbers of nodes which use 802.11 wireless communication module. The nodes are all equal (we use flat architecture). Flat architecture means all nodes are equal in responsibility as opposed to cluster based; in which cluster headers are coordinators others are naïve node only used as a relay. Each node has its own transmission range. If source and destination nodes are in different transmission range they will communicate in the form of multi hop communication mode. The other point we have to consider is; since the communication range of two or more nodes can be overlapped, the bandwidth of one link can be consumed by more than one node. In this section we are going to design QoS routing model in which bandwidth, delay and jitter will be considered for route selection. Therefore, first we will discuss about those metrics and how their computations performed.

In our enhanced AODV protocol we have improved three components. The first component was hello messages in original AODV it simply used to check the connection between two nodes. In our enhanced protocol hello messages are used to calculate the delay and jitter on a given link between two nodes. Also the available bandwidth between two nodes will be reported to the neighbor using hello messages. Those metrics collected from the hello messages, then used as input between in RREQ messages. Then RREP use those metrics to select the best path between source and destination. We have demonstrated our algorithm in different scenarios. In the following section we are going to present the general architecture of our enhanced protocol. Then we will discuss QoS metrics calculation as well as the algorithm run by each component in the architecture.

4.2 Architecture of proposed solution

In proposed solution we enhanced AODV protocol so that it considers quality of links when the path is selected. We described the architecture of the proposed solution as shown in the figure 4.1. The architecture shows the flow of the operation. We can categorize the operation into two. The first one is a route discovery process. This includes route request (RREQ) and route reply (RREP). This operation is done on demand when the nodes (source node) have data to transmit. The second one is QoS state gathering in this; QoS metrics which later determine the route that should be selected as the best route will be gathered. Also, they detect and report link disconnection by using Route error (RERR) message.

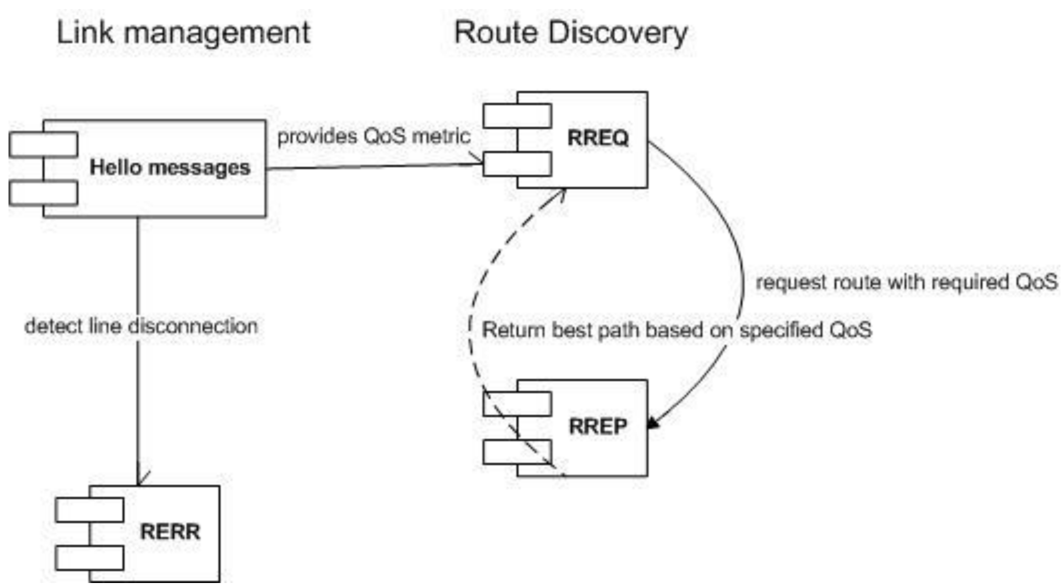

Figure 4 1*Architecture of Proposed solution*

The above architecture shows our enhanced AODV protocol, it contains four components. We have modified three of them. In hello message we modify for QoS state gathering and in the route discovery process, we have modified both RREQ and RREP packets. In the following subsection we are going to elaborate all the components explained above.

4.2.1 Hello messages

Description of the component:

A Hello messages are periodic message between nodes and its neighbor. Originally it is used for local connectivity management, we use this as an advantage and we use it for QoS state gathering which later used by route discovery components to select best path.

A hello message is used for connectivity management and QoS state gathering as explained above. In the following section we are going to discuss how metrics are calculated and distributed by hello messages.

4.2.1.1 Metrics calculations

Metrics are parameters of quality of services which describes the quality of the selected path. Most of IP routing protocols just use number of hops (distance) as quality metric. But there are several metrics that hinder the quality of the line. Since our research focus on quality of services in MANET we are going to discuss how those QoS metrics are calculated in MANET. In our research we focused on three metrics these are bandwidth, delay and delay variation or jitter as a basic metrics.

As we already discussed in the second chapter reactively determining Quality of service metrics will resulted in increase of initial route discovery time. In order to minimize that in our research we take advantages of hello messages between neighbors nodes which proactively (even when there is no data transmit) sent. In AODV hello message is used for local connectivity management. For example if node A and node B are neighbors A will send hello messages for B in order to detect it in a given interval. The same is true for node B. here in this paper we consider three QoS metrics available Bandwidth, Delay and Jitter.

Nodes estimate their available bandwidth by listening to their respective channel, When nodes B send hello messages for nodes B it estimates the bandwidth between Node A and itself; and send it to A. then A will store this recorded in its neighbor management table.

Delay and jitter can be determined from the time difference between sent packet and received hello message packet. Then the node will store the value. This will be done proactively while route discovery process which uses this value will be done reactively. Because of this we can call our approach hybrid approach.

The metrics we used in our modified AODV protocol should be gathered from underlying link layer. Link layer treat the physical frequency spectrums as a series of different independent wireless channel. Under different technology the number of channels differs. For example TDM or FDM use slotted channels based on time slot or frequency sub bands respectively they are generally contention less. But other technology such as 802.11 uses only one channel. They are contention based, i.e the nodes competes for accessing channel. Since the network we are considering is based on 802.11 technologies we assume single channel [1].

We calculate available bandwidth; from underlying links and this metrics was then incorporated in hello messages. We call such approach cross layer approach [1]. Cross layer in a sense that network layer interact with MAC layer at some point to provide QoS. As we know MAC layer can be contention free or it can be contention based. Contention free applies to those which use multiple channels and the channel is used by each communication at a time. In our case we use 802.11 MAC which is contention based adjacent nodes contended for channels available between them. The MAC layer at use additional control traffics to avoid collision for node in a contention. So when we gather information about residual bandwidth that is why we add weight factor. In the following section we will go in detail on metrics calculation one by one.

4.2.1.1.1 Available Bandwidth estimation

Bandwidths are shared frequency spectrum between neighbor nodes; it is the physical medium that carry data signals between nodes when data is sent between two nodes there may be different routes between them and each route may have different bandwidth capacity. As we already stated communication in MANET is multi-hop communication. For example, if we have four node A,B,C,D networks; when data travels between node A and D it may follow A-B-C-D path which means A and B are in the same transmission range, so communication between them is possible, but A and D are found outside of each other communication range; so they can't reach each other directly. In our research, we used bandwidth of nodes which uses 802.11

wireless communication standards. Two methods of bandwidth estimation are widely covered in the literature [10]. The first one is bandwidth estimation which uses hello packet, and called hello bandwidth estimation and the second one is called listen bandwidth estimation.

Hello bandwidth estimation uses hello messages of AODV. Normally hello of AODV contains only one field that is the address of the node which initiates the messages; but when it is used for bandwidth estimation two fields are added to it those fields are consumed bandwidth and time stamp. This information is combined with information of the bandwidth of the technology used in our case 802.11 enables each node to estimate free bandwidth on the link.

The second method is listen method in which nodes listen to the channel every second to identify how many times the link will be free or busy.

As we stated in second chapter we are going to use hybrid available bandwidth estimation for the following reason.

- ✓ It is passive bandwidth estimation; the nodes utilizes MAC layer protocol for bandwidth estimation therefore there is no additional traffic added unlike the active bandwidth estimation.
- ✓ The second reason is it overcomes the disadvantages of listen bandwidth; i.e the listen bandwidth always tricked when the path is broken it has no knowledge to detect the broken path so it do not release the path even if it is broken. So here when listens bandwidth estimation is used in conjunction with hello bandwidth estimation the broken path can be detected and released by hello messages which is used by many routing protocol. in our paper, since we enhance the AODV protocol we utilizes hello messages of AODV protocol for this purposes.

Each node estimates their residual bandwidth and put it on hello message described in fig 3.2 below [10].

$$AB = \frac{rbw - cbw}{wf} \quad \text{--} \quad [3.1]$$

Where: AB is Residual bandwidth

rbw is Raw Bandwidth

cbw is consumed bandwidth

The wf is "weight factor" is introduced due to, characteristic of 802.11 wirelesses.

Weight factor is a constant number introduced due to characteristics of 802.11 wireless communications. The control packet at Mac layer such us request to send (RTS), clear to send (CTS), is the reason why weight factor is added. As stated in paper [10] in most cases the value taken for weight factor of 802.11 is 1.41. Here control packet for hello is added that is why the values is more than that of listen bandwidth explained below. In our paper, we used this value too.

Consumed bandwidth (cbw) must be calculated or estimated from the MAC layer for this we use directly the listen method discussed in [10] paper. According to the paper the consumed bandwidth can be calculated from the channel busy time or free time. MAC layers know that the channel is busy when the following condition met.

- NAV time set to a new value
- Receive state is changed from idle state to any other state
- Send state changed from idle state to any other state.

So based on this each node can calculate their consumed bandwidth as follows [10]:

$$cbw = \frac{(rbw * busytime) / overalltime}{wf} \qquad \text{……………………………………………[3.2]}$$

Where cbw is consumed bandwidth by the node

Rbw raw bandwidth is the actual bandwidth of the channel

Wf is the weight factor added due to 802.11 wireless characteristics.

Weight factor is a constant number introduced due to characteristics of 802.11 wireless communications. The control packet at Mac layer such us request to send (RTS), clear to send (CTS), is the reason why weight factor is added. As stated in paper [10] in most cases the value taken for weight factor of 802.11 is 1.128. In our paper, we used this value too.

After bandwidth on each link was estimated, the next point is to combine the bandwidth on one given path (which is made up of different links because of multi hop communication). The author of paper [27] state that bandwidth are categorized under concave metrics; which means the bandwidth on one path is combined by taking the minimum bandwidth on the links.

$Bw(ab+bc)=\min[Bw(ab,bc)]$; This means the minimum accepted bandwidth of the path between **A** node and **D** node is the minimum of those two links on the path. So our modified AODV protocol first find the minimum bandwidth on the different route and compare it with accepted minimum bandwidth requirement if the requirement met the path will be selected if not it will be rejected.

4.2.1.1.2 Delay calculation

Delay is the latency occurred due to propagation or queue or computation during transmission. The total delay can be summarized as follows:

$D_{tot} = P_D + Q_D + C_D$ ………………………………………………………………… [4.2]

Where D_{tot} is total delay, P_D propagation delay, Q_D queue delay, C_D Computing delay. In our work in order to make delay estimation easy and more accurate we have calculate delay from the hello messages sent between nodes; as we have explained as follows.

In Ad hoc network a given node does not have global knowledge about its network. Rather nodes only know the link between its neighbors. In AODV this is managed through hello packet. As indicated in paper [46] delay is additive metrics which means the delay on the path is determined from the summation of delay on each links on the route.

$D(a,d) = d(a,b) + d(b,c) + d(c,d)$

This means the delay on the route A to D is the sum of each links on this route. The delay on each link can be calculated from hello packet as follows:

$D = (HRT - HST)$ ……………………………………………………… [4.3]

Where D is delay

HST hello sent time

HRT Hello receive time

On the other hand delay can be also calculated as end to end delay by using route request messages of the protocol. For example when RREQ messages disseminated on the network it can reach to destination on different paths at different time. We can look at scenario networks which have four node A,B,C,D; let say node *A* broadcast RREQ by setting sent time to *current_time*. Then the request packet reaches node *D* (destination) on the following two path.

First path →A→B→C→ by the time of *current_time* + 5 let say

Second path→A→E→C→D by the time of *current_time* + 6

From this we can understand that the first path have less delay so the path decision maker will take this as metric to select the best path.

Globally calculating delay using RREQ makes our delay calculation reactive and increase the initial delay; since RREQ only sent if and when there is data to send. Due to this in our paper we have used delay calculation from hello messages as in equation 3.3 above,

4.2.1.1.3 Jitter consideration

As stated in [27] jitter is also additive metrics which means the jitter on one path is the sum of the jitter on each link on the path. It is important metrics especially for audio or video transmission. So the path with minimum jitter is preferable. Jitter also can be calculated from hello packet arrival time difference.

J = Δ(HAT) where J is jitter

HAT is hello Arrival time;

For example let say node A and node B is neighbor in the same transmission range let say node A receive hello packet in interval of 5ms if this is changed to for example 6ms the jitter of the link will be 1ms.

In the same fashion of delay, jitter on the path will the sum of all jitter on the links that creates the paths.

Hello packet in AODV is used for local connectivity management. Nodes send hello packets to their neighbors in some defined intervals. And neighbors always check the connection to their neighbor when they received hello messages in the defined interval unless it mean there is disconnection. And the route on this link will be updated. Hello packet in other terms is the same as Route Reply (RREP) message with Time to live (TTL) equal to one. In the normal AODV the header of hello packet is only contains the address of the nodes who initiates it. In our paper we have modified this packet to include available bandwidth, Delay and Jitter found on the link the modified hello packet will be the same as the following:

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |R|A|    Reserved     |Prefix Sz|               |
+-+-++-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Destination IP address                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Destination Sequence Number                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Lifetime                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
+ Available bandwidth | Delay |jitter |                         +
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4 2 Modified hello packet header

A hello message is used to gather Quality metrics that are available bandwidth, delay and jitter. As explained above. In hello messages we have added information about metrics discussed above we have set their length at 8 bits each so we have added some data's to this control messages this may increase the overall overhead. These metrics we have explained above later combined and used as composite metrics on which routing decision based during the route discovery process.

4.2.1.1.4 Combination of the metrics

Another issue raised with metrics is how to combine multimeric in to single composite metrics. As we have discussed above bandwidth is concave metrics while delay and jitters are additive metrics. Combining these metrics is very important as it reduces computational complex. For example selecting path based on two or more metrics is NP complete problem. It needs optimization algorithm to get the best solution according to paper [1]. In order to simplify this we combined those metrics while maintain the effects of all metrics. As paper [28] stated finding available band width can be simplified to finding the tight link (bottleneck bandwidth) between source and node. This is why we call available bandwidth as concave metrics. Here we compare those tight links (bottleneck bandwidth) or the links with the minimum bandwidth of each path.in this case the one with large bottleneck will be the better. The other metrics we have considered are delay and jitter. Since they are additive metrics we just take the total value for both of them. We use the composite metrics combined from available bandwidth, delay and jitter. We can combine them as follows.

Cost of one path can be combined as:

$$PC = \frac{B\min}{(Dt + Jt)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [3.4]$$

Where PC is the total cost of the path

B_{min} is the minimum bandwidth (bottleneck bandwidth) on the given path

Dt is total delay

Jt is total jitter on a given path respectively.

A large value of PC implies the quality of the path is better; that means the path has large available bandwidth when compared to others; while delay and jitter of the path is low. On the other hand, if the value is small this is an indication that the quality of the path is low. In our enhanced AODV protocol the routing decision prefers the largest value of the PC.

4.2.2 Enhanced Route Discovery Process

As we have explained above, hello messages distribute nodes metrics information to neighbors. In AODV neighbors information stored in neighbor management table. In the enhanced information we have added available bandwidth, delay and jitter value to the neighbors management table. When the route discovery process started it takes initial values from this table.

In the above section we have discussed how quality of service metrics calculated and combined as a single path cost. In this section, we presented how the original AODV protocol is enhanced using those QoS metrics. We already described the AODV algorithm in second chapters. The original AODV is a best effort routing solution for MANET in which routes are selected based on distance (number of hops). The protocols have three parts. The first one is local connectivity management, the second one is a route discovery process and the third one is route maintenance process. In our research, we are going to modify both parts.

The route discovery process starts whenever the source node wants to transmit data to the destination node. The node first checks its route table entry, whether there are a fresh path to destination or not. If path found data immediately transmitted if not Route discovery process starts.

RREQ (Route Request) is initiated by node to discover the path to destination. It is broadcasted all nodes until it reaches destination or until it reaches nodes which have a fresh route to destination. Along the path whenever RREQ reaches some node that intermediate nodes creates reverse forward path, which later used by route reply. RREQ includes a QoS requirement for path selection.

RREP (Route Reply) route reply initiated when intermediate node have a fresh route to destination or if the node itself is destination node. It returns route which full fill QoS requirement.

RERR (Route Error) is used to report if link is failed. The link will be maintained if its lifetime is not expired.

As pointed out in above, AODV on demand best effort protocol, which does not consider QoS totally. This means the path is simply selected based number of hops or distances. Nevertheless, as already stated, our primary aim is to plan the protocol, which considers quality of services. This QoS is described by different metrics. In our research we focused on three metrics which include bandwidth, delay and jitter. In the following section we are going to discuss how QoS metrics are included in the AODV.

4.2.2.1 Improved AODV RREQ packet

RREQ or route request packet is responsible for route discovery. When nodes wants to deliver some packets it first checks its route entries. If the route exists, it uses it; if not the node will initiate the route request packet. Route request packet contains, source IP address, source node sequence number, destination IP address, destination sequence number and broadcasting id. Broadcasting ID with source IP addresses uniquely identify the packet. In our enhanced AODV RREQ messages will be used for the following:

1. RREQ messages will have headers which contains three metrics available bandwidth, delay and jitter in addition to hop count.
    a. Available bandwidth is gathered from the intermediate node by comparing it with a first node if the bandwidth of the second node is small it will be registered finally minimum bandwidth (bottleneck Bandwidth) will be registered when RREQ reach destination.
    b. Delay and jitter are additive metrics as we already said so the RREQ simply sum up all delay and jitter found in the link on the path
    c. Finally, when it reaches the destination the path costs calculated as follows

$$PC = \frac{B\min}{(Dt + Jt)}$$

The algorithm for RREQ is as follows:

Algorithm 1 RREQ messages

```
1. Source node initiates RREQ messages
2. Take initial link available Bandwidth, delay and jitter as
   input
3. If(intermediate node){
   Bandwidth=min(prev_bandwidth:curr_bandwidth)
   Delay = delay+curr_delay
   Jitter = jitter + curr_jitter
   }
4. Else if(destination node)
   {
   Pc =bandwidth/(delay + jitter)
   }
5. Call RREP()
```

4.2.2.2 Improved Route reply packet

Route reply packet is generated by destination node or the node which have a fresh route to the destination. As we stated earlier the freshness of the route is determined from the sequence number. In traditional AODV protocol, Route reply packet is generated as soon as the RREQ packet reaches the destination. When RREQ propagated through network each node creates reverse forward route. That is, for example, if RREQ is generated by node A and propagated to B and C. Node C creates reverse forward route to the source node A as C→B→A. This reverse forward node is used by RREP.

Route reply involves route decisions on our enhance AODV route is selected based on the quality mentioned above. If the cost of the path is equal the route will be based on the hope count or distance.

Algorithm 2 route reply

```
Input pathpc;
For i = 0 to max number of path{
 For j = 1 to max number of path
{
If(pathpc[i] > pathpc[j]
{
Select pathpc[i];
Else
Select pathpc[j];
Else if (pathpc[i] = pathpc[j]
{
Select path with minimum hop count
}
Send back selected node
}
```

Let see the following scenario:

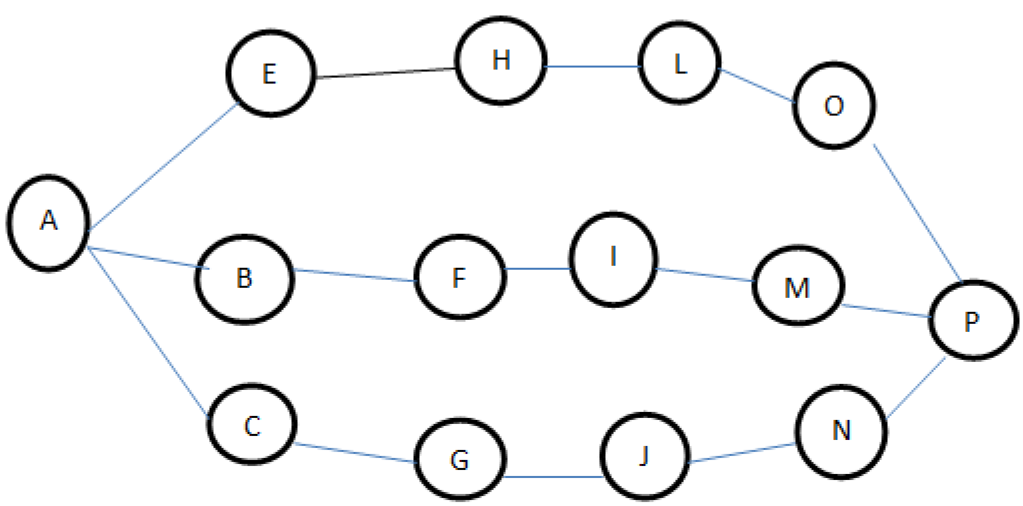

Figure 4 3MANET Scenario networks

In this scenario node *A* wants to send data to node *P*. At this time node *A* has two options the first one is getting recent unexpired route to node *P* from the route table if its lucky, second option is to find a brand new route by propagating route request packet. The first one is held if there is a fresh route to node *p* that as we have mentioned before route have life time when they stored in route table if the route is not expired, then node *A* will use it, on the other hand if the sequence number in RREQ is greater than that in route table the route will not be used. If the first option doesn't hold, then node *A* starts route discovery processes by broadcasting RREQ packet. Then the packet is broadcasted as described in *algorithm 1*.

After the RRE Q reaches the destination in our case node *P*. the general algorithm seems the following.

Algorithm 3 scenario

```
Step 1 node A wants to send data to P
If(route to P exist){
SendTheData()
}
Else{
Send RREQ()
}
If(node = P)
{
Send back RREP
}
```

Route reply process will be done by using the QoS metrics gathered from the path. This metric is Available bandwidth, delay and jitter. We combine them into one single path cost as follows:

$$PC = \frac{B\min}{(Dt + Jt)}$$

Where: Bmin is the minimum bandwidth (bottle neck bandwidth) on the path.

Dt is total delay on the path

Jt is total jitter on the path

From this combination we can see that the path with large value is likely, had good available bandwidth and less delay and jitter.

Then the path selection algorithm will be as follows

Let say we have path1 and path2

Algorithm 4 Route decision

```
If(path1 cost > path2 cost)
{
Select path1
}
else if(path1 cost<path2 cost)
{
Select path 2
}else
 {
Select path with minimum hopcount
}
```

In AODV all valid routes will be stored; until their life time expired; the information stored in the table includes, destination IP address, destination sequence number, as well as hop count from source to destination. In the enhanced AODV path cost information is stored in routing table in addition to those information we have mentined.

We combine the whole algorithm as follows:

Algorithm 5 Route Discovery Process

```
1. Input source bandwidth, delay, jitter
2. Send RREQ
3. If(destinationnode)
   PC = bandwidth/delay + jitter
   Make route decision as
   For I = 0; I up to max path number {
   For J = 1; J up to max path number {
   {
   if{pathpc[I] > Pathpc[J])
   {
   Select path[I]
   }
   Else{
   Select path[J]
   Else
   {
   Select path with less hop count
   }
4. Send RREP
5. End
```

The route discovery process is responsible to discover new routes if there is no valid route in the routing table. It is a combination of route requesting and route replying messages. Route request is sent from source node and route reply is replied from destination.

4.3 General operation of the enhanced AODV protocol

In this section we combined the entire above algorithm and put them in one algorithm as follows in this algorithm the operation of how to gather metrics and how to combine those metrics in to one path cost then finally how these QoS metrics was integrated in the path discovery process is addressed.

Algorithm 6 Over all algorithm

```
1. Gather metrics
2. If (dataTosend()&&validroute)
   {
   sendData()
   }else
   Goto third step
3. Send RREQ()
4. If(destinationNode)
   {
   Call RREP()
   }else
   forwardRREQ()
5. while(validRouteTime && RouteBroken)
   Call RERR()
6. End
```

4.4 MANET Scenario with enhanced AODV protocol

4.4.1 Scenario one: RREQ flow

In this section we have presented sample ad hoc networks with seven nodes. The nodes are all equal, and demonstrated in the fig 4.4 below. In this scenario we have a node *S* and node *D* which are source and destination respectively. When node *S* wants to send data it initiates RREQ messages. Then RREQ messages will be flooded in entire networks as depicted in the following picture.

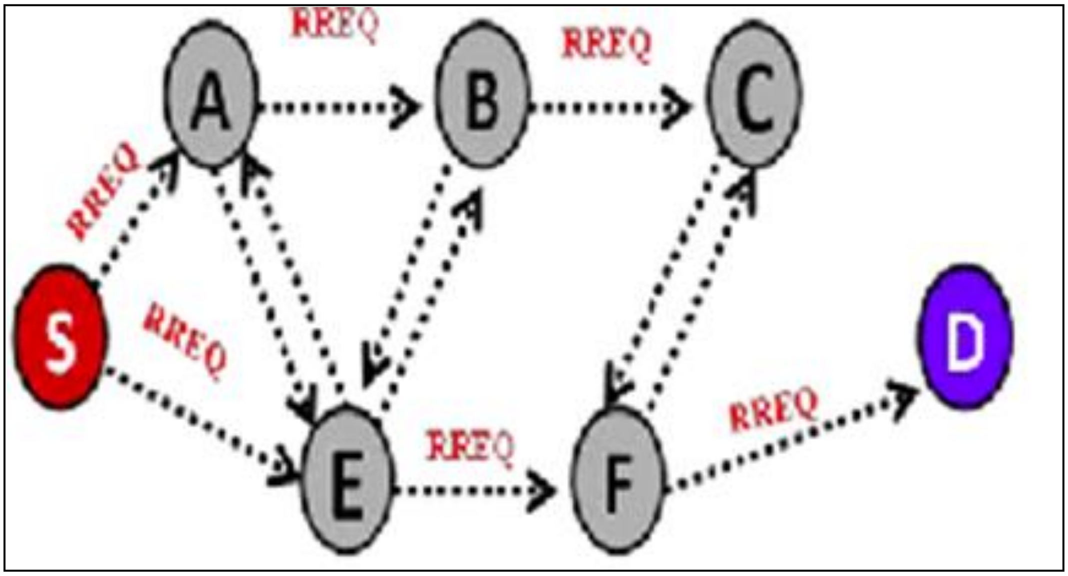

Figure 4 4Scenario: RREQ flooding [15]

When S node initiates requests the RREQ message will reach the destination node D possibly by the following path.

PATH 1 S→A→B→C→F→D

PATH 2 S→A→E→F→D

PATH 3 S→E→F→D

PATH 4 S→A→E→B→C→F→D

PATH 5 S→A→B→E→F→D

When RREQ sent it gathers the path cost of each path. Then RREP decides the best path. The decision is primarily based on the path cost which is explained above. If two paths have equal best path cost the evaluation will be based on hop count.

For example: Let say path 2 and path 3 have equal best path cost

PATH 2 S→A→E→F→D pc=2

PATH 3 S→E→F→D pc=2

Then the decision now will be based on hop count. Based on hop count obviously path 3 will be the shortest.

PATH 3 S→E→F→D pc=2

According to our enhanced protocol two paths will be stored in the route table for singe path inquiry. So path 3 will be the primary route from node S to node D and path 2 will be used in case the primary path broke up.

4.4.2 Scenario 2 path selection procedure

In the second scenario we are going to see our modified AODV algorithm in the following network environment and assumption.

Assumption:

1. Links between each nodes is symmetrical link
2. The route is not expired
3. Node A is source node and node G is destination

The network seems the following;

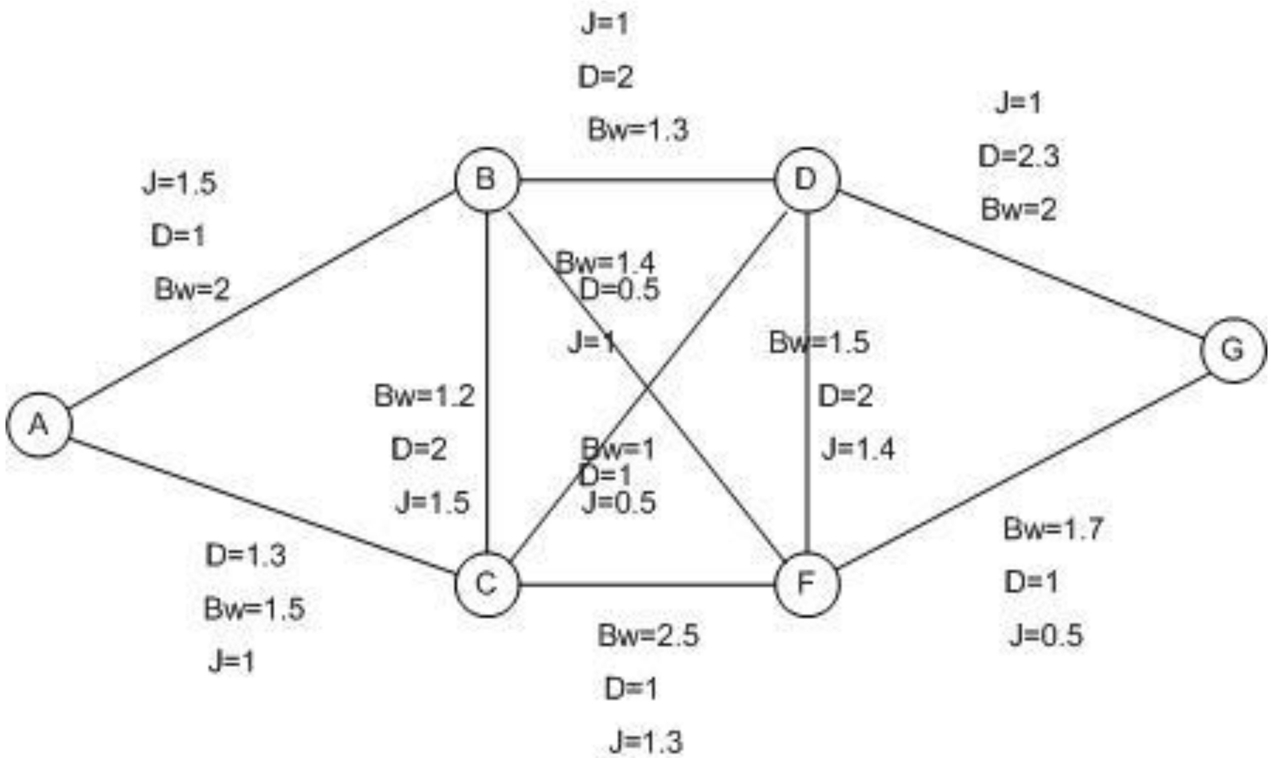

Figure 4 5 Scenario: modified AODV route selection

In the above picture let say node A is source node and node G is destination node. As described above when nodes have data to transmit it initiates the route discovery process. Before route discovery process commenced the value of QoS metrics will be gathered by hello messages and stored in neighbor management table as shown above in fig 3.6. Here in the following we are going to show how path discovered.

RREQ messages disseminated to get the path to destination. During this time it calculates the path costs as follows.

1. It selects the bandwidth bottleneck on each path. Bandwidth as stated in above is concave metrics in which the capacity of the path in terms of bandwidth is gained by taking its bottleneck. In the above scenario, let's see, two possible paths

   P1 = A→C→F→G

   P2 = A→B→D→G

   Are two disjoint paths

When RREQ transmitted from Node A to D it compares bw(A,B)and bw(B,D) takes the smallest. In our case the smallest is bw(B,D) then it compares this with bw(D,G) again in our case bw(B,D). So the bandwidth bottleneck on this path is on the link between node B and node D.

Where bw(B,D) means the available bandwidth between node B and node D.

Available bw = 1.3

2. The other metrics found on our path is delay and jitter. Both as described in section 3.3.1 these two metrics are additive metrics. So during RREQ dissemination it adds up both metrics to get total delay and jitter on the path. In our case, for example

Total delay = d(A,B) + d(B,D) + d(D,G) = 1+ 2+2.3 = 5.3

Total jitter = j(A,B) + j(B,D) + j(D,G) = 1.5 +1 +1 = 3.5

3. Finally the path cost is computed as equation explained above in section 3.3.1.4 by the following formula

$$PC = \frac{B\min}{(Dt + Jt)}$$

P1c = 1.3/(5.3+3.5) = 1.3/8.8 ~ 0.15

By the same procedure path cost for path 2 will be

P2c = 1.5/(3.3+2.8) = 1.5/(6.2) ~ 0.24

Then the path cost will be stored in in route table along with hope count. Then route Reply messages compare paths based on their path costs as follows.

1. Path with large path cost means the path have better bandwidth and minimum delay and jitter. So path with largest cost will be selected.

2. If two paths have equal path costs then the evaluation will be based on hop count. The path with minimum hop count will be selected.

In our above scenario path will be selected as best path.

4.4.3 Scenario 3 route maintenance

In the following scenario we are going to see how route maintenance is handled in our enhanced AODV protocol.

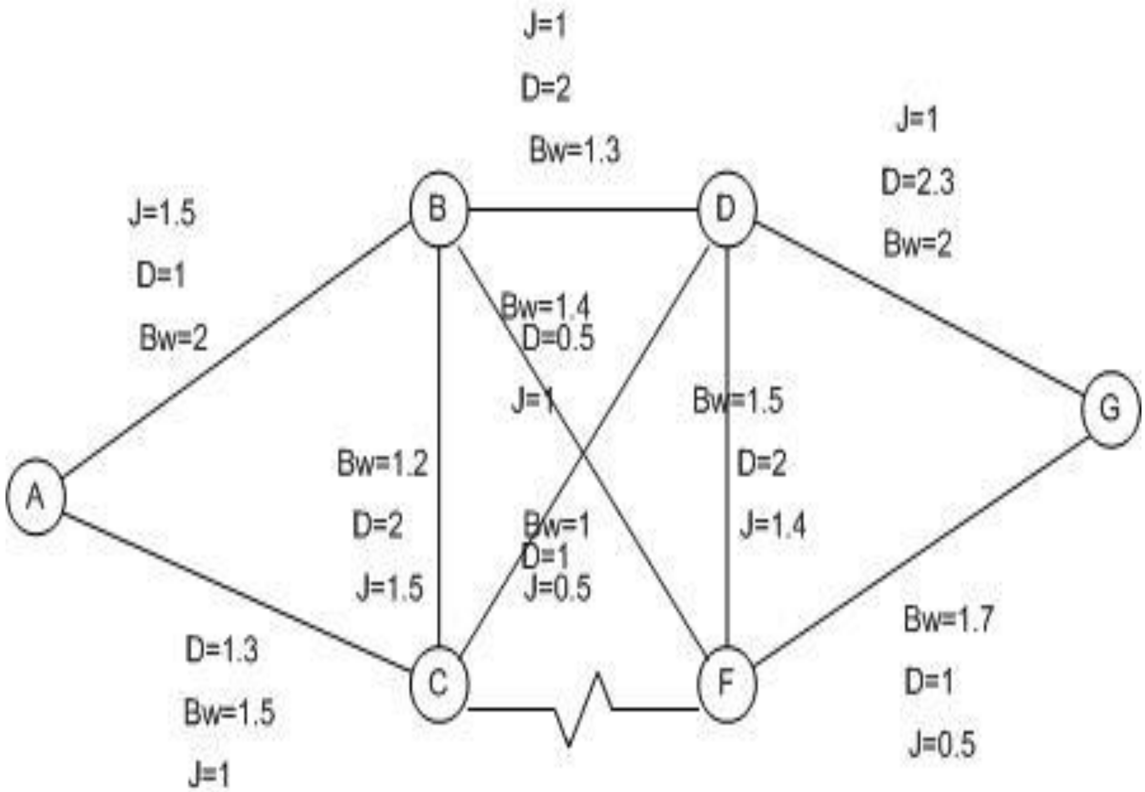

Figure 4 6 Scenario 3: route maintenance

In the above picture let say:

1. Path 2 (A→C→F→G) is selected
2. It life time is not expired
3. However, it is broken between node C and F

Then path disconnection is detected by hello messages, then reported back to node proceeded by the broken link. The route discovery will be initiated again.

To wind up in this chapter we presented how our enhanced AODV protocol works the feature of AODV we did not mentioned will be used as they are in original AODV. The QoS incorporated

AODV we discussed was implemented and simulated over network simulator (NS2). In the next chapter we are going to shed light on how we have implemented and simulated our enhanced AODV protocol.

4.5 Summary

In this chapter we have presented the overall enhancement of the AODV protocol in order to incorporate QoS which is important for some application such as voice communication. We start by describing the architecture of our enhanced protocol. Hello messages, RREQ and RREP are the component we have modified. A hello message is used to distribute about available bandwidth between neighbor node. Each node calculates its available bandwidth by listening to its channel. Listening will be done at MAC layer by using busy time of the channel, then the nodes, then subtract the consumed bandwidth from the raw bandwidth to get the available bandwidth. Then, using the hello messages the node transmits the information about its available bandwidth to its neighbors. Then the bandwidth information is then stored in the neighbor management table. In addition to bandwidth information delay and jitter also calculated from hello sent time and hello received time.

When any nodes want to transmit data it initiates a route request by generating RREQ packet. In the our enhanced AODV metrics information of the first node is inputted in the RREQ. Then RREQ is flooded in the entire network. When an intermediate node accepted the RREQ packet the bandwidth in RREQ is compared with the nodes available bandwidth than the minimum (to find the bottleneck) is selected. This is used to get the bottleneck bandwidth of the path. Delay and jitters are additive metrics so the sum of all delay and jitter of each link on the path will be stored finally. As soon as the request packet reaches the destination the metrics convert to the composite metrics as path cost. Path cost is the ratio of the bottle neck (minimum bandwidth) the path to the summation of total delay and total jitter. The reason why we have combined this metric is to simplify the path finding computation. Then after that RREP is triggered.

When the request reaches the destination, as we have said earlier the path cost is computed from the individual metrics (bandwidth, delay and jitter). Then RREP is going to compare the path cost of all the possible path from source to destination. Then the one with the largest path cost will be the best path. Here largest path cost means that the path has a large bandwidth bottleneck (tight link) and minimize delay and jitter.

Finally AODV uses two tables. The first one is the one which stores neighbor information. In our enhanced AODV. This table holds bandwidth, delay and jitter information in addition. The second table is the table which is used to cache routers, this table originally holds the route life time and hop count information. But now we have added path cost information on this. Then now the path will have time out, hop count and path cost; when it's stored in the table.

In this chapter generally we have presented the architecture of our enhanced AODV protocol. In the next chapter, we are going to discuss about its implementation and simulation.

CHAPTER FIVE

IMPLEMENTATION AND PERFORMANCE EVALUAITON

5.1 Introductions

We have already described how our enhanced AODV works in chapter four. In this chapter, we are going to discuss how we have implemented and evaluated our new enhanced protocol. For the implementation, we have used network simulator version 2.35. After we have simulated then we evaluated our enhanced AODV by comparing with the original one. As evaluation metrics we have used throughput, packet Loss ratio, end to end delay,and overhead.

In order to create scenarios for evaluation of our new protocol we used Tcl script. In order to evaluate our protocols performances we used a constant bit rate traffic generated (CBR).

NS is discrete-event based network simulator widely used for analysis of computer networks. Especially it is used by many researchers in ad hoc simulation. It embeds the operation of the TCL script built on top of two programming languages C++ and OTCl. TCLCL is another language used as connecting link between C++ and Otcl. In NS2 physical activities such as packet transmission are converted to events. Then events are executed in the order in which they are queued and when they are scheduled to occur. NS2 is a very useful tool to simulate complex network operation. NS2 uses a timer for event scheduling and monitoring for each protocol implemented in ns2 unique timers will be used. One drawback of ns2 its inability to collect the output and plot them so that the can be presented well. However; they generate trace files which tracks all the network traffics. In order to filter those trace files and calculates the necessary performance metrics we used AWK script.

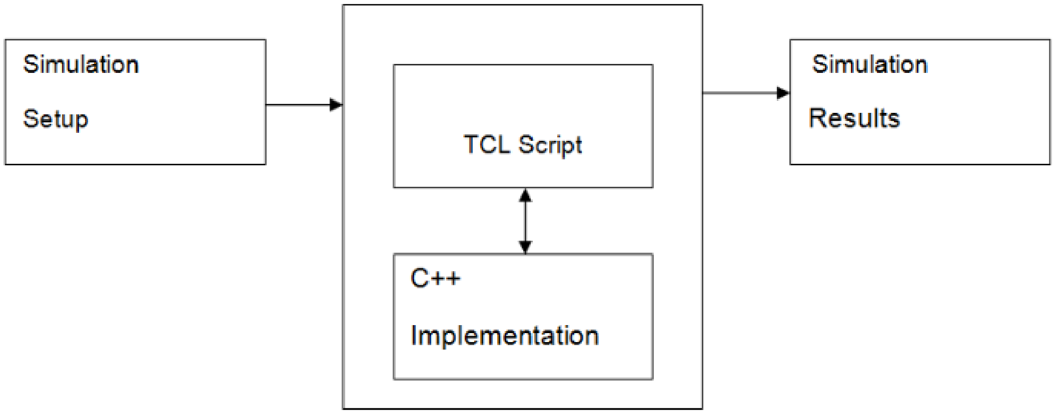

Figure 5 1 NS2 Operation Phase

5.2 Simulation environment and assumption

In order to make our evaluation more efficient we create different simulation scenarios. The first scenario is based on the number of nodes. We have shown in figure 5.2 sample screen shot from the simulation.

a) Simulation parameters

Channel Type	Channel/Wirelesschannel
Radio-Propagation Model	Propagation/Tworayground
Network Interface Type	Phy/Wirelessphy
Mac Type	Mac/802_11
Interface Queue Type	Queue/Droptail/Priqueue
Antenna Model	Antenna/Omniantenna
Max Packet In Ifq	50
Number Of Nodes	5, 10, 20, 50,100 (To Check Effect Of Node Density)
Traffic Types	Constant Bit rate (CBR) traffic generator

Table 5 1Simulation parameters

b) Assumption

We assumed the following points during the simulation

- We assumed constant movement of nodes
- Symmetrical connection between nodes means; connection from A to B and B to A is in equal link quality.
- We did not consider the effect of the physical layer

c) Simulation scenario

In order to make our evaluation more effective and fair, we have evaluated our works by using a different number of nodes. As explained in table 5.1 we have used a node number from 5,10,20,50,100. In figure 5.2 we have showed sample screenshot for 20 nodes scenario. Sample Tcl scripts for creating network environment is presented in appendix A.

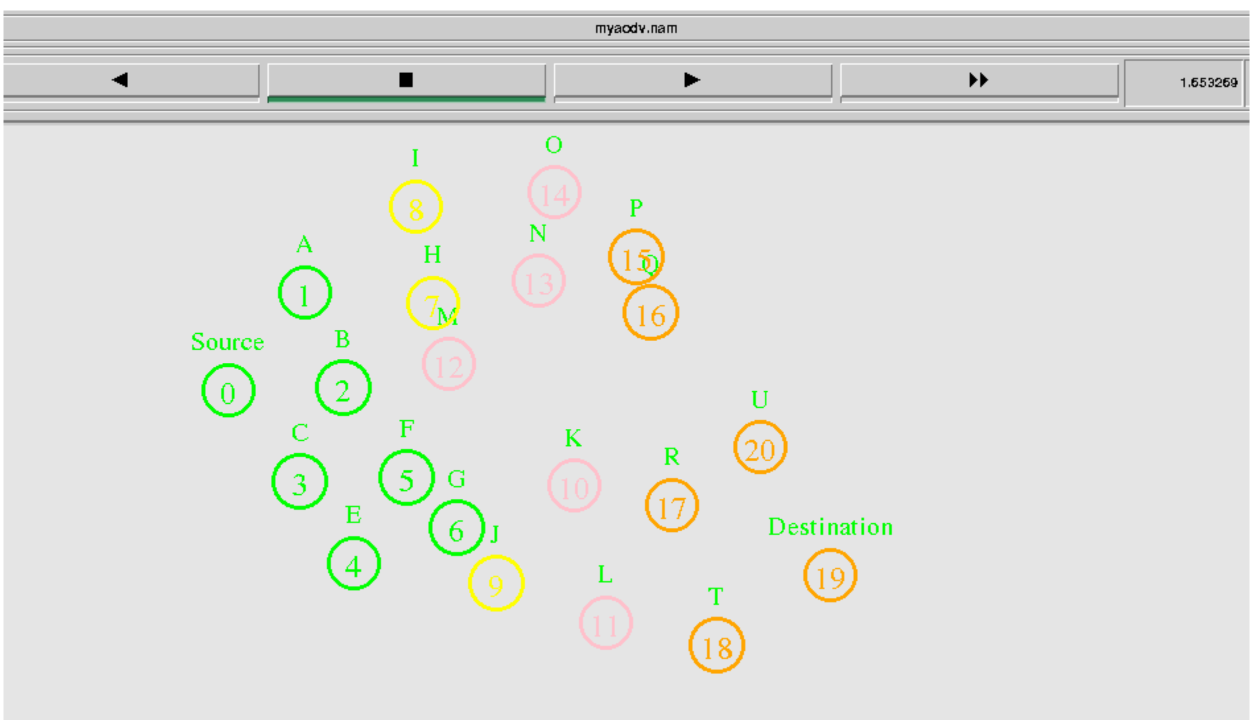

Figure 5 2 *simulation scenario*

5.3 Result and evaluation

Performance evaluation metrics are the metrics we used to evaluate our protocol performances. They are sometimes called output metrics; because they are generated from the output scripts of the protocols. As stated in paper [50] throughput, average end to end delay, packet loss ratios are important metrics for evaluating performance. Ns2 have trace facilities which traces the files of transmitted during simulation time. The trace files, records all network layer, application layer and make the layer data exchange between nodes. In our work we have calculated the throughput, end to end delay, packet loss ratio and energy consumption. We used AWK script for to calculate these metrics from trace files. In the following section we are going to present the results for these metrics for both original AODV and our enhanced AODV protocols.

5.3.1 Throughput

Throughput is the amount of packet reach destination per second. It is the measurement at the network layer it includes application packet plus network layer control packet. Here in our research, we used throughout as an important metric as evaluation metrics. We have compared the AODV and the enhanced AODV as the result is shown in the above table the enhanced AODV shows better results. We used (constant bit rate) CBR traffic in during simulation, and then we have compared both the modified and original AODV. Throughput can be calculated as the ratio of totally received data to given simulation time [48].

$$Throughput = \left(\frac{recvdSize}{stopTime - startTime}\right) * \left(8/1000\right)$$

Where recvdsize is the amount of packet transmitted in that time interval between starttime and stoptime. Throughput is measured in kbps. The following figure 5.3 we have presented the throughput of both the original and modified AODV in terms of node density and pausing time.

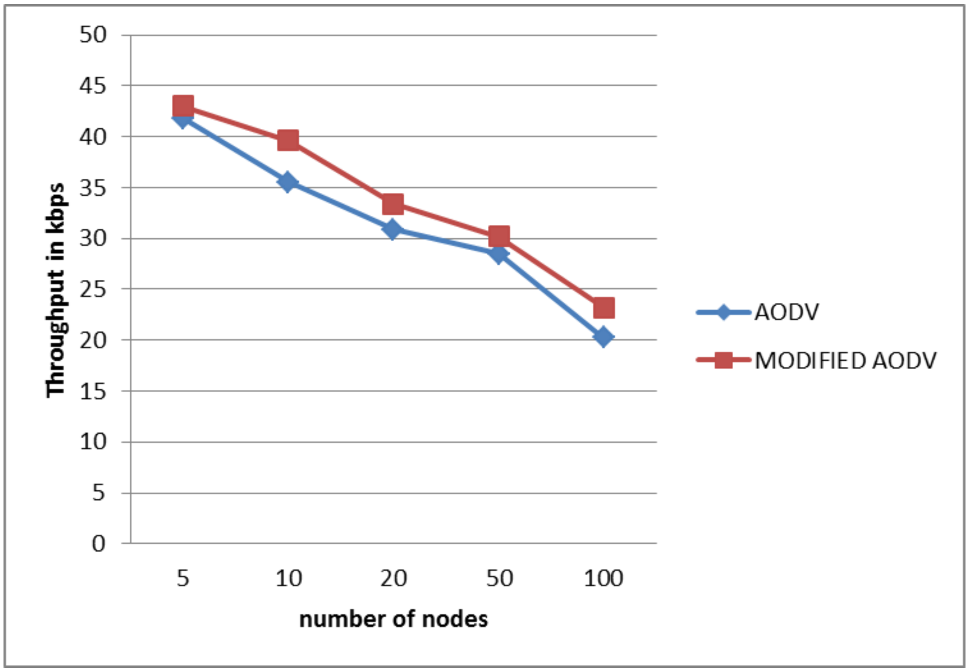

Figure 5 3 Throughput variation in terms of number of nodes

As depicted in figure 5.3 in terms of throughput our new protocol shows good performance. As the amount of nodes increase; throughputs decrease for both protocols.

5.3.2 Packet loss ratio

Packet loss ratio is the ratio of lost packet per packet sent at one time between the source node and destination node. It is a good way to see the performance of protocols. Some application can tolerate packet loss while others not. For example packet loss in multimedia transmission can only result in degradation of quality of the image or video. However, for other files it may be resulted in a cut off of some part of the data. As depicted in the figure 5.4 in terms of packet loss ratio the enhanced AODV shows better results.

$$packetlostratio = (\frac{drippedpacket}{totallysentpacket})(100)$$

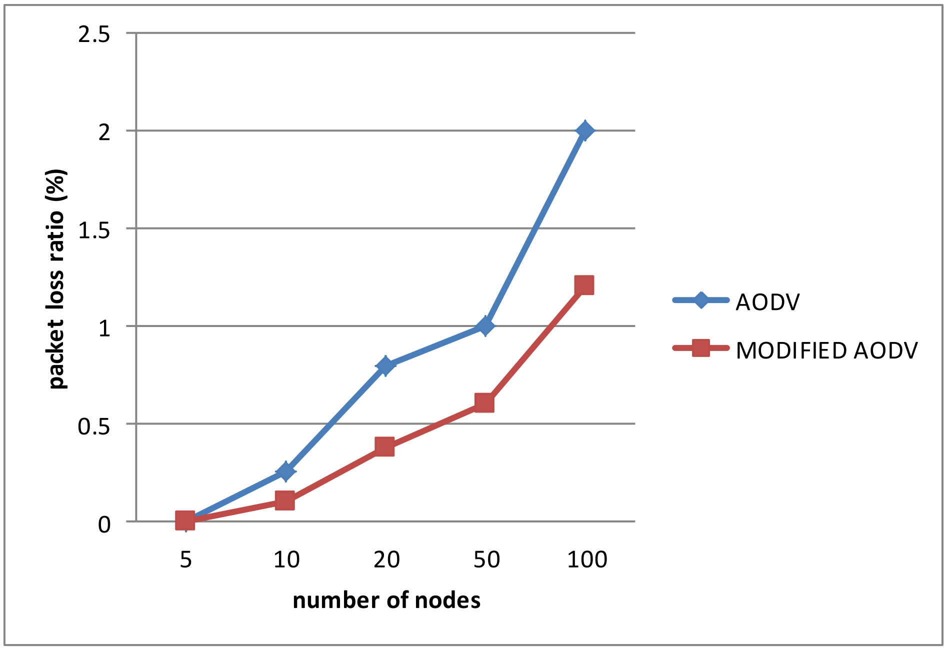

Figure 5 4 packet loss ratio in terms of number of nodes

As shown in figure 5.4 packet loss ratio is increased with the number of nodes. with only five nodes there is no loss but as the number increased the loss percent also increase, as stated in [48] packet loss ratio up to one present do not hinder the qulaitty of multimedia data's. generally , the from the result we can conclude that the enhance AODV have less packet loss than the original one.

5.3.3 End to end delay

End to End Delay is the average time taken by a data packet to arrive in the destination. It also includes the delay caused by route discovery process and the queue in data packet transmission. Only the data packets that successfully delivered to destinations that counted. End to end delay of individual packet can be calculated by the formula shown below.

```
start = start_time[packet_id];
end = end_time[packet_id];
end to end delay = end - start;
```

The lower value of end to end delay means the better performance of the protocol. As depicted in the following the graph end to end delay of the packet is our enhanced protocol shows better result.

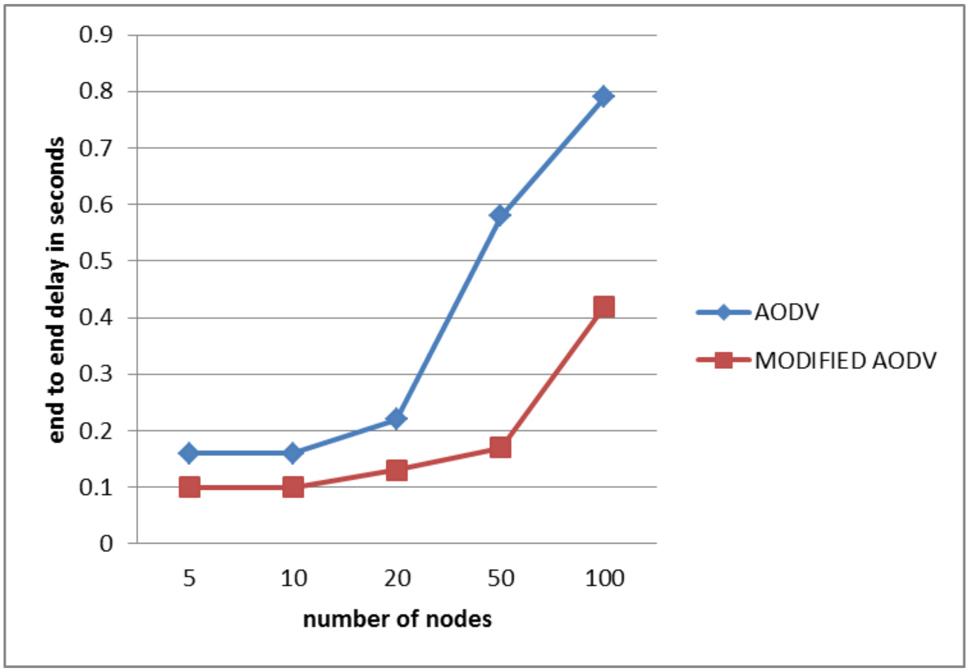

Figure 5 5 End to End delays in terms of number of nodes

As depicted in the above graph average end to end delay is increased as the number of nodes increases. The enhanced AODV have less end to end delay relative to the original AODV.

5.3.4 Over head

Overhead is the term used to describe the control packet in the protocol; control packets are, for example, those packets which used for path discovery in our case. Since we have added QoS consideration to the original protocol the overhead is little bit increased in the modified AODV.in hello message we have added information about metrics, such as available bandwidth, delay and jitter. In a RREQ also the value of these metrics incorporated during broadcasting. When the route is replied it the route reply packet holds path cost in addition to hop count. Therefore, the enhanced AODV are more overhead than the original.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Introduction

In this chapter, we are going to give the summary of what have done in this paper and draw conclusion based on the result presented in chapter five. Also in this chapter we gave a recommendation on the application scenario in which our protocol can work well. Finally, we suggested to which direction our work could be extended under future work section.

In this paper, we have proposed QoS extension of the AODV protocol for mobile ad hoc networks based on available bandwidth, delay and jitter. Based on the proposal we have designed our new enhanced protocol. To gather information about QoS metrics our protocol uses hello messages; available bandwidth, delay and jitter on each link gathered and used for path selection by route selection.

Our enhanced protocol was implemented and simulated in network simulator (ns2) version 2.35 one of the network simulator used by many researchers. Our protocol showed better results in terms of throughput, end to end delay and packet delivery ratio, while over head little bit increased when compared with original AODV.

6.2 Conclusion

MANET as we already described it; have unpredictable link. Providing quality of services in such networks is difficult due to this. Even if QoS provision in MANET is difficult; due to their potential application many researchers gave their full attention to the matter. As we have described in the second chapter MANET have application in the disaster area, temporary laboratory, in police departments, in firefighting and so on. Generally they are the only means of communication when there is damage on the other networks. They are characterized by dynamic configuration, link instability, high mobility, frequent topology change and soon. So providing QoS is difficult because of these characteristics. QoS of services can be provided by reserving resources on the router for application need quality services as in infrastructure based networks. However, since MANET is infrastructure less, it is difficult to reserve resources. Because of this the best approach in providing QoS in MANET is by QoS routing. QoS routing is the routing mechanism in which the quality of link such as link bandwidth, link delay and so on is considered when finding the best route. In our work we have enhanced AODV protocol, which is originally best effort services.

AODV is the best effort protocol that is designed for MANET networks. It considers only hop count as a criterion to select a path during path discovery. We have included in our work available bandwidth, delay and jitter in addition to hop count when path is selected. All the three metrics calculated locally by each node and the information are distributed to neighbor nodes by using Hello messages. Each node calculates its available bandwidth by listening to its channel. Listening will be done at MAC layer by using busy time of the channel, then the nodes, then subtract the consumed bandwidth from the raw bandwidth to get the available bandwidth. Then, using the hello messages the node transmits the information about its available bandwidth to its neighbors. Then the bandwidth information is stored in the neighbor management table. in addition to bandwidth information delay and jitter calculated from hello sent time and hello received time. Delay and jitter also starred in the neighbor management table.

When any nodes want to transmit data it initiates a route request by generating RREQ packet. In the enhanced AODV metrics information of the source node is inputted in the RREQ. Then RREQ is flooded in the entire network. When an intermediate node accepted the RREQ packet the bandwidth in RREQ is compared with the nodes available bandwidth than the minimum (to find the bottleneck) is selected. This is used to get the bottleneck bandwidth of the path. Delay and jitters are additive metrics so the sum of all delay and jitter of each link on the path will be stored finally. As soon as the request packet reaches the destination the metrics convert to the composite metrics called path cost. Path cost is the ratio of the bottle neck (minimum bandwidth) the path to the summation of total delay and total jitter. The reason why we have combined this metric is to simplify the path finding computation. Then after that RREP is triggered.

When the request reaches the destination, as we have said earlier the path cost is computed from the individual metrics (available bandwidth, delay and jitter). Then RREP is going to compare the path cost of all possible paths from source to destination. Then the one with the largest path cost will be the best path. Here the largest path cost means that the path has a large bandwidth bottleneck (tight link) and minimize delay and jitter.

Finally AODV uses two tables. The first one is the one which store neighbor information in our enhanced AODV. This table holds bandwidth, delay and jitter information in addition to other data's. The second table is the table which is used to cache routes, this table originally holds the route life time and hop count information. But now we have added path cost information on this. Then now the path will have time out, hop count and path cost; when it's stored in the table.

We have finally implemented our works in network simulator 2 (ns2), after implementation, we have evaluated by comparing both the original AODV and the enhanced one. We have compared them in terms of throughput, end to end delay, packet loss ratio and overhead. As the result shows the enhanced AODV performs better in terms of throughput, end to end delay, and packet loss. However; in terms of overhead, since on some control packet such as hello message, RREQ and RREP header is added in enhanced AODV the overhead is little bit increased.

6.3 Recommendation

In this paper, we have investigated QoS metrics that is important for providing quality of services, then we have used available bandwidth, delay and jitter as metrics to enhance the AODV protocol; which is originally only best effort services. We have evaluated our protocol performance and compared them with the original one by using CBR traffic which is related to multimedia codec. Based our results we generally recommend the application area where the enhanced protocol can be used as follows:

- Our new enhanced protocol can be used to transmit audio files with good performance but add initial delays. An application such as voice over IP can use our new enhanced. Voice over IP is a connection oriented application so the delay in initial can be included in the call set up process and after Quality path is selected it can be fairly used to transmit voice data's.

- Also, any data's other than, multimedia such as FTP can use at a lower rate in order to minimize packet loss.

Quality of service provision as we already stated it is the hot research issues currently. Even if it is difficult to guarantee the Hard QoS provision in MANET but QoS routing can be more enhanced in the future. We recommend the following direction for anybody interested to further our work. In our paper we tried to enhance the already existed AODV protocol for MANET. We added QoS provision mechanism using QoS routing approach. We put in consideration metrics such as bandwidth, delay and jitter. However; for further direction we recommend the following direction:

- There are more metrics that can hinder performance of routing protocols as well as provision of Quality services. So in the future one can extend our work by studying more metrics and add them to route making decision.
- The other things that make difficult QoS provision in MANET is frequent topology change. There are topology control algorithm that is already existed so one can combine topology control algorithm with our work to make it more efficient

Appendix

A. TCL script (Simulation script)

Myaodv.tcl (our simulation script)

```
#
#simulation script written by Gemechu to simulate modified qos enabled aodv protocol
#

#setting Simulation Environment
set opt(chan)    Channel/WirelessChannel;    #channel type
set  opt(prop)        Propagation/TwoRayGround;      #radio-propagation model
set  opt(netif)     Phy/WirelessPhy;                  #network interface type
set opt(mac)     Mac/802_11;                  #MAC type
set   opt(ifq)              Queue/DropTail/PriQueue; #interface queue type
set opt(ifqlen)  50;                          #max nbr of packets in ifq
set opt(ll)      LL;                          #link layer type
set opt(ant)     Antenna/OmniAntenna;         #antenna type
set opt(rp)  MYAODV;                          #routing protocol
set opt(x)       1000;                        #x dimens_ion of the topography
set opt(y)       800;                         #y dimens_ion of the topography
set       opt(stop)                  600.0; #simulation time
set opt(start-src)     1
set opt(stop-src)     600
set opt(nn)   20
set    val(energymodel)             EnergyModel ;#energy model
set val(initialenergy)  100

#creating simulator object
set ns [new Simulator]

#initilize trace and nam file
        set tracefd [open myaodv.tr w]
        $ns trace-all $tracefd
```

```
        #$ns use-newtrace
        set namtrace [open myaodv.nam w]
        $ns namtrace-all-wireless $namtrace $opt(x) $opt(y)
    #set up topology

        set topo [new Topography]
        $topo load_flatgrid $opt(x) $opt(y)
        create-god $opt(nn)
        set chan_1_ [new $opt(chan)]

        # For model 'TwoRayGround'
        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
     #setting phsical and mac layer variables

        Phy/WirelessPhy set freq_ 2.472e9
        Phy/WirelessPhy set RXThresh_ 2.62861e-09; #100m radius
        Phy/WirelessPhy set CSThresh_ [expr 0.9*[Phy/WirelessPhy set RXThresh_]]
        Phy/WirelessPhy set bandwidth_ 11.0e6
        Mac/802_11 set bandwidth_ 2Mb
        Mac/802_11 set basicRate_ 2Mb

    #node configuration
         $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 off \
                        -movementTrace off \
                        -channel $chan_1_ \
                              -energyModel $val(energymodel) \
                              -initialEnergy $val(initialenergy)\
                              -rxPower 35.28e-3 \
                              -txPower 31.32e-3 \
                              -idlePower 712e-6 \
                              -sleepPower 144e-9 \
                              -propdelay 10ms

     ###  Creating The WIRELESS NODES

           set n0  [$ns node]
           set n1  [$ns node]
     …….
     ……
     …..
           set  udp13  [$ns  create-connection  UDP  $n2 LossMonitor $n19 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"

     ### PROCEDURE TO STOP

           proc stop {} {

                             global ns tracefd
                             $ns flush-trace
                             close $tracefd
                             exec nam myaodv.nam &
                             exit 0

```

```
                        }

        puts "Starting Simulation........"
        $ns at 25.0 "stop"
        $ns run

```

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