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Optimal Path Selection for AOMDV Routing Protocol with Efficient Energy and Bandwidth in Mobile Ad hoc Network

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A Thesis Submitted to the Department of Computer Networking in Partial Fulfillment for the Degree of Master of Science in Computer Networking

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This is to certify that the thesis prepared by *Dawit Milkiyas*, titled: *Optimal Path Selection for AOMDV Routing Protocol with Efficient Energy and Bandwidth in Mobile Ad hoc Network* and submitted in partial fulfillment of the requirements for the Degree of Master of Science in Computer Networking complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Dedication

To: My Father (Milkiyas Benti)

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List of Acronyms

AODV- Ad hoc on demand Distance Vector

AODMV- Ad hoc On-demand Distance Multipath Vector

AOMDV- Ad hoc On-demand Multipath Distance Vector

AQOR - Ad hoc QoS On-demand Routing

CBRP - Cluster Based Routing protocol

DSDV - Destination-Sequenced Distance-Vector Routing

DSR - Dynamic Source Routing

DST - Distributed spanning trees based routing

FSR - Fisheye State Routing

GSR - Global state routing

IP-AOMDV - Improved Ad hoc On-demand Multipath Distance Vector

MANET- Mobile Ad hoc Networks

MMRE - Maximal Minimal Residual Energy

MSR - Multipath Source Routing

OLSR - Optimized Link State Routing

OTCL - Object-oriented Tool Command Language

OEAR - Optimized Energy Aware Routing

PDAs - Personal Digital Assistants

PAN - Personal area network

RREQ - Route Request

RREP - Route Reply

SMR - Split Multipath Routing

WRP - Wireless Routing Protocol

ZRP - Zone Routing Protocol

Abstract

Mobile Ad-hoc Networks (MANETs) are decentralized, self-configuring, and dynamic nature wireless networks which have no fixed infrastructure. These can provide several advantages, however Mobile Ad hoc Networks are energy and bandwidth constrained since nodes operate with limited battery power and limited bandwidth. Due to that, energy and bandwidth are the important parameters in order to design mobile ad-hoc network. How to find the efficient route for MANET routing protocol with efficient energy and bandwidth is the main goal of this thesis. In this paper, during route discovery process, the destination node receive the route request message only if it have enough battery power for transmitting the packet and the primary path for data transmission is selected between source and destination node based on maximal-minimal residual energy and maximum available bandwidth approach. The results of the simulation show that the new proposed protocol, which is Improved AOMDV (IP-AOMDV) can effectively improve the networks' packets delivery, increase throughput and minimize packet dropping ratio when compared with AOMDV protocol. NS2.35 simulation tool is used to evaluate the performance of both routing protocols.

CHAPTER ONE: INTRODUCTION

1.1 Background

An ad-hoc wireless network is a collection of devices/nodes that come together to dynamically create a network, with no fixed infrastructure or centralized administration [1]. In this network, the data packets sent from a source node to a destination is relayed through one or more intermediate nodes. A Mobile Ad-hoc NETwork (MANET) is an interconnection of mobile devices where wireless paths are used for multi-hop communications without any physical infrastructure [1]. In order to transmit the data packet, the MANETs provide communication between nodes by providing multiple routes between sources and destination. In MANETs, there is no central authority which control communication session between nodes which means they are infrastructure-less, dynamic network of collections of mobile devices which are communicated with each other without any centralized administration. During data transmission, a numbers of hops are required to exchange information between nodes. Each mobile node in MANET is acting as a router as well as a host. Mobile ad hoc networks are characterized by low channel bandwidth, limited energy, dynamic topology, and node mobility. Main application areas of ad hoc network are briefly described in [12].

Routing protocols have a great role in data dissemination across a network. In routing protocols, two major classifications are unipath and multipath where each node act as relay node to receive and transmit the information to other nodes [2]. Routing protocols in MANET are used to provide connectivity between different nodes and also responsible for communication. The role of routing protocol is not only establishing the path from source to destination but also finding a route which has high quality. The two major problems in MANET routing protocol are limited bandwidth and limited power of nodes which is how to balance the energy of nodes and the communication bandwidth. Due to that it is necessary to concentrate on the mechanism of delivering the packet at the destination node through efficient path by considering energy and bandwidth parameters. In MANET, there are several routing protocols which are used to transmit the packet from source to destination node. AOMDV is a MANET routing protocol that is used to find the multipath in route discovery process [3]. For multipath routing, if the primary path is failed due to some problems another alternative route can be used to transmit the data packets towards the destination and for improving reliable communication. In AOMDV protocol, the delay of multipath allows the source nodes to dynamically find its route. In this protocol, source node sends the route advertisement toward destination node by using the hop count value. Intermediate node receive the route advertisement and forwards route request control message through alternative path toward the destination node. When a route advertisement is received by destination node, the destination node keeps the hop counts and the list of next-hop in its routing table entries. The destination sorts out all the paths by maximum hop count value and finally the best route is selected and the data is forwarded through this route. In AOMDV, the Route Request (RREQ) control message propagates from source node to destination to find multiple reverse routes. The corresponding Route Reply (RREP) generate these reverse paths to the source node and the path is established between source and destination.

Nodes in Mobile ad-hoc networks (MANET) are suffered from limited battery life and limited bandwidth. So, energy is the most important parameter which requires consideration while designing routing protocol for mobile ad-hoc network. In MANET, the limited bandwidth of wireless network is also the critical issue which needs consideration. In the existing works [3], [38]-[42], [44], different techniques and approaches were proposed to transmit the data in a better route from source to destination. And also different path selection mechanisms were presented to deliver the packet in optimized selected path. But still the major problem that needs consideration is how to ignore the nodes which do not have enough energy to participate in the route establishment and how can we select the best path by considering the efficient residual energy of nodes and available bandwidth. The main objective of this paper is to develop the efficient energy and bandwidth based routing protocol which enhance packet delivery ratio, and maximize throughput by minimizing packet dropping ratio.

This newly proposed work intends to show a simple way to dynamically check whether or not the remaining energy of the node is enough to participate in the route discovery processes. This approach minimize packet loss which may be caused due to energy depletion of nodes and it can also minimize the routing overhead. The proposed protocol can also focuses on the mechanism of selecting the efficient and optimal route for data forwarding by considering the node with minimum remaining energy from each path and available bandwidth of multiple disjoint paths. When compared with AOMDV routing protocol, our proposed protocol improves the packet delivery ratio and throughput by minimizing packet loss ratio.

1.2 Statement of the Problem

Mobile nodes along the heavy traffic path could deplete their energy and reach the maximum bandwidth limit and experience undesirable amounts of packet drop [4]. In MANET, the nodes are mobile and contain no infrastructure. For this type of network, an efficient routing protocol needs to be designed to provide reliable packet delivery in a timely manner. Mobile nodes in mobile ad-hoc networks are featured with limited battery power and bandwidth. The performance of routing protocol degrades if battery power of nodes gets exhausted and if available bandwidth is insufficient during data transmission from source to destination. This issue not only affect lifetime of the node but also the ability of the node to forward packets or it affect packet which is transmitted toward the destination node [5]. So in MANET, routing protocol should provide energy efficient and bandwidth aware route between source and destination pair.

One of MANET routing protocol is AOMDV protocol. For the given network topology, when one node wants to send packets to another node, it will first find all possible path between sender and receiver using AOMDV algorithm. This existing AOMDV routing protocol algorithm optimizes routing for lowest delay but does not consider how to select the efficient route between source and destination with energy of the nodes and available bandwidth of the paths. That means, AOMDV routing protocol prefers shortest path for route establishment. But this may lead to selection of certain nodes which in turn deplete their battery power very quickly. The nodes selected in the shortest path may have less battery power and insufficient bandwidth. This will result in partitioning of network and will degrade performance of network. It is very dangerous when the intermediate node forward RREQ packet simultaneously without considering their energy level and available bandwidth. If we accidentally use it to establish the path between source and destination, it will easily lead to the emergence of network segmentation. We can transmit packets using any path but the key issue is how to select the best path which enhance packet delivery ratio and for dynamically ignore the nodes having energy below threshold value.

In existing AOMDV protocol [3], all neighboring nodes including nodes having less battery power and low bandwidth channel can participate in route discovery process which may leads packet loss. Sending the RREQ message to nodes having less battery power and low bandwidth channel also increases routing overhead and causes path breakage. For AOMDV routing protocol, the key issue which needs consideration is how to choose efficient route and deliver the packets to the end nodes. Using less battery power of nodes and insufficient bandwidth by considering only shortest route may leads to packet loss and greatly affects the packet forwarded toward destination node. This existing routing protocol does not consider the energy and available bandwidth on the path. In AOMDV routing protocol, when the packet is forwarded to the destination node from source node, the packet sent by source node may be dropped due to some problems such as insufficient bandwidth and limited battery power. So it is important to select the best primary path which is efficient and which can improve the performance of the protocol. To address this problem, routing protocol which consider residual energy of the nodes and available bandwidth of the path must be developed during the establishment of the route. In the newly proposed protocol, each node must be validated for participating in route discovery process based on energy threshold i.e. the amount of energy required to complete the communication event without any link break. And also selecting the path having highest life time and maximum available bandwidth plays an important role to provide higher packet delivery ratio and throughput. AOMDV protocol can be suitable for dynamic network topology. But the performance of AOMDV routing protocol is very low in a relative network topology. The new proposed protocol improve the performance of this existing protocol in a relatively static network scenario.

Therefore, for AOMDV protocol, how to efficiently select the best and efficient route between source and destination by considering the energy of nodes and the available bandwidth of the link is the critical issue. To improve the performance of the protocol, the best path that must be selected during route discovery is the path which can provide higher packet delivery fraction and higher throughput by considering the life time of the nodes and available bandwidth of the paths.

1.3 Objectives

General objectives

The general objective of this paper is to select the optimal path for AOMDV routing protocol with efficient energy and bandwidth in mobile ad-hoc network.

Specific objectives

- Reviewing different articles related to AOMDV routing protocol for MANETs
- Studying and analyzing the problem of route discovery process in AOMDV routing protocol.
- Propose the new technique which consider energy and bandwidth to select the efficient path during route discovery for AOMDV routing protocol.
- To maximize packet delivery ratio.
- To increase throughput
- Test the change happen due to the new system

1.4 Methodology and Tools

The methods used to accomplish the research objectives follows the following steps.

1.4.1 Literature review

General literature review made on different related works to obtain an in-depth understanding of the area which include; previous studies, books, journals, websites, and published articles related to the subject.

1.4.2 Designing (hardware testing) for the Proposed model and simulate

The researcher propose the desired requirements that should be addressed while conducting this work and designed its architecture.

1.4.2.1 Simulation design for ad hoc nodes

This is to achieve the objective of the research for improving the performance of AOMDV routing protocol. To accomplish this task there are two alternatives. The first alternative is designing the node. The other alternative is to model the node using simulation tools. Currently, since it is impossible to get (buy) the node (the hardware) in the local market, the second option of modeling the node using simulation tool is used.

1.4.2.2 Simulation

For simulation purpose ns-2 simulator is used. Ns-2 is event driven, open source, portable simulation tool that used in studying the dynamic nature of communication networks. Users is feeding the name of a TCL simulation script as an input argument of an NS-2 executable command ns. NS-2 consists of two key languages one is the C++ and second is the Object-oriented Tool Command Language (OTCL). In NS-2 C++ defines the internal mechanism (backend) of the simulation objects, and OTCL defines external simulation environment (i.e., a frontend) for assembling and configuring the objects. After simulation, NS-2 gives simulation outputs either in form of text-based or animation-based. Since Ns-2 simulation tool is the easiest tool and the existing routing protocol is implemented with this tool, we use it for implementing our newly proposed protocol.

1.4.2.3 Evaluating the performance

After designing the nodes on simulation tool, its performance is checked and analyzed by using the simulation tools with different values of parameters. In order to evaluate the effectiveness of the new proposed system, the following evaluation metrics are used.

- Average Packet delivery ratio: **-** This indicates the amount of packets sent per packets delivered at destination node within available remaining energy and bandwidth on the selected paths.
- Average Throughput: - The amount of data packets received by the destination per unit time. This is always a key parameter which determine the performance of routing protocol.
- Average packet dropping ratio: **-** This refers to amount of packets lost per received packets.

1.5 Scope and Limitations

This paper focuses on how to exclude the nodes having less battery power from participating in route establishment in order to minimize packet loss problem which can be caused by node's energy depletion. The proposed work also focuses on how to select the efficient path during route discovery for data forwarding. This can be achieved by concentrating on a maximal-minimal node's residual energy and maximum available bandwidth from each route. The proposed protocol increases packet delivery ratio by minimizing packet loss rate for AOMDV routing protocol. This can also maximize throughput during route discovery. And the proposed work do not consider the security issue.

1.6 Organization of the Thesis

This thesis work comprises of six chapters. The next chapter covers the literature review on MANETs such as different types of networks, characteristics of mobile ad hoc networks, design challenges, applications of MANETs, routing protocols in MANET. Chapter 3 discusses about different related research works. In Chapter 4, we present the design of the proposed system. It discusses about the design considerations, system design issue, architecture, proposed approach and Algorithm for the new proposed protocol. Chapter five presents an experimental set up, simulation results and performance evaluation. Finally, conclusions and future work are presented in Chapter 6.

CHAPTER TWO: LITERATURE REVIEW

2. Introduction

The use of wireless networks and mobile devices has increasingly grown due to the emergence of low cost wireless networking, and due to a wide range of applications. Since the mobile nodes depend upon the capacity of their battery power, which depletes with time, the scenario in mobile ad hoc networks is not fixed. Currently, the investigation on mobile ad hoc networks have increased to improve the network performance. Since the traditional routing protocols is not efficient [6], it is important to improve the performance of a mobile ad-hoc network by improving the routing protocol. In MANET, the radio propagation conditions change rapidly over time. This is because the network topology in MANET is dynamic and every mobile nodes in MANET can move in a random fashion. MANET also has a limited resources [7]. Now a days, developing routing protocols for MANET has been the hottest research area and many proactive and reactive protocols have been proposed from a variety of perspectives ([6], [8] and [9]-[11]). This chapter gives a brief overview of wireless networks and outlines the various types of Ad hoc networks with their routing protocol.

2.1 Wireless networks

A Wireless network [6] can be referred to as the interconnection of a network devices where the devices in the network communicate to each other with the help of a wireless channel. These wireless nodes have the capability to exchange information with each other either with the help of a wireless infrastructure based or through infrastructure-less. Wireless networks that can communicate with each other without the need of the underlying infrastructure is referred to infrastructure-less networks. One of the precious example of the network with no infrastructure is Mobile Ad hoc network.

2.2 Mobile Ad Hoc Networks

With the rapid growth in mobile and telecommunication technology, there is a great enhancement of personal communication devices such as laptops, mobiles and Personal Digital Assistants (PDAs). These devices get easy access to network via wireless interfaces. Unlike in infrastructure network, in a mobile ad hoc networks there is no central authority such as gateways/access points which control communication session [8]. Instead of that in order to exchange information, the nodes in ad hoc network by themselves are intelligent enough to relay the packet from source to destination. Routing decisions on such networks are highly dependent on the channel availability and the nodes within range.

2.2.1 Types of Mobile Wireless Networks

There are three main types of mobile networks as mentioned in [12].

- Infrastructure Networks
- Ad-hoc Networks
- Hybrid Networks

A) Infrastructure Network

For infrastructure networks, all nodes in the networks communicate through central administration such as access point and router. For example, when two neighbor devices (laptops) communicate to each other through a wireless access point, not directly. To send data packet to the neighbor nodes the access point is used as an intermediate node for relaying the packet between source and destination. In such network, all communication takes place between the wireless node and the access point which means that the communication is not between different wireless nodes.

Figure 1: Infrastructure Network

B) Ad hoc networks

Ad hoc network is the type of wireless networks without fixed infrastructure. Ad-hoc network types are important for the architecture where the deployment of an infrastructure is either not cost effective or is not feasible. One of the key feature which make ad hoc network differ from infrastructure is that the functionality normally performed by infrastructure network components, such as routers, switches, and access points can be achieved by the regular nodes which are participating in the network. There is an assumption in ad hoc networks that the nodes which are participating in the networks are mobile and they have limited resources such as energy, bandwidth, storage etc. For ad hoc network routing protocols there are several design goals and some of the typical design goals [13] are:

Minimal control overhead: Control messaging consumes processing resources such as bandwidth, and battery power to both transmit and receive a message. Hence, reducing control messaging is also one of the mechanism which helps to conserve battery power.

Multi-hop routing capability: In mobile ad hoc network, sender and receiver node may not be within the same transmission range. Because the wireless transmission range of mobile nodes is often limited. Hence, to make the communication between source and destination, the routing protocol must able multi-hop communication by providing routes between sources and destinations.

Dynamic topology maintenance: Once a route is constructed, it is likely that some link in the route will fail due the movement of the nodes. In order for a sender to communicate with a receiver, a viable routing path must be maintained. Since the path breakage are common for ad hoc networks, failed link must be maintained quickly with a minimum of associated overhead.

Loop prevention: During route discover process, when source node along the path chooses the next hop to the destination node is also a node that occurred earlier in the route loops in routing protocol occur. In mobile ad-hoc networks, routing loops are significantly wastes the resources and are detrimental to the network. Since packet processing and transmission is expensive in terms of energy and bandwidth, the loops must be removed at all times.

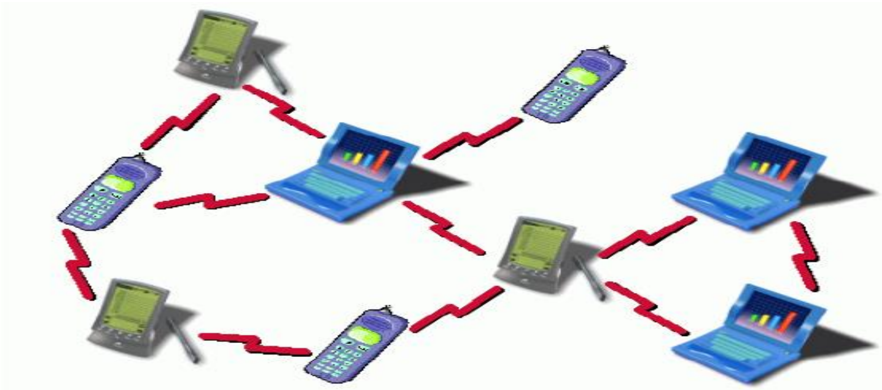

Figure 2: Ad-hoc Networks

.C) Hybrid Networks

Hybrid wireless networks is another type of network in which mobile node in the network have connectivity either via a gateway node, or directly.

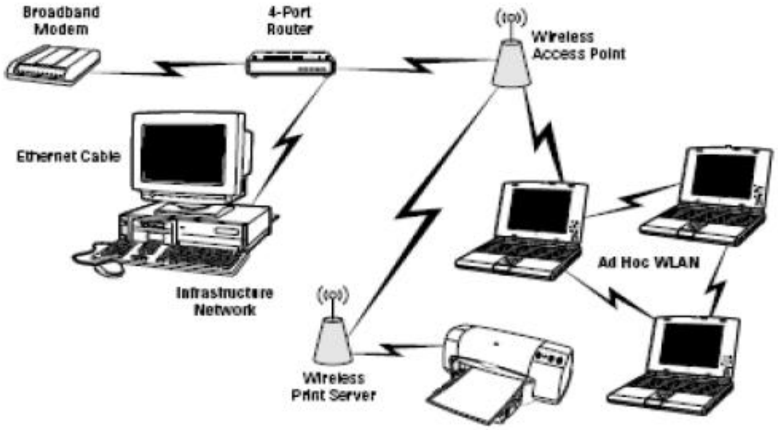

Figure 3: Hybrid Networks

The network topology in mobile ad hoc network may change frequently. Because the mobile devices in MANET moves continuously. Each mobile node in MANET acts as the host for receiving and transmitting and act as the router (intermediate nodes) for routing the packets from a source to destination node. During the mobility of the node, changing network topology must be communicated to other nodes continuously.

2.2.2 Characteristics of a MANET

MANET is characterized by some specific features as mentioned in [12]:

a) Energy Constraint: Energy efficiency becomes the major design issue as nodes in the MANET rely on their battery power.

b) Multi hop Routing: In this networks, there is no dedicated central authority and every devices in the network acts as a router to route the packets to other neighbor nodes.

c) Dynamic Topologies: Due to arbitrary movement of nodes at varying speed and also due to external factors such as noise, the topology of the networks changes unpredictably and in a random manner.

d) Mobility: The mobility in ad-hoc networks causes topology changes and leads dynamic, unpredicted and frequent network topology, which would require an efficient routing protocol

e) Autonomous and infrastructure less: In MANET, each node may act both as a host and a router.

f) Distributed Operation: The nodes are connected by wireless links and the communications among nodes are wireless. The control of the network is distributed among the nodes.

g) Light-weight terminals: Mostly the nodes in Mobile Ad-hoc Networks have less CPU capability and have a little storage and memory size.

h) Link stability: In order to provide the reliability of Ad hoc networks, link stability plays a major role and as the Ad hoc nodes are mobile, link stability must be considered for MANETs.

i) Security Threats: There are few security threats such as eavesdropping, Denial of Service (Dos) etc.

2.2.3 Design Issues

While designing the network topology in MANET, the following parameters has always been challenging the performance of Ad hoc networks [12].

a) Data Rate Enhancement: One of the key parameter which is used to determine the performance of any routing protocol is throughput. With the increased use of wireless devices, providing methods to enhance the throughput has thus far been a challenge.

b) Providing Reliability: Since Ad hoc networks are formed on the go, in Ad hoc networks the link stability for reliable communication is always a challenge.

c) Power Demands: Because of the nodes in Ad hoc devices have limited battery power, long lasting energy of these devices has always been a challenge. So that, how to efficiently use the residual energy of nodes in Ad hoc networks is the critical issue.

d) Security: The data transmitted and available resources in Ad hoc network is greatly exploited due to the existence of malicious nodes. The security issue in ad hoc network is a fastly growing and currently it is the area of research.

2.2.4 Applications of MANET

Some of the typical applications of mobile ad-hoc networks discussed in [12] are:

Personal Area Networking: Devices like laptops, PDAs, mobile phones create a temporary network of short range to share data among each other called the personal area network (PAN).

Civilian Environments: MANET finds its use in many civilian activities like taxi cab network, meeting rooms, etc.

Collaborative work: The need for collaborative computing might be more important for some business environments where people do need to have information sharing on a given project and outside meetings to cooperate.

Military battlefield: In order to exchange the data/information between the soldiers, military information head quarter, MANET allow the military to take merits of common place wireless network technology.

Conferencing: One of the most known applications of mobile ad-hoc network is mobile conferencing. For mobile users where they need to collaborate in a project outside the typical office environment designing an ad hoc network is essential.

Emergency Services: Another important role of application in the ad hoc networking domain is responding to emergency situations such as disaster recovery.

Home Networking: The devices such as computers, laptops can also create an ad hoc network at home where each device can communicate with the others without taking their original point of attachment into consideration.

2.3 Routing Protocols in MANET

Routing is a process of selecting the route in a network for transmitting packets from source node to destination [12]. Routing is the way of transmitting the packet from source node to a destination node through one or more intermediate nodes. It basically involves two processes like finding an optimal routing path and transfers the packets in the internetwork. Routing information of a node is maintained in a routing table. The routing table maintains the information of neighbor nodes and about possible destinations. However, the potential problem to this technique is that some destinations might be unreachable. The following are the main activities involved in the data transmission through the network:

- Determination of optimal routes between source and destination pair
- Delivery of packets to the correct destination node.

Routing protocols are used for finding and selecting the path for data transmission. The routing protocols in MANET also specifies how mobile devices in the network exchange the information with their neighbors node and report changes which happened. Optimal path selection must needs consideration since ad hoc networks have lower available resources when compared with infrastructure based networks. To select optimum route for forwarding the packet across the network, routing protocol uses metrics such as bandwidth, delay, time, energy consumption, hop count etc. [12]. Routing algorithms maintain routing tables in order to ensure route selection process, which includes the total route information for the packets. Based on their algorithm, this information of the path varies from one routing protocol to another.

2.3.1 Properties of MANET Routing Protocols

Ad hoc routing protocols may consist many properties and some of the common properties of mobile ad-hoc routing protocols are:

i) Distributed Operation: In mobile ad-hoc network, routing protocol should not be depend on a central administration which means the protocol should be distributed.

ii) Loop Free: In order to avoid the wastages of resources such as energy and bandwidth, routing protocol the ad hoc should establish the loop free paths which improve the overall performance of the networks.

iii) Unidirectional Link Support: For MANET routing protocols, uni-directional paths are favorable that can handle a situation where two unidirectional links form the only bidirectional connection between the nodes.

iv) On-Demand Based Operation: In order to minimize the control overhead in the network and to provide the better utilization of network, the ad hoc network routing protocols should be reactive.

vi) Sleep period operation: Since ad hoc networks nodes may have energy constraints, nodes may want to stop transmitting and/or receiving the packet for arbitrary time period.

2.3.2 Types of Routing Protocol

The traditional routing algorithm such as link-state and distance-vector do not scale in large mobile ad-hoc networks. This is because periodic or frequent route updates in large networks may consume significant part of the available bandwidth, increase channel contention and may require each node to frequently recharge their power supply. To overcome the problems associated with the link-state and distance-vector algorithms a number of routing protocols have been proposed for MANETs. These ad-hoc routing protocols are divided into different three groups which are, proactive, reactive/on-demand and hybrid protocols [12].

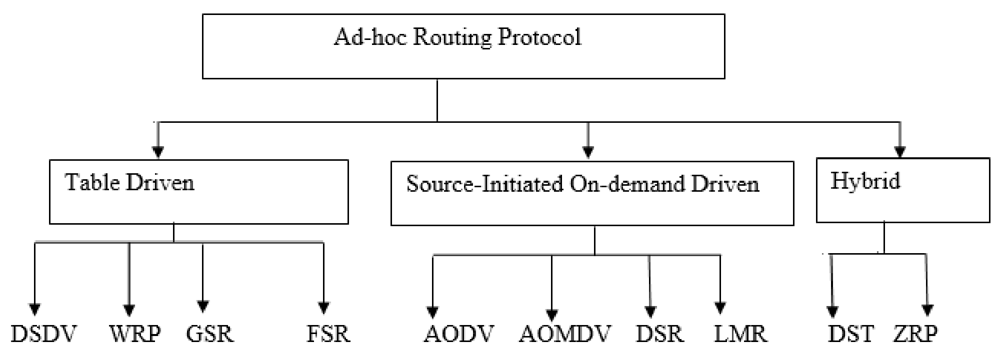

Figure 4: Types of Ad hoc routing protocol

In proactive protocols, the paths to all of the destination nodes are determined at the start up, and paths can be maintained. This can be achieved by using a periodic route update process. In on-demand protocols, the routes are initiated by the source node only when they are required. This can be achieved by using path discovery process. The features of both proactive and on-demand protocols is integrated into one for hybrid routing protocols. Each group of routing protocol has a number of different routing techniques, for finding optimal path between source and destination and for routing the packet.

2.3.3 Proactive versus Reactive Approaches

According to their routing mechanism, routing protocols in Ad hoc network can be generally categorized into reactive (on-demand) and proactive [14]. In proactive routing protocols, mobile devices in ad hoc network should keep the lists of paths to all possible destination nodes. In this protocol, when the information needs to be transmitted, the path is already known and the packet can be forwarded immediately toward the destination node and any changes which happen in the topology are propagated through the network. Some of the examples are: "destination-sequenced distance-vector" (DSDV) routing [15], "wireless routing protocol" (WRP) [16], "global state routing" (GSR) [17], and "fisheye state routing" (FSR) [18], etc.

For reactive/on-demand routing protocol, the path between source and destination pair is established when needed (on-demand). The path is maintained by a route maintenance process if the route is failed after the path is established. Some of the examples are: "ad hoc on-demand distance vector routing" (AODV) [8], "ad hoc on-demand Multipath distance vector routing AOMDV [3], "dynamic source routing" (DSR) [19], and "Cluster Based Routing protocol" (CBRP) [20], etc.

The advantages of proactive routing protocols is that new communications with arbitrary destinations experience minimal delay. This protocol has also its own disadvantages. The problem of this protocol is that to update routing information at all nodes, it is suffered from the additional control overhead. To address this problem, on-demand protocols adopt the inverse approach by finding the path to a destination node only when needed. When compared with proactive routing protocols, on-demand/reactive routing protocols consume much less bandwidth. But for discovering a path to a destination prior to the actual communication they will experience the long delay. Reactive routing protocols may also generate excessive traffic in comparable with proactive protocol. Because they need to broadcast route requests if the route discovery procedure is required frequently. But on-demand routing protocol can decreases routing overhead, and minimize energy, storage, and bandwidth requirements when compared with proactive routing protocol.

2.3.4 Clustering and Hierarchical Routing

One of the most important issue in MANET is scalability. Scalability in ad hoc networks is the ability of the network to guarantee an acceptable level of service to packets, even in the network with the large number of devices. For proactive routing protocols, when the number of devices in the network increase, the number control packets in the topology increases. This may increases the routing overhead and the nodes may consume a large amount of remaining energy and available bandwidth. In on-demand routing protocols, large numbers of control message (route requests and reply) to the entire network may eventually become packet broadcast storms. Typically, when the network size increases beyond certain thresholds, the computation and storage requirements become infeasible. The frequency of routing information updates may be typically increased when mobility is considered, thus worsening the scalability issues. So to solve these problems and to produce efficient and scalable solutions hierarchical routing is used. The idea of hierarchical routing is combining the nodes in a certain groups and then assigning nodes with different functionalities outside and inside a group. Both update packet size and the routing table size are reduced by maintaining them only in the part of the network. For reactive protocols, limiting the range of broadcasting route request also helps to increase efficiency. The most popular mechanism of building hierarchy is to combine/group nodes close to each other into clusters. Each cluster has a cluster head which a leads nodes to enable communication between nodes on behalf of these clusters. Some of the examples of hierarchical ad hoc routing protocols are: “zone routing protocol” (ZRP) [21] and “zone- based hierarchical link state” (ZHLS) routing protocol [22], “Distributed spanning trees based routing protocol” (DST) [26].

2.3.5 Review of Ad hoc Proactive Routing Protocols

This section presents brief descriptions for several existing proactive routing protocols.

a) Dynamic Destination-Sequenced Distance-Vector Routing

The Destination-Sequenced Distance-Vector (DSDV) Routing Algorithm [15] is a proactive hop-by-hop distance vector routing protocol. In proactive protocol, the number of intermediate devices to reach the destination and the sequence number is given by the destination node. This protocol ensures that every nodes in the network keeps lists of all available destination nodes in their routing table. The destination sequence number propagated to provide the loop-free routes and to identify stale routes from new ones. If any change has happed in its table from the last update sent, each node periodically transmits its routing table. The routing table updates can be forwarded along the routes in two different ways. Those are full dump and incremental update. In a full dump, information listed in routing table is sent to the neighbors. In the incremental update packet, if there is space, those entries whose sequence number has changed may be included. An incremental update where only those entries from the routing table that have had a metric change since the last update are sent. Incremental updates are sent along the route for the network which is relatively stable to minimize extra traffic and full dumps are relatively infrequent. For a fast changing network, incremental packets can increased largely. So the full dumps will be more predicted. In addition to the routing table information, each route update message includes the unique sequence number which is assigned by the source node. The route labeled with the highest sequence number is used. If two different routes have the same sequence number, the route with the best parameter or shortest path is selected. If a better route were found very soon, the nodes delay the transmission of a routing update by settling time so as to reduce those updates that would occur.

b) The Wireless Routing Protocol (WRP)

The Wireless Routing Protocol (WRP) [16] is a proactive distance-vector routing protocol. Each node in the network maintains a distance table a routing table. Storing predecessor and successor in the table enables loops to be detected. Each nodes in the network uses the update messages in order to periodically exchange their routing tables with their neighbor nodes. The nodes present on the response list for the update message are required to acknowledge the receipt of the update message. The node is required to send an idle “Hello” message to ensure connectivity if there is no change in the routing table since last update. On receiving an update message, the node modifies its distance table and looks for better paths using the new information.

c) Global State Routing (GSR)

Similar to DSDV, Global State Routing (GSR) [17] takes the idea of link state routing protocol. But this protocol reduce the flooding in order to improve routing messages. The algorithm of this protocol enables each to maintain the neighbor list, a next hop table, a topology table, and a distance table. For each destination node, the link state information is maintained in the topology table together with the timestamp of the information. The table of next hop contains the next hop through which the packets for destination node must be forwarded. The distance table contains the shortest distance to each destination node and the routing messages are generated on a link change. The node updates its topology table when it receives a routing control message. This protocol reconstructs its routing table and broadcasts the information to its neighbor nodes if the sequence number stored in the table is older than the sequence number of the control message.

d) Fisheye State Routing (FSR)

Fisheye State Routing (FSR) [18] is an improvement of GSR. The large size of update messages in GSR wastes a considerable amount of network resources. For reducing wastages, FSR uses the methods protocol exchanges information about closer nodes. In this protocol, each update message does not contain information about all nodes which reduces the update message size. FSR protocol allow each node to get accurate information about its neighbor nodes. For this protocol, accuracy of information decreases as the distance from the node increases. In FSR, as the information moves closer to the destination node and the packets are routed correctly, the route information becomes more and more accurate.

e) Optimized Link State Routing protocol (OLSR)

The Optimized Link State Routing Protocol (OLSR) [23] is developed for mobile ad hoc networks. The nodes which are selected as an intermediate by some neighbor nodes announce this information periodically in their control packet messages. Thereby, a node announces to the network, that it has reachability to the nodes. MPRs are used during route discovery to form the path from a source to any destination node in the network and MPRs is used in this protocol to facilitate efficient flooding of control messages in the network. Optimized Link State Protocol is a proactive routing protocol where the paths are immediately established only when there is data to be transmitted and it is an optimization version of a pure link state protocol. The topological changes in this protocol leads the flooding of the topological information to all available nodes in the network. Optimized link state routing protocol is natively based on a simple hop-count metric for the path discovery process. As there is no route discovery delay associated with finding a new route, having the path available within the standard routing table can be useful for some systems. The routing overhead generated here may be greater than that of a reactive protocol, but it does not enhance the number of routes being created [24], [25].

2.3.6 Review of Ad hoc Reactive Routing Protocols

Unlike to proactive routing protocols, in reactive routing protocols all up-to-date routes are not maintained at every node. Instead of that, the paths are created as and when required. When a source node wants to transmit the packet to a destination node, it initiates the route discovery mechanisms to find the route to the destination node. Under this section several typical reactive (on-demand) routing protocols are introduced.

i) Ad Hoc On-demand Distance Vector Routing (AODV)

Ad hoc on-demand distance vector (AODV) routing [8] adopts the concept of destination sequence number adopted from destination-sequenced distance-vector routing (DSDV) [15]. This protocol also adopts concept DSR [19] which is a modified on-demand broadcast route discovery approach. The source node initiates a path discovery process and broadcasts a route request (RREQ) message to its neighbors when a source node wants to send a packet to some destination and does not have a valid route to that destination. Then after until the RREQ control packet reaches the destination node, the neighbors node forward the route request to their neighbor.

Each node in AODV maintains its broadcast ID and its own sequence number. Each RREQ message contains the sequence numbers of the source and destination nodes and is uniquely identified by the source node's address and a broadcast ID. In order to ensure loop-free routing and use of up-to-date route information, AODV protocol utilizes destination sequence numbers. If intermediate nodes have the path to the destination node whose destination sequence number is greater or equal to that contained in the RREQ message, they can reply to the RREQ control packets. To set up the reverse path, each intermediate devices keeps the address of the neighbor node from which it received the first copy of the RREQ control packets and duplicated copies of the RREQ control packet are dropped. After the route request (RREQ) control packet reaches the destination, the destination node responds a route reply (RREP) packet back to the neighbor node from which it first received the RREQ control packet. The intermediate nodes along this path set up forward path entries in their routing tables when the RREP message is routed back along the reverse path. When a node detects a path failure or a change in neighbor-hood, a route maintenance procedure is invoked. If a source node moves from one position to another, it can reinitiate the path discovery process to find a new path to the destination node.

ii) Dynamic Source Routing (DSR)

Dynamic source routing (DSR) [19] is an on-demand routing protocol for wireless ad hoc networks. DSR is based on the concept of source routing, in which a source node indicates the sequence of intermediate routes in the header of a data packet. Like other on-demand routing protocols, the operation of DSR can be categorized into two processes. Those are route discovery process and route maintenance process. This routing protocol enable the node to check its route cache when it needs to forward the packet to some destination node, in order to determine whether the node has already an up-to-date route to the destination. The node initiates the route discovery procedure if no route is found. This can be by broadcasting a route request control packet to neighbouring nodes. The address of the source and destination nodes, a unique identification number generated by the source node are included in this route request message.

The RREQ control packets is propagated through the network and the route record keep track of the sequence of nodes. When intermediate node receives a route discovery request, it checks whether its own address is already listed in the route record of the route request message. If not, it appends its address to the route record and forwards the route request to its neighbours. When the destination node receives the route request, it appends its address to the route record and returns it to the source node within a new route reply message. The destination node can use that route to send the reply if the destination already has the path to the source; otherwise, it can use the route in the route request message to send the reply.

In this protocol, the route maintenance uses route error packets and acknowledgement messages. The node creates a route error message and sends it to the source of the data packets if it detects a link failure when forwarding data packets. The source node removes all routes from its route cache that have the address of the node in error when the source node receives the route error message. For establishing a new path, the source node may reinitiate the path discovery process. The important optimization to reduce the route search overhead is enabling the intermediate node to forward a RREP message to the source node if it has route to the destination node.

2.3.7 Review of Ad hoc Hybrid Routing Protocols

Hybrid routing protocols may exhibit exhibiting reactive behavior given a different set of circumstances, while proactive behavior given a certain set of circumstances. Hybrid routing protocols includes the feature of both proactive and reactive routing protocols can be integrated in various ways. Based on the characteristics of the network, these protocols allow for flexibility.

a) Distributed spanning trees based routing protocol (DST)

In DST [26], the nodes in the network are grouped into a number of trees. Each tree has two types of nodes; route node, and internal node. The root controls the structure of the tree and whether the tree can merge with another tree, and the rest of the nodes within each tree are the regular nodes. In order to determine a route, DST protocol proposes two different routing approaches. Those are distributed spanning tree shuttling (DST) and hybrid tree-flooding (HFT). Control packets are sent to all the neighbours in HTF and adjoining bridges in the spanning tree, where each packet is held for a period of time called holding time. In DST, the control messages disseminated from the source are rebroadcasted along the tree edges. When a control reaches down to a leaf node, it is sent up the tree until it reaches a certain height referred to as the shuttling level. The advantages of the DST based routing protocol algorithm is that it creates a single point of failure. Because it depends on the root node to configure the tree.

b) Zone routing protocol (ZRP)

In ZRP [21], routes are immediately established for nodes within the routing zone. In this protocol, the nodes in the networks have a routing zone. This routing zone defines a range of hops where each node is needed to maintain network connectivity proactively. The paths are determined reactively for the nodes that are reside outside of the routing zone. This means that, it can use any on-demand routing protocol to determine a path to the expected destination. As compared with pure proactive protocols, the benefits of this protocol is that it has significantly minimize reduce the amount of network overhead. It also reduce the delays associated with pure reactive protocols such as DSR, by allowing routes to be discovered faster. This is because, in order to determine a route to a node outside the routing zone, the routing only has to travel to a node which found on the boundaries of the required destination. One of the disadvantages of ZRP protocol is that the protocol can behave like a pure proactive protocol for large values of routing zone, while for small values it behaves like a reactive protocol.

2.3.8 Multipath Routing Protocols in MANET

Most of the standard on-demand routing protocols such as AODV and DSR, are mainly intended to discover a unipath/single path between a source and destination node. In a single route, nodes of the broken route simply drop data packets when the route disconnects. Because no alternate path to the destination is available until a new route is re-established. Multipath routing [3] is the mechanism of finding multiple alternative paths through a network. Which means that it is the process of searching for multiple paths between source and destination pairs. These multiple paths between source and destination can be used to compensate for the dynamic and unpredictable topology change in ad hoc networks. Some of the advantages of multipath routing protocols are increasing bandwidth and fault tolerance. Recently, several different multipath routing mechanisms have been proposed [29]-[31] and this section introduces some main characteristics of these multipath protocols. AODVM [29] and AOMDV [3] routing protocols are the extension of the AODV [8] routing protocol, whereas SMR [30] and MSR [31] are based on DSR [19].

i) Ad hoc On-demand Multipath Distance Vector (AOMDV)

Ad hoc On-demand Multipath Distance Vector (AOMDV) [3] is the protocol which is used for computing multiple loop-free and link-disjoint routes. This loop-freedom is guaranteed by using a notion of “advertised hop count”. Link-disjointness of multiple routes is achieved by using a particular property of flooding. In this protocol, the routing entries for each destination contain a list of the next-hops together with the corresponding hop counts in order to keep track of multiple routes. For each destination node, an intermediate node maintains the advertised hop count, which is defined as the maximum hop count for all the routes. In AOMDV routing protocol, each duplicate route advertisement received by a node determine an alternative routes to the destination node. In order to improve the loop freedom, a an intermediate node only accepts an alternative route to the destination if it has a lower hop count than the advertised hop count for that destination. When a route advertisement is received for a destination with a greater sequence number, the next-hop list and advertised hop count are reinitialized.

AOMDV can be used to find link-disjoint routes. To find disjoint routes, each node does not immediately reject duplicate RREQs. In this protocol, each RREQ control packet carries an additional field called first hop to indicate the first hop (neighbour of the source) taken by it and each node maintains a first hop list for each RREQ to keep track of the list of neighbours of the source through which a copy of the RREQ has been received. In an attempt to get multiple linkdisjoint routes, the destination replies to duplicate RREQs regardless of their first hop. The destination node only replies to RREQs arriving via unique neighbours in order to ensure link-disjointness in the first hop of the RREP. Each RREP takes different reverse path to the source to ensure link-disjointness even though each RREP may intersect at an intermediate node.

ii) Split Multipath Routing (SMR)

Split Multipath Routing (SMR) proposed in [30] is an on-demand multipath source routing protocol that builds multiple routes using a request/reply cycle. SMR can find an alternative route that is maximally disjoint from the source to the destination. In SMR protocol, when the source node needs the path to the destination node but no route information is known, it floods the Route Request (RREQs) message to the entire network. In order to find maximally disjoint paths, the approach of this protocol has a disadvantage of transmitting more RREQ packets. Since RREQ control packet is flooded several duplicates copies of these messages can be traversed through different paths to reach the destination node. Then the destination node selects multiple maximally disjoint routes and sends route reply control packets back in reverse to the source node through the selected paths. The destination node must know the all available routes in order to select the proper maximally disjoint path. In SMR, the source routing model is used where the RREQ control packet include the information of the node to comprise the route. In the SMR algorithm, the destination node sends a route reply in the reverse path for the first RREQ it receives, which represents the shortest delay path. The destination node then waits to receive more RREQs control packets. From the received RREQs, the path that is maximally disjoint from the shortest delay path is selected. The shortest hop path is selected if more than one maximally disjoint route exists. The path whose RREQ was received first is selected if more than one shortest hop path exists. The destination then sends an RREP for the selected RREQ.

iii) Multipath Source Routing (MSR)

Multipath Source Routing (MSR) [31] is an extension of the on demand DSR [19] protocol. The approach used by MSR protocol is used to distribute traffic among multiple routes in a network. When compared with DSR, Multipath Source Routing uses the same route discovery procedure. But in MSR, instead of only one path, multiple paths can be returned back from destination node to source. When a source requires a route to a destination node but no path found in the cache, the source node flood a RREQ control packet throughout the network to initiate a route discovery process. A route record in the header of each RREQ control message records the sequence of nodes that the packet passes. Then after, every intermediate node contributes to the path discovery procedure by appending its own address to the route record. The RREP will reverse the route in the route record of the RREQ and traverse back through this route after the RREQ reaches the destination. Each route is given a unique index and stored in the cache, so it is easy to pick multiple paths from there. Independence between routes is very important in multipath routing; therefore disjoint routes are preferred in MSR. The complete routes are in the packet headers for route discovery process of MSR where looping will not occur. It will be immediately eliminated when a loop is detected. Source routing approach is used in this protocol, where intermediate nodes are used to forward the data packet from source to destination node according to the path in the packet-header. The routes are all calculated at the source and a multiple-route table is used for the information of each different route to a destination. This table contains information for each route to the destination node: the index of the path in the route cache, the delay, the destination ID, and the calculated load distribution weight of a path. The traffic to a destination is distributed among multiple routes and the weight of a path simply represents the number of packets sent consecutively on that path.

iv) Ad hoc On-demand Distance Vector Multipath Routing (AODVM)

Ad hoc On-demand Distance Vector Multipath Routing (AODVM) [29] is an extension to AODV for finding multiple node disjoint paths. Instead of discarding the duplicate RREQ packets, intermediate nodes are required to record the information contained in these packets in the RREQ table. For each received copy of an RREQ message, the receiving intermediate node records the source that generated the RREQ, the destination for which the RREQ is intended, the neighbour that transmitted the RREQ, and some additional information in the RREQ table. In this protocol, intermediate relay nodes are precluded from sending back an RREP control message directly to the source. Destination node updates its sequence number and generates an RREP packet when it receives the first RREQ packet from one of its neighbor nodes. The RREP packet used in this protocol contains an additional field called "*last hop ID*" which announce the neighbour from which the particular copy of RREQ control packet was received. This RREP control packet is sent back to the source node via the route traversed by the RREQ message. The destination node updates its sequence number when it receives duplicate copies of the RREQ control packet from other neighbours and generates RREP packets for each of them. These RREP control packets also contain the IDs of their respective last hop nodes like the first RREP packet. When an intermediate node receives an RREP packet from one of its neighbours, it deletes the entry corresponding to this neighbour from its RREQ table and adds a routing entry to its routing table to indicate the discovered route to the originator of the RREP packet (the destination). Then the node distinguish the neighbour node in the RREQ table through which the path to the source is the shortest, and transmit the RREP control message to that neighbor node. In order to ensure that a node does not participate in multiple paths, the entry corresponding to this neighbour is then deleted from the RREQ table. The nodes delete the entry corresponding to the transmitting node from their RREQ tables when they overhear any node broadcasting an RREP message.

The destination node is unaware as to how many of these RREP control packet that it generated actually made it back to the source node and the intermediate nodes make decisions on where to transmit the RREP control packets. Thus, for the source to confirm each received RREP message, the Route Confirmation message is necessary. The Route Confirmation message can be added to the first data packet to be sent on the corresponding route. It will also contain information with regards to the hop count of the path, and the first and last hop relays on that path.

v) Cluster-Based Multi-hop Multipath Routing Protocol (CBMMRP)

Shanthy and SujiPriya [20] have proposed a Cluster-Based Multi-hop Multipath Routing Protocol (CBMMRP). To avoid congestion this routing protocol distributes traffic among diverse multiple paths. This improves the sharing rate of channel and optimizes bandwidth usage and to minimize routing control overhead and enhance the network scalability cluster-based multi-hop multipath routing protocol uses hierarchical clustering structure.

2.4 Quality of Service Aware Routing Protocols

Quality of Services (QoS) provisioning can be achieved over different layers in the protocol stack, starting from the physical layer up to the application layer [7]. The main goal of the QoS routing protocols is to establish the path from a source to the destination that satisfies the needs of the desired QoS [9, 11]. Only a small number of QoS routing protocols have been proposed in mobile ad-hoc networks where most of them are discussed in under section. The first major work on MANET QoS was the INSIGNIA framework proposed by Zhang *et al* [31], where resources are reserved in an end-to-end manner through a Resource Reservation Protocol (RSVP). This QoS framework is designed to support adaptive services. It allows packets of video, audio, and real-time data applications to specify their maximum and minimum bandwidth needs and plays a central role in resource allocation, restoration control and session adaptation between communicating mobile hosts. Based on the end-to-end available bandwidth, QoS approaches attempt to provide assurances in support of adaptive services. Singh and Raghavendra [32] have proposed a Power Aware Multiple Access Protocol (PAMAS). In this protocol, a node turns off its radio interface for a specific duration of time. Because of the possibility of multiple access interference, the node will not be able to forward and receive packets during that time. The sleep time is of the order of packet duration, which could be very small. For low bandwidth mobile networks, this techniques would be quite viable where small data packets can be combined to form large packets.

Perkins *et al* [33] have extended the basic AODV routing protocol to provide QoS support in ad hoc wireless networks. Packet formats have been modified to provide QoS and in order to specify the service requirements, which must be met by the nodes transmitting a route request or a route reply. In this work, to support QoS routing, modification is made to routing table structure where several modifications have been applied into the route request and route reply messages. Each routing table entry corresponds to a different destination node. The minimum bandwidth extension field and maximum delay extension field are appended to each routing table entry. One of the drawback of this routing protocol is its simplicity. This routing protocol can also potentially enable quality of service provisioning. This protocol uses bandwidth and delay as quality of service metrics.

Liao *et al* [34] investigates a multipath QoS routing protocol. This protocol attempts to discover multiple alternative paths that jointly satisfy the bandwidth requirements. In this routing protocol, the original bandwidth request is essentially categorized into several sub-bandwidth requirements. Then each sub-path is accountable for one sub-bandwidth requirement. This routing protocol is a reactive routing protocol that uses the information about the available bandwidth at each node for discovering paths. With very limited bandwidth where a single path satisfying the QoS requirements is unlikely to exist, the multipath QoS routing algorithm is suitable for ad hoc networks.

Conditional Max-Min Battery Capacity Routing (CMMBCR) algorithm was proposed by Toh [35]. The algorithm of this routing protocol selects the path with minimal total transmission power, if all the devices in the path have residual battery power higher than a threshold value. Otherwise, paths including nodes with the lowest residual battery power are avoided. This method considers both the residual power of nodes and the total transmission energy utilization of paths. The path with minimum total transmission power among these routes is selected when all devices in some probable paths have enough remaining battery power.

Ad hoc QoS On-demand Routing (AQOR) is proposed by Xue and Ganz [36]. In terms of end-to-end delay and bandwidth in mobile ad-hoc networks, this protocol is a resource reservation and signaling algorithm which provides end-to-end QoS support. For available bandwidth and end-to-end delay, the algorithms of this protocol presents the detailed computation. Along the route that is being used by the source node, AQOR reserves bandwidth on each node. When a QoS violation has been detected, AQOR also offers an adaptive route recovery model. Which makes the destination node do a reverse path exploration. The resource reservation and bandwidth calculation model used in AQOR shows promising results.

Chen and Heinzelman [37] propose a QoS aware routing protocol. In this work, the authors study the estimation of the bandwidth by transmitting the bandwidth information through control packet. The researchers compare hello bandwidth estimation and listen bandwidth estimation methods of estimating bandwidth. In order to minimize the congestion and to reduce the chance of lost hello messages incorrectly signaling a broken route, these approaches work equally well in static topologies by using large weight factors. The hello messages and listening to the channel performs better and improves end-to-end throughput, packet delivery ratio.

CHAPTER THREE: RELATED WORK

Mobile Ad Hoc Networks (MANETs) is the type of network with no fixed infrastructure, where devices are free to move in any direction. The nodes have limited battery power and suffered from scarce of bandwidth parameters. Hence to optimize the performance of the network, efficient energy and bandwidth based routing protocols are important metrics. For selecting efficient path during data transmission, energy efficient and available bandwidth is a major issue in the ad hoc routing protocol. Recently several works have been proposed for MANET Routing protocols to improve the performance of the network. Here are some of existing related works:

Marina K. and Dass. [3], study Ad hoc on demand Multipath Distance Vector (AOMDV) routing protocol which is an extension of AODV protocol to find the multipath in route discovery process. Multi paths of this protocol are loop-freedom and disjoint routes. In this protocol, when the source node needs the path to the destination node, it initiates a route discovery procedure. AOMDV routing protocol compute and establish multiple loop free routes during route discovery process. When an earlier path fails, this routing protocol switches the paths to a different routes with available multiple redundant routes. Thus a new path discovery process is avoided. In this protocol, the new path discovery procedure is initiated for construction of the path only when all the routes to a specific destination fail. For AOMDV routing protocol, since the link disjoint paths are computed for efficiency, the failure of the paths is independent of each other. The path discovery process typically involves a flood of the route request (RREQ) message for the destination node and waiting for a route reply control packet (RREP). At every intermediate node, if the multiple copies of a RREQ control messages received, the node must drop the RREQ packet. When intermediate node receive a non-duplicated copies of route request control message, it sets up a reverse route to the source node by using the previous hop as the next hop. If there is the valid path to the destination node, the intermediate node generates a route reply packet, otherwise the node rebroadcast the RREQ control packet along the destination. After the destination node receives a non-duplicated RREQ message for itself, it generates a route reply control packet which is routed back to the source node through the reverse path. The forward path is constructed between source and destination node as the route reply (RREP) control messages proceeds towards the source node. The AOMDV routing protocol algorithm optimizes routing for lowest delay. This means that, AOMDV routing protocol prefers shortest route or the path with minimum hop count for path establishment. But this may lead to selection of certain nodes which in turn deplete their battery power very quickly. During route discovery process, this routing protocol does not consider available resources such as energy and bandwidth to select efficient path and for providing high delivery ratio. This will result in degrading performance of the network.

The below algorithm 1 is designed for AOMDV routing protocol in order to select the path and to ensure data transmission from source to destination.

```
if (seq_num^d_i < seq_num^d_j ) then
 seq_num^d_i:= seq_num^d_j;
   if (i≠d) then
     advertised_hopcount^d_i: = ∞;
     route_list^d_i= NULL;
     insert ( j , advertised_hopcount^d_j +1) into route_list^d_i ;
   else
     advertised_hopcount^d_i:= 0;
end if
else if (seqnum^s_i=seqnum_j^s) and ((advertised_hopcount^s_i,i) >
(advertised_hopcount_j^s,j)) then
  insert ( j , advertised_hopcount_j^s +1) into route_list_d^s ;
end if
```

Algorithm 1: Route Update Rules of AOMDV Routing Protocol [3]

Yumei Liu [38], investigates the approach called the Maximal-Minimal nodal Residual Energy (MMRE) into the existing ad-hoc on-demand multipath distance vector routing protocol. This proposed protocol is called MMRE-AOMDV protocol. During the route discovery process, MMRE-AOMDV protocol find minimal nodal residual energy of each path and sorts multiple routes by descending order of nodal remaining energy. Then it use the path with maximal nodal remaining energy to transmit the data packets. In addition to the routing information already found in the existing AOMDV routing protocol, MMRE-AOMDV protocol uses the route with maximal nodal residual energy to transmit data packets from source to destination node.

Seema V., Rekha A. and Pinki N. [39], Study the optimized energy aware routing (OEAR) which is new energy efficient scheme. OEAR routing protocol finds the optimal and the most stable route out of the entire existing paths from source to destination using on-demand routing. While selecting the route, the algorithm of proposed routing protocol not only considers remaining energy of the node but also it concentrates on the number of data packets which are buffered in the node.

Tripti Sh. and Dr. Vivek K. [40], Introduce the solution to utilize available bandwidth of the link for on demand multiple disjoint routes. In order to find the available bandwidth of the path, the approximate bandwidth of a node is used. In this protocol, the source node selects the primary path for data forwarding on the basis of route bandwidth. During route discovery procedure, the proposed approach of this work establish multiple bandwidth aware paths between a source and destination pair. In this protocol, the existing information and the available bandwidth of the node forwarding is included in the route request and route reply control messages. During the path discovery process, the source node is able to learn the bandwidth of the multiple routes by using the Maximum-Minimum approach in order to measure the route quality. Once the source node receives the route reply control packet, it stores its next hop information and chooses the route with the greatest available bandwidth as its primary route for data transmission. In order to find the optimal route in the change of the network topology, the bandwidth of the route is determined periodically.

Saleh .A Alghamdi [41], Have proposed to balance the load for ad hoc on-demand multipath distance vector (AOMDV) routing protocol. In this proposed work, the adaption is done in order to enhance the reliability of the given network by considering the parameter of route weight of all the available multiple routes. This proposed method regulates the usage of both node energy and available bandwidth by exploiting the availability of multiple paths for data transfer. The distribution of packet across multiple routes increases the quality of service of the given network by ensuring the usage of both node energy and network bandwidth. The basic technique of path finding given in the AOMDV routing protocol is used exactly in the load balancing AOMDV protocol based on the flooding of route request packets (RREQ) across the whole network. Each reverse route is established on reception of positive route reply packet (RREP). During route discovery process a set of multiple disjoint paths are established by interleaved exchange of the RREQ and RREP route establishing packets. Among these multiple discovered paths, based on effective energy utilization assessment the primary paths for actual data transfer is selected. In this paper, a message M comprising of Q packets of data can be divided into fixed C-sized chunks of data to be distributed among K available multiple channels.

Dr. E.Karthikeyan, T.Sivaraman [42], proposes the protocol which is extended by modifying AOMDV. In the source node the value of highest residual energy should be assigned as maximum value such as node's initial energy. When an intermediate node receive RREQ, if the sequence number of just received packet is greater than this node then it updates its residual energy with residual energy of RREQ if it is less than maximum energy of RREQ of this node. When an intermediate node receives RREQ, if the sequence number of just received packet is equal to this node, it updates its residual energy. The main goal of this paper is to develop energy and bandwidth aware routing protocol for MANET. In order to transmit the actual data packets between source and destination node, this protocol select the primary path with maximal-minimal residual energy and maximal-minimal bandwidth approach.

Unlike other works, our proposed approach concentrates on energy threshold value based scheme for dynamically validating the nodes which are participated in route establishment and this proposed techniques also selects the best path from validated path with maximal-minimal residual energy and maximum average bandwidth. The main goal of our paper is to find efficient energy and available bandwidth shortest path between source and destination node. This paper concentrates on how to select the path with longest life time and maximum available bandwidth in order to improve the performance of AOMDV routing protocol. This can be achieved into ways. The first phase is by excluding the nodes with less battery power from participating in route discovery process. This can minimize the packet loss which can be caused by energy depletion problem and also minimize routing overhead. Threshold energy level can address this problem by selecting the nodes having enough energy level for route discovery process. Setting energy threshold avoids the nodes with lower energy from participating in the construction of the path. The second phase is by selecting the efficient path based on maximal-minimal node's residual energy and maximum average residual bandwidth. This improves the packet delivery ratio and throughput.

CHAPTER FOUR: PROPOSED SOLUTION

4. Introduction

Recently, Mobile Ad hoc Networks (MANETs) have a great role because of their self-configuration and self-maintenance capabilities and also because of the development of wireless communication technologies [43]. In Mobile Ad hoc Networks (MANETs), a number of nodes are used to transmit information from source to destination where delivering the packet at destination is challenges due to different factors such as energy depletion and shortage of bandwidth. Due to this reason, how to improve the delivery ratio of packets by considering parameters like energy of nodes and available bandwidth is the crucial issue in a MANET. Therefore, the new efficient energy and bandwidth based technique needs to be considered for routing protocols in order to achieve high delivery ratio and to improve the protocol's performance.

This chapter is dedicated to improve the packet delivery issues for AOMDV routing protocol in MANETs. Section 4.1 presents the overview of existing protocol. Design consideration and design scenario for proposed work is described in section 4.2 and 4.3 respectively. Section 4.4 presents the detail of proposed system architecture. Under section 4.5, the proposed approach and the proposed algorithm are briefly presented to achieve our goal.

4.1 Overview of AOMDV routing Protocol

To transmit the packet, AOMDV routing protocol find the routes between source and destination node only when needed (on-demand). In order to route the packet from source to destination, AOMDV routing protocol performs two processes. Those are route discovery process and route maintenance process. AOMDV uses hello messages to know its neighbors and to ensure symmetric links. During route discovery process of AOMDV routing protocol, Source node initiate route discovery process. When intermediate node receives a Route Request control message two cases are involved. If the intermediate node does not have a valid path with destination, then the Route Request control packet is forwarded toward the destination node. Otherwise if it has a valid route, the intermediate node sends back the RREP control packets. During route discovery procedures, if the RREQ message is received at intermediate nodes multiple times, the duplicate copies are discarded. This can be achieved by using the Broadcast_id-Source_id.

During route discovery process of AOMDV protocol, the details of routing information for each destination keeps a list of hop counts and the next-hops. AOMDV routing protocol assure loop-free routes by accepting multiple alternate paths to destination node. When the path advertisement is received for a destination node, the list of next-hop and the advertised hop count are reinitialized. To find node disjoint paths, each intermediate node discard duplicated RREQs and each RREQs coming through a different neighbour of the source defines a node-disjoint path. In AOMDV routing protocol, any two RREQs control messages arriving at destination node via a different neighbor nodes. In an attempt to get multiple link-disjoint paths, the destination node only replies to RREQs control packet entering through different neighbor nodes. The advantages of using AOMDV protocol is that it enables intermediate nodes to reply to route request, while still choosing disjoint routes. But since it is a multipath routing protocol, the destination node acknowledges to many RREQ control messages.

4.1.1 An overview of control packet flow in AOMDV protocol

In AOMDV routing protocol, three main control messages are used for discovering and maintaining the path between source and destination nodes. These three control packets are:

a. Route Request (RREQ): RREQ control packet is the packet that is sent by the source node to request a route to a particular destination from its neighboring nodes. Since route request control messages are broadcast in nature, all neighboring nodes receive the transmitted control packets. When the neighbor node receives the RREQ packet, it sets up a reverse path entry to the source node from which the RREQ is received.
b. Route Reply (RREP): As the name indicates, Route Reply (RREP) packet is a control packet that is sent by the intermediate node in response to the received RREQ packet.
c. Route Error (RERR): RERR denotes route error. RERR control messages are sent from a node to its neighboring nodes to indicate a loss of a link.

4.2 Design Consideration

Under this section, we discuss some issues that needs consideration in our proposed work. In AOMDV routing protocol, some of the major challenges that needs consideration during data forwarding are: energy efficiency, packet loss minimization, traffic control/routing overhead. In this paper, we concentrates on critical issue which is how to select the efficient route in AOMDV protocol to improve packet delivery ratio, increase throughput and minimize packet dropping ratio with efficient energy and bandwidth.

Some of the points that needs to be considered in the proposed approach are:

1. Packet Losses: The main target of AOMDV protocol is to establish the route and transmit the packet from source node to destination node. So that, for AOMDV protocol, it is important to avoid any packet drop as much as possible. When the packet is forwarded to the destination node from source node, the packet sent by source node may be dropped due to some problems such as insufficient bandwidth and limited battery power. So that it is important to choose the primary route which is efficient and which can improve the performance of the protocol. To solve this problem, selecting the path having maximum life time and maximum bandwidth as a primary path can provide higher delivery ratio and throughput when compared with the existing methods.
2. Routing overhead: One of the major challenge in AOMDV routing protocol is routing overhead. This is the number of routing packets transmitted per data packet towards the destination. It is the metric that describes how many routing packets for route discovery and route maintenance need to be sent so as to propagate the data packets. To perform route discovery process, a *RREQ* message is flooded in the network to establish the path between source and destination. In this existing protocol, every intermediate nodes have to receive RREQ control messages and broadcast it. But not every intermediate node which receives the RREQ control message will broadcast it. So that, it is important to concentrate on the available resources of the nodes such as energy in order to avoid unnecessary control packet and for minimizing routing overhead.
3. Energy efficiency: In AOMDV routing protocol, the energy efficiency is the most important issue that needs to be considered in order to select the path with highest lifetime. For finding energy efficient route establishment, maximal-minimal based node's residual energy approach is used. And also the energy level of nodes must be checked for participating in route establishment.

4.3 Design Scenario

Under this section, we describes the proposed approach scenario in which the data packet is delivered to the destination node from source node through energy efficient and maximum available bandwidth. The proposed approach is applicable in multipath network architecture, in which a source node forwards the data packets toward the destination through intermediate nodes to improve the packet delivery ratio and throughput during communication. AOMDV routing protocol needs more efficient path for delivering the packet at destination node and to minimize packet loss. Therefore, our newly proposed approach finds the energy efficient and bandwidth aware path to provide highest delivery ratio and throughput. The proposed protocol also apply energy threshold checking scheme for validating nodes and for minimizing packet loss and routing overhead during route discovery process.

4.4 Proposed System Architecture

In MANETs, the source node disseminate the data to the destination in different ways such as direct communication and multi-hop communication. In direct communication mode, each source node sends its data directly to the destination node. Whereas, in multi hop communication mode, each node sends its data to the destination through intermediate nodes. In multi-hopping MANET, data generated from source node can be forwarded toward the destination node either in flat or hierarchical way (clustering). In MANETs, the data communication between source and destination can be also in a single path (unipath) or multipath way. For a single path data communication, the data is transmitted from source node to destination in a single way. Whereas, in a multipath data transmission, the data sent from source node can reach the destination in a multiple way.

For transferring the actual data from source to destination node, AOMDV routing protocol uses multipath communication mode. In this proposed protocol, there may be multiple alternative paths between source and destination and the source have to transmit the packet through efficient route which can improve the performance of the AOMDV protocol by considering the life time of nodes and available bandwidth.

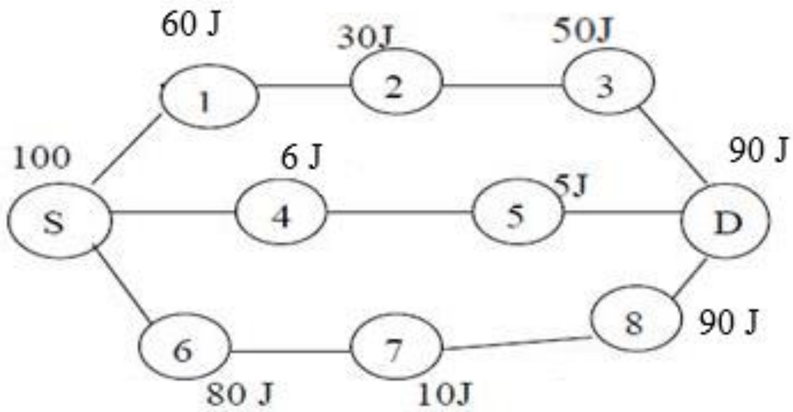

Figure 5: Architecture for illustration of proposed model

The above architecture shows how the packet is transmitted from source (S) to destination (D) through intermediate nodes and illustrates how the new proposed protocol selects the efficient path when compared with the AOMDV routing protocol. The core components of the proposed architecture are:

Source Node (S)-Node which sends data to destination node

Destination Node (D)-Node which is capable of receiving the data packet from the source node

Intermediate Nodes- Nodes capable of forwarding the data packet between the source and the destination.

As discussed above, the AOMDV routing protocol algorithm uses shortest path (the path with minimum hop count) to select the path from source to destination. But this have its own drawback since the packet delivery ratio of route with shortest path may be low as compared with other paths, especially when energy of nodes and available bandwidth of the link is not considered. The main goal of this paper is to find best and efficient path which improves packet delivery ratio, throughput and minimize packet dropping ratio by considering the remaining energy of nodes and available bandwidth. To achieve the proposed goal, the initial energy for the node is assigned. Then based on transmission and reception power, the threshold value for energy of nodes is predefined to validate the node whether its remaining energy is sufficient to participate in the route discovery process or not. When a route request control packets is broadcasted in the network, not all intermediate node which receives the control message will broadcast it. The threshold value is used as a criteria to dynamically check whether residual energy of nodes is enough or not to receive and transmit packet. If not, the RREQ message sent by source node is dropped.

To approve this, when source node sends RREQ message to its neighbors, each neighbor node check whether its remaining energy is below threshold value or not. If its residual energy is below threshold value, it drop RREQ message and no RREP message is sent back for source node through this node. Then after, the efficient route which provide high delivery ratio is selected from multiple alternative paths based on maximal-minimal residual energy and maximum average bandwidth. From the above scenario, let we discuss how some of the existing protocol selects the route and how our newly proposed protocol select the efficient path based on remaining energy of the nodes.

- In order to transmit the packet from source to destination node, the algorithm of existing AOMDV routing protocol prefers the shortest path (the path with minimum hop count) which is S-->4-->5--->D as a primary path and other as backup path [3]. But this may not be energy efficient route to provide higher delivery of packets as compared with other paths because of its low energy level. i.e life time of the path is short which may leads packet loss.
- Other proposed work focuses on residual energy for selecting best path [44]. In this approach the destination node selects neighbor node with highest remaining energy as the next hop, which selects the path S-->6-->7-->8-->D as a primary path and other as backup path. The destination node selects the efficient path through the next hop with highest residual energy. For destination node (D), the next hop with highest remaining energy is node 8. But when compared with path S-->1-->2-->3-->D, this is not efficient route to provide high packet delivery ratio with available energy resources. Because the life time of this path is shorter than the first (S-->1-->2-->3-->D) path in terms of the path lifetime. In this approach, the node's with minimal residual energy which determine the path life time is not considered.

In contrast to existing work, our newly proposed protocol apply energy threshold to validate node for their energy level and selects the path with highest life time as a best path in order to guarantee large amount of packets at destination node with established path which is S-->1-->2-->3--->D. In order to improve the performance of AOMDV protocol and for providing higher delivery ratio and throughput, this thesis selects the efficient route between source and destination pair. The proposed approach also take into account the available bandwidth of the route between source and destination which is further discussed in 4.5.1.2.

4.5 Approach and Algorithm for Proposed Protocol (Improved AOMDV (IP-AOMDV))

The path discovery of AOMDV routing protocol is modified under this proposed protocol. In this paper, we concentrates on how to select the best and efficient path during route discovery process to improve the performance of AOMDV routing protocol. Our proposed approach is designed to increase the survivability of the network and maintaining the network connectivity to lead a longer battery life of the terminals. This is in contrast to AOMDV, which does not consider battery power of the nodes and available bandwidth of the link but optimizes routing for lowest delay using hop count. The newly proposed work ensures the survivability of the network by establishing routes that ensure all nodes equally exhaust their battery power and also provide high delivery ratio by concentrating on maximal-minimal of nodal residual energy and maximum average bandwidth from each route.

4.5.1 Proposed Approach for Improved AOMDV (IP-AOMDV)

Our multipath routing protocol is extended by modifying route update rules of AOMDV protocol in order to generate more efficient routes than AOMDV routing protocol. This proposed approach maximize packet delivery ratio, throughput by decreasing the dropping ratio. To achieve the proposed goal, we consider energy threshold value for selecting only nodes having sufficient residual energy. The proposed approach also focuses on the maximal-minimal residual energy and maximum average bandwidth as a routing metric for selecting a node and to construct a route between the source-destination pairs.

Broadcast ID
Destination IP Address
Destination Sequence Number
Source IP Address
Source Sequence Number
Hop Count
Minimum Residual Energy
Sum Residual Bandwidth

Figure 6: Modified RREQ packet format

For RREQ packet structure modification, the original packet structure of RREQ packet is altered for exchange of requirement of energy and bandwidth for specific communication event from source node. This new structure involves pre-calculated energy and involves additional field in the RREQ packet which will contain minimum residual energy and the sum of residual bandwidth information. In RREQ packet structure, when particular source node broadcasts RREQ control message, that node will also add the minimal residual energy and the sum of residual bandwidth information in this field along with normal filling process of fields. Every node in the network will receive the broadcast type packet Route request (RREQ) message. If the node which receives RREQ control packet is not destination node, it will further forward this control packet in to its neighboring node in again broadcast type provided if it satisfies the condition. In this proposed work, every receiving node will check the required energy for specific communication event and calculate its residual energy for comparison. After comparison if it satisfies the conditional criteria it will forward this packet further else will drop this packet.

The general procedures of our newly proposed routing protocol (IP-AOMDV) are:

1) Validating the nodes that have enough energy to receive and transmit the packet.

During route discovery process of the routing, every node receiving RREQ (Route Request) messages forwards it only if its energy is greater than threshold; otherwise it drops it. Therefore, the RREP control packet is reached to the source only through energy efficient nodes. In this way the data is transmitted via energy efficient path.

2) Finding minimal nodal residual energy of each route and the sum of residual bandwidth between any source and destination pair in the route discovery process, that is, min_re_energy, sum_re_bandwidth.

Several changes required in the route discovery phase of AOMDV to find the maximal-minimal residual energy and maximal available bandwidth of each route between any source and destination node.

3) Select the efficient path using maximal-minimal nodal residual energy and maximum average bandwidth to forward data packets.

4.5.1.1 Energy Threshold Value Checking Scheme

In mobile ad-hoc networks the nodes have multiple roles such as the transmitter, receiver and the router. The mobile factor of the nodes in the mobile network confides the battery energy. Hence energy efficiency plays an important role in MANET. In this energy efficient model, a threshold energy value is proposed for every node in the network to dynamically check whether the node can participate in the path discovery process or not. The algorithm of this scheme proposes to select a node i only if Re_Energyi is greater than Thres_Energy, where Re_Energyi is the remaining energy of the node i and Thres_Energy is the threshold energy. The residual energy of the node i can be calculated by the initial energy of the node i minus energy consumed by node i.

If the residual energy is greater than energy threshold value, then the transmission of route request packet is continued through that node. Every node depends on the local information of the energy level to decide whether to participate in the route selection or not. The main goal of this approach is to avoid an energy hungry node which may not forward packet on behalf of others and this reduces routing overhead and minimize packet loss which may be caused due to due to the energy depletion of nodes. In this scheme, every node determines whether or not to forward the RREQ messages based on their residual energy. Before broadcasting to neighbor nodes, the node drops the RREQ control messages if the residual energy of the node is less than the threshold value. That means, the intermediate nodes doesn't forward the RREQ packet if they have no enough battery level. They have to check the available battery level before forwarding the packet. The destination node receives the route request message only when all the intermediate nodes on the way have enough energy level for receiving and transmitting the data packet.

During route update process, the algorithm of this protocol considers the power level of each node. Whenever the node involves in any sort of transaction it loses some energy whose value depends on factors such as the transmission power, receiving power, the size of packets and distance between these nodes. The proposed optimization function considers all these factors and determines which nodes should be selected for energy efficient transmission of data. In order to calculate the threshold energy required, transmitting and receiving power of packets must be calculated. The energy required for transmitting packet (E_{TX}) can be calculated by considering transmission power, packet size, and the distance between two neighbor nodes. And the energy required for receiving packet (E_{RX}) can be calculated by considering reception power, packet size, and the distance between two neighbor nodes, where the distance between two neighbor nodes can be calculated using Euclidean formula [45].

Threshold energy can be calculated as:

$$Thres\_Energy = (E_{TX} + E_{RX} + Idle\ power)$$

Where *Thres_Energy* = threshold energy, E_{TX} and E_{RX} are energy required for transmitting and receiving a packet respectively, and the idle is the energy loss while listening to a channel.

In our newly proposed work, when source node wants to forward the packet to the destination node, the path discovery process must be initiated by flooding route request control messages. During route discovery, the sender node broadcasts the RREQ message to neighboring nodes for finding the path. Before replying or broadcasting it again, any intermediate node receiving the RREQ message computes its battery level with threshold energy. That means, when an intermediate node received a RREQ control message at time t, the node compared its current remaining energy capacity with the predefined threshold value in order to validate the node for data forwarding.

If the residual energy of RREQ receiving node is below the threshold value or computed value, then the RREQ message is dropped and hence will get hidden from destination node. This approach is applied on every intermediate nodes to dynamically validate the nodes which can participate in path establishment. Therefore, when destination node generates route reply (RREP) packet, it will not involve this particular node in the route. This modification result in less routing overhead thereby minimizing control packet in the network and minimize packet loss. But if the remaining energy of RREQ receiving node is greater than the threshold value, the minimal residual energy of the node and the sum of residual bandwidth is appended to the RREQ control message and transmit to the neighbor nodes which is discussed further in section 4.5.1.2.

In this scheme, the destination receive a route request message when all intermediate nodes along the route have enough battery levels (greater than predefined energy threshold value). If all the paths to destination node have less residual energy than the threshold, the RREQ message will not be reached at the destination. That's why first applying the threshold value based scheme and filtering out the path who's any of the node have energy value less than the threshold value.

This technique reduces packet loss which can be caused due to energy depletion and minimize routing overhead which can be caused by control packet and eliminate the congestion due to this unnecessary control message. This proposed approach also minimize the energy consumed and the wastage of limited node's bandwidth during transmitting control packet for broadcasting RREQ or replying RREP and for recalculating the route.

In the existing AOMDV routing protocol, even if the energy of RREQ receiving node is not enough for transmitting the packet, the intermediate node receive, broadcasts route request control packets to neighbor nodes and sends back the route reply packet to source node. Therefore, to address the drawback of AOMDV routing protocol, the receiver must check whether its residual energy is below the threshold value or not before broadcasting RREQ message for its neighbor nodes. This allow us to avoid selecting the nodes with less battery power (less than energy threshold value) and to exclude them from involving in the routing setup. That means, the node with energy below threshold value is no longer able to take part in communications.

4.5.1.2 Nodal Residual Energy and Available Bandwidth Based Scheme

In route discovery process, the path discovery is initiated whenever a node needs to send information to another node for which there is no information in the routing table. In order to create a set of routes that allow to transmit the packet towards the destination node, the source node starts the multiple paths discovery process based on the on-demand routing scheme. The source node checks its routing table for any available path toward the destination when it requires a route toward a destination. If the route is not available, the source performs route discovery procedure. It broadcasts Route Request (RREQ) control packets to all of its neighbors. When a node receives an RREQ control packets, it ensures that the received route request is non-duplicate RREQ by comparing the RREQs' identifiers for preventing looping paths. Otherwise, the RREQ-receiving nodes verify whether they have any valid path toward the destination in their routing tables. If they have, they forward the route request (RREQ) message to those valid path neighbors. When the destination receives the first RREQ, it waits for a certain time and collects all other RREQs arriving during this time interval.

Our protocol ensures loop free route and indicate the freshness of the path in the same way as AOMDV routing protocol. Our newly proposed protocol involves energy and bandwidth metrics that helps in finding out the better routing path and it selects the path with highest life time and maximum available bandwidth. When a source node needs to forward data to destination, it sends RREQ control message to its neighbor nodes. After intermediate node is validated and receives RREQ, it ensures that the received RREQ is not a duplicate RREQ, in order to prevent looping paths. If the neighbor node is the destination, it sends RREP. Otherwise, validated intermediate node send RREQ to all of their neighbor nodes with min_re_energy and sum_re_bandwidth to find the destination. When the destination node gets the first route request (RREQ), it waits for time t and collects all other route request RREQ) coming in this time interval. In this phase, up on receiving neighbor node's information, the destination node compute these metrics for selecting efficient route. After time t, destination node determine the efficient path based on maximal-minimal residual energy and maximum average bandwidth from each path and send RREP. It also stores some other relatively inferior paths as backup paths, which may be used if there are some network failures, thereby avoiding energy, bandwidth and time wastage in recalculating the path. After the destination inform the path to source node and when the source gets the RREP, it sends the data packets toward the selected route. For the new solution, we modify the RREQ packet by adding the minimum residual energy of the node and the sum of residual bandwidth information and neighbor nodes compute with their residual energy and available bandwidth information. Each node broadcast this route request message periodically and update its neighbors depend up on minimum residual energy and available bandwidth.

Generally, this paper concentrates on how to improve the performance of existing protocol in terms of delivery ratio and throughput. After intermediate nodes are validated for transmitting the packet, the destination node identify optimal route by using node's maximal-minimal residual energy approach and maximum average bandwidth.

As every operation of node requires energy, like transmission and reception of packet, total load carried out for entire communication is responsible for energy consumption provided through battery supplies. Hence residual energy provides the information about energy remaining in the battery and which is used as routing metric in modified algorithm. Residual energy of each node can be calculated as:

$$Re\_Energy\_i = Einitial\_i - Econsumed\_i$$

Where Re_Energy_i is residual energy of node_i, and Einitial_i, Econsumed_i indicate the initial energy and consumed energy of the node_i respectively. Consumed energy is the energy consumed for transmitting and receiving the packet. Once the residual energy of node is calculated, each node computes its energy with energy of its neighbors and only minimum energy is sent along the path. Finally, the destination node descends the minimum nodal residual energy received from each route and reply the path with maximal-minimal energy as a reverse path.

In addition to residual energy, this new protocol also concentrates on availability of the bandwidth among alternate paths in order to forward the packets via the efficient path and for providing higher packet delivery fraction and throughput. In our proposed protocol, the available bandwidth can be estimated by using RREQ messages. Every node calculate its residual bandwidth and broadcasts the sum of residual bandwidth using RREQ messages. We modify the AOMDV RREQ message structure to include the sum of residual bandwidth information. The node can obtain the neighboring residual bandwidth information through RREQ messages, add its own residual bandwidth and the sum of residual bandwidth is forwarded along the path. Each node that needs to forward the actual packet has to be aware of its available bandwidth and the information of its neighboring nodes within the interference range. Since the channel bandwidth is shared among neighboring nodes, the node must give the attention to the channel and estimates available bandwidth. The link's available bandwidth depends on the ratio of idle and busy time period for a predefined interval. The available bandwidth of the channel can be estimated depending on channel utilization ratio and idle period synchronization.

Available Bandwidth = Channel bandwidth *(Idle/intervaltime)

Where Channel bandwidth is the bandwidth of the link and Idle is the idle period of the wireless channel over a time interval.

Each node in the network evaluate and estimates residual bandwidth by using the formula:

Residual Bandwidth = Channel Bandwidth – Consumed Bandwidth

Every node determines consumed bandwidth by monitoring packets it feeds to a network within a specific time window. From source to destination, the available bandwidth throughout the path must be known for bandwidth constrained routing protocol. To calculate the total residual bandwidth of the route between source and destination pairs, the summation of residual bandwidth of all links along the path must be computed. The total residual bandwidth of the path refers to the sum of the residual bandwidth of every link across each path, and it is given by:

Sum RBw= $\sum_{n=1}^{m} Residual\ Bandwidth(n)$,

where sum RBw is the sum of residual bandwidth of the path, residual bandwidth(n) is the residual bandwidth of node n, and m is the number of nodes in the path.

In order to restrict insufficient bandwidth of the link, the least required bandwidth is predefined. This least required bandwidth or minimum required bandwidth is used to limit the bandwidth of the link which is not enough to transmit the packet. This means that, it can restrict the insufficient bandwidth of the link from participating in computation. After receiving neighboring information, each node calculate its residual bandwidth, add its residual bandwidth into received information from neighbor node and the sum of residual bandwidth is sent along the path toward the destination node. Finally, the destination node calculate the average bandwidth of each route and reply the path with maximal average bandwidth as a reverse path. Thus, the path with maximum average bandwidth can have more link quality and it can be used for providing better packet delivery ratio and throughput in IP-AOMDV. In the case where the remaining energy of the node and the available bandwidth of the link is efficient for the same path, the proposed algorithm selects the efficient path. But if the remaining energy of the nodes is efficient for one path and the available bandwidth of the link is efficient for another path, the proposed algorithm check whether the bandwidth of the link is greater than minimum required bandwidth and gives the priority to energy efficient path and another route with efficient bandwidth is selected as a backup path. In this proposed work, after the required residual energy and available bandwidth for data transmission is satisfied, a node updates additional minimum residual energy and sum of residual bandwidth fields of RREQ as follow, then rebroadcast RREQ.

Minimum residual energy = min (residual energy of current node, minimum residual energy of RREQ received)

Sum residual bandwidth = (residual bandwidth of current path + sum of bandwidth of RREQ received).

As a general, this thesis computes both maximal-minimal node's residual energy and maximum average bandwidth parameters in order to select the best route from multiple alternative paths.

4.5.2 Proposed Route discovery algorithm for Improved AOMDV

The key idea of this protocol is to ignore nodes with less battery power in order to exclude them from participating in route establishment and to find the path with maximal-minimal nodal residual energy and maximal average bandwidth during route discovery process. Once a new route with highest lifetime and maximal available bandwidth is emerging, it is reselected to forward rest data packets. To achieve the proposed goal: the first step is finding all possible number of paths by applying threshold value based scheme and the second step is applying maximal-minimal residual energy and maximum average bandwidth based scheme for selecting the efficient path from multiple alternative paths.

Algorithm 2: Route Update Rules of IP-AOMDV

```
if (seqnum_i^d < seqnum^d_j ) then
  seqnum_i^d := seqnum^d_j;
  if (i≠d) then
//Threshold Energy based node validation using IP-AOMDV Protocol
   if (re_energyi < Thres_Energy)   // if the node's residual energy
                                       is less than threshold value
   discard (packet);
   else
// Forward path
   if (re_energyi < min_re_energy^d_j ) then
       min_re_energy^d_j:= re_energyi;
   end if
   if (re_bandwidthi > min_re_bandwidth) then
       sum_re_bandwidth_i^d = re_bandwidth_i + re_bandwidth^d_j
   end if
    advertised_hopcount_i^d:=∞;
    route_list_i^d = NULL;
    insert ( j , advertised_hopcount^d_j +1, min_re_energy^d_j,
            sum_re_bandwidth_i^d) into route_list_i^d;
     end if
     else
     advertised_hopcount^d_i:= 0;
     end if
//Reverse path
if ((advertised_hopcount_i^s,i) > (advertised_hopcount^s_j,j))then
if (min_re_energy^s_i < min_re_energy_j^s) and (avg_bandwidth^s_i <
        avg_bandwidth_j^s) then
      insert (j, advertised_hopcount^s_j+1, max_re_energy_j^s,
           max_avg_bandwidth_j^s) into route_list_d^s;
    end if
```

CHAPTER FIVE

EXPERIMENTAL SETUP AND PERFORMANCE EVALUATION

5.1 Experimental Setup

In this chapter we discuss experimental setup for our proposed model which is discussed in the previous chapter. Since it is quite a complex task to make a comparison between existing and the proposed protocol on a real time network, the simulation environment is used to simulate the new proposed protocol with existing routing protocol. For this thesis we select NS-2 as the simulation environment. This simulation tool is one of the most commonly used simulation environment for wireless networks and it is used in few of the research papers discussed in the previous chapter.

5.1.1 NS-2 Overview

The simulator we have used to simulate our newly proposed protocol is the Network Simulator-2. Network Simulator Version 2, which simply abbreviated as NS-2, is an event driven simulation tool that can be used to study the nature of communication networks [46]. Network Simulator-2 can be used for the simulation of both wired network and wireless functions and protocols such as UDP, TCP and various routing protocols. In networking research, NS-2 simulation tool has gained lot of popularity due to its flexibility.

5.1.2 Basic Architecture

NS2 simulation tool provides users with ns executable command which take on the name of a Tcl simulation scripting file as an input argument. Users input the name of a Tcl script as an input argument of an NS2 executable command ns. At the end of the simulation a trace file is created which is used to plot graph and to create animation. Network Simulator-2 includes two key languages, which are C++ and Object-oriented Tool Command Language (OTcl). The C++ defines the internal mechanism (a back end) of the simulation objects and the OTcl sets up simulation by configuring and assembling the objects as well as scheduling discrete events. NS2 simulator provides a large number of built in C++ objects. It is advisable to use these C++ objects for this simulator to set up a simulation using a Tcl simulation script. However, advance users may find these objects insufficient. They need to use OTcl configuration interface and to develop their own C++ objects in order to put together these objects. Nowadays NS2.35 is popularly used network simulator. This tool converts a .tcl file into .tr and .nam files. The network simulator can be described as a software or hardware that predicts the behavior of the network without the presence of the actual network. After simulation, NS2 outputs either animation-based or text-based simulation results. Tools such as NAM (Network AniMator) and XGraph are used to interpret these results graphically and interactively. Then after, in order to analyze a particular behavior of the network, users can extract a relevant subset of text-based data and transform it to a more conceivable documentation/presentation.

5.2 Performance Evaluation

This section investigates the performance of our proposed approach IP-AOMDV with conventional AOMDV. To analyze the performance of proposed IP-AOMDV scheme with existing protocol, the network simulator NS-2 is used.

5.2.1 Simulation Environment

For performance evaluation, nodes are randomly deployed in 1000 m × 1000 m area. Simulations are carried out using network simulator NS-2. Each node is equipped with a transceiver. Different nodes communicate via radio signals having transmission range of 250 m. In our simulation, IEEE 802.11 is used as MAC layer protocol. The mobility of the nodes is determined by random waypoint mobility model. For Constant Bit Rate (CBR) data sessions, node pairs are randomly selected and 512 bytes data packet size is used. The performance of Improved AOMDV (IP-AOMDV) and AOMDV routing protocols are evaluated by using NS 2.35 by illustrating different parameters.

Figure 6 and Table 1 below illustrates the simulation model and the simulation parameters respectively. After running C++ objects with Tcl simulation script, the result of simulation generated as trace files and the awk file is prepared for analyzing the trace files into graphs for various performance metrics.

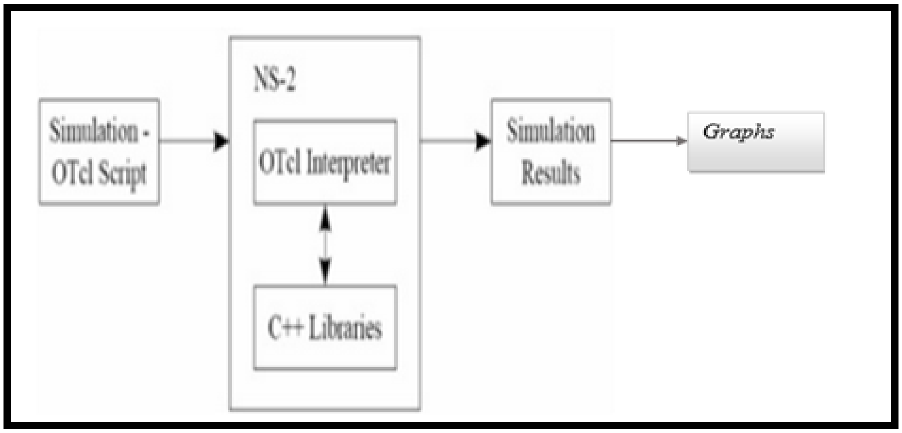

Figure 7: Simulation model

The simulation experiment is carried out by using LINUX. In this paper, various parameters are simulated for number of nodes 100 under simulation time 10, 15, 20, 25, 30 seconds. Table 1 below gives the list of simulation parameters used for analysis of our proposed approach.

Table 1: Simulation parameters

Parameters	Values
Simulator	NS-2.35
Traffic Type	CBR
Number of Nodes	100
Simulation time	10,15,20,25, 30 seconds
Packet size	512 bytes
Mobility Model	Random way point model
Routing protocols	AOMDV, IP-AOMDV
Antenna Model	Omni
Radio propagation model	Two Ray Ground
Dimension	1000m*1000m
Speed	20m/s
Channel Type	Wireless Channel
MAC Type	802.11
Initial	100 Joules

5.2.2 Performance Metrics

The performance of new protocol IP-AOMDV is evaluated using following metrics to compare the performance with the existing protocol of AOMDV.

i) Packet delivery Ratio: -The packet delivery ratio is the ratio of the data packets delivered to the destinations to those generated by the sources.

ii) Packet Loss: - Packet Loss is the difference between the number of data packets sent and the number of data packets received. It is calculated as follows:

Packet Loss= Number of data packets sent-Number of data packets received.

iii) Throughput:-The amount of data packets received by the destination per unit time.

In this thesis, based on the proposed algorithm, parameters such energy threshold, maximal-minimal residual energy and maximum average bandwidth are coded in NS-2. All proposed approaches are coded in NS-2 and the code is validated by simulating and comparing the results obtained in the respective existing work.

5.2.3 Simulation Results and Discussion

The performance of AOMDV and IP-AOMDV protocols are evaluated in terms of variation in simulation time. Table 1 - Table 4 shows the observed values of AOMDV and IP-AOMDV protocols with respect to varying simulation time on simulation.

Table 2: Average Packet Delivery Ratio of AOMDV and IP-AOMDV

Average Packet Delivery Ratio		
Simulation Time (s)	AOMDV	IP-AOMDV
10	96.5681	96.8268
15	96.5191	97.4249
20	96.9019	97.5479
25	97.1791	97.6387
30	97.0805	97.7669

Average Packet Delivery Ratio: Table 2 and Figure 7 represent the average packet delivery ratio of AOMDV and IP-AOMDV protocols. Figure 7 compares the average packet delivery ratio of AOMDV and proposed protocol in varying simulation time. The packet delivery ratio of proposed protocol is increased with increasing simulation time. The graph shown below demonstrates that the average packet delivery ratio of IP-AOMDV routing protocol is better than AOMDV routing protocol. For existing protocol, the packet delivery ratio is decreased at simulation time 15 and 30. Because the existing protocol consider only the shortest path and the residual energy of the node along the shortest path may be less than threshold value which cannot transmit the packet and drop the packet. But the proposed protocol selects only the node which have enough residual energy during route discovery process. The proposed approach dynamically check and validate each node along the path and only the nodes having enough battery power can be selected for receiving and transmitting the packet. Higher packet delivery ratio of the proposed protocol is because of the selection of the efficient path by considering maximum available bandwidth of the route and highest path lifetime among alternate paths to forward the packets.

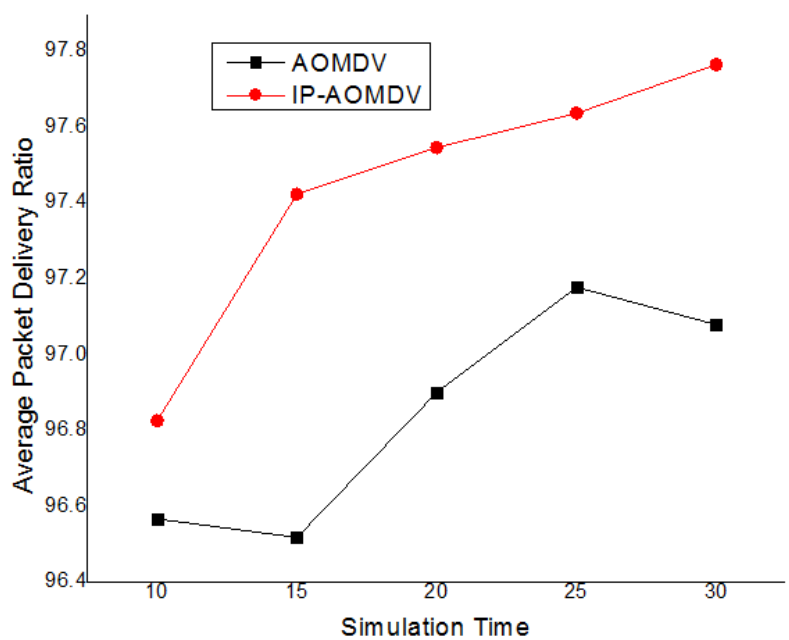

Figure 8: Average Packet Delivery Ratio of AOMDV and IP-AOMDV

Table 3: Average Throughput of AOMDV and IP-AOMDV

Average Throughput		
Simulation Time (s)	AOMDV	IP-AOMDV
10	2095.97	2452.16
15	2631.79	3327.23
20	3008.34	3663.55
25	3349.82	3892.68
30	3256.77	4010.77

Throughput: Table 3 and Figure 8 represent the Average Throughput of AOMDV and IP-AOMDV routing protocols. Figure 8 compares the throughput of AOMDV and IP-AOMDV protocol in varying simulation time. The throughput of proposed protocol is increased with increasing simulation time. For AOMDV routing protocol, the average throughput is decreased at simulation time 30. This is because of the existing protocol selects the path with minimum hop count and the remaining energy of the node along the shortest path may have less battery power (less than threshold value) which leads the packet loss. In contrast to this protocol, the proposed protocol selects only the node having enough residual energy during route discovery phase. The proposed approach dynamically check and validate each node along the path and only the nodes which have enough battery power can participate in route discovery process for transmitting the packet. The graph below demonstrates that the new protocol results high throughput as compared to AOMDV protocol. This higher throughput of the new protocol is because of the selection of the best and efficient path with highest lifetime and maximum available bandwidth among alternate paths to forward the packets.

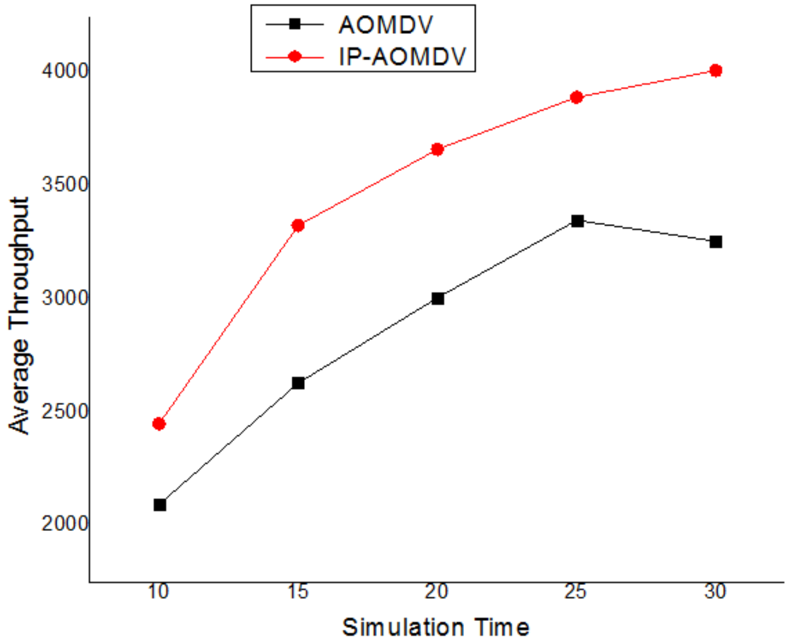

Figure 9: Average Throughput of AOMDV and IP-AOMDV

Table 4: Average Packet Dropping Ratio of AOMDV and IP-AOMDV

Average Packet Dropping Ratio		
Simulation Time (s)	AOMDV	IP-AOMDV
10	3.43186	3.17322
15	3.4809	2.57511
20	3.09812	2.45213
25	2.82088	2.36126
30	2.91948	2.23311

Packet Dropping Ratio: Table 4 and Figure 9 shows the Average packet dropping ratio of AOMDV and IP-AOMDV routing protocols. Figure 9 evaluate the dropping ratio of AOMDV and IP-AOMDV protocol in varying simulation time. Simulation result in Figure 9 illustrates that the IP-AOMDV protocol results less dropping ratio when compared with AOMDV protocol.

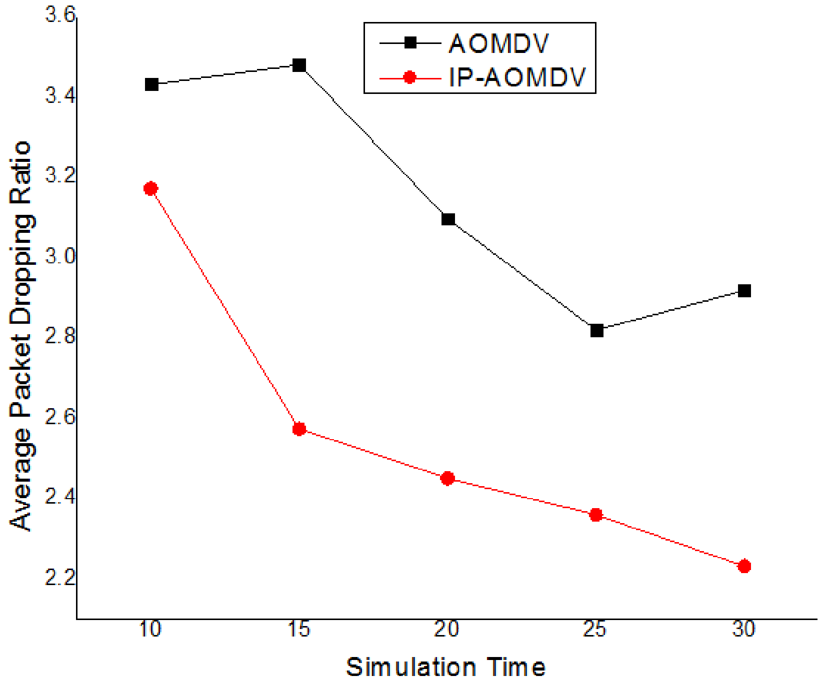

Figure 10: Average Packet Dropping Ratio of AOMDV and IP-AOMDV

CHAPTER SIX

CONCLUSIONS

A Mobile Ad hoc NETwork (MANET) is a dynamically formed self-configured network by an autonomous system of mobile nodes connected by wireless links. With the advancements of wireless technology, finding the best path for MANET routing protocol is increasing rapidly. One of the most popular routing protocols for mobile ad-hoc network is the Ad hoc On-Demand Multi-path Distance Vector (AOMDV) routing protocol. On-demand is a major characteristic of AOMDV, which means that routes are established only when they are needed by a source node. The two most important parameters; the energy of nodes and available bandwidth of the link is not considered in this protocol. The limited battery power and low bandwidth channel in this protocol may lead to node breakdown consequently affecting the packets which are delivered at destination. In order to solve the problem of existing protocol, we design the new protocol called Improved Ad hoc On-Demand Multi-path Distance Vector (IP-AOMDV). In this paper, IP-AOMDV protocol is proposed to select the best and efficient route between source and destination by using maximal-minimal residual energy and maximum average bandwidth approach. Our protocol also use energy threshold value for excluding nodes having energy less than threshold value from participating in route discovery process. The newly proposed protocol improves the performance of AOMDV protocol in a relatively static network scenario by increasing the packet delivery ratio and throughput. The proposed algorithm of the new protocol is implemented and simulated using NS-2 simulator. The simulation result illustrates that the IP-AOMDV routing protocol is very better than AOMDV.

In future we will put a greater effort to improve its overall performance by enhancing recent power efficient strategies in order to minimize communication costs.

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APPENDIX: Sample source code and screenshot for proposed work

Appendix A: Network Animator (NAM) and Trace File

The below images show the NAM screenshots for the NS-2 simulations at different point of time of the simulations. The below image shows the nodes at the start of the simulation and the green colour represents that the nodes have high energy levels. Figure shows the nodes at the start of the simulation.

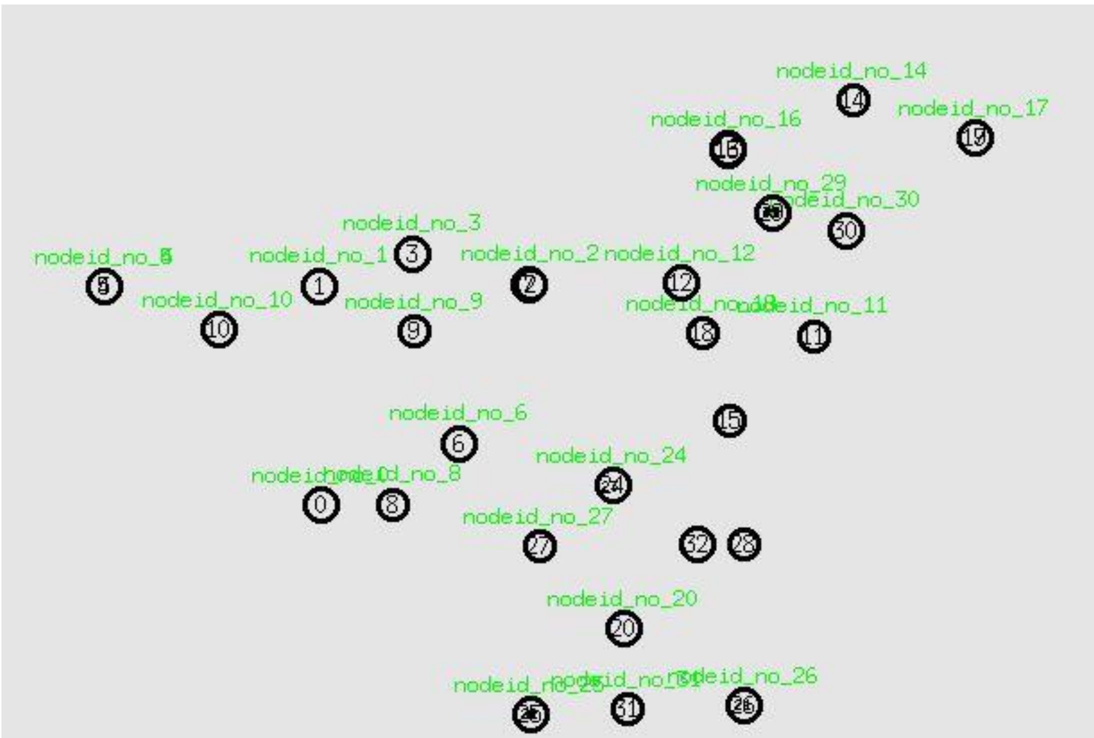

Figure 11: Nodes at start of Simulation

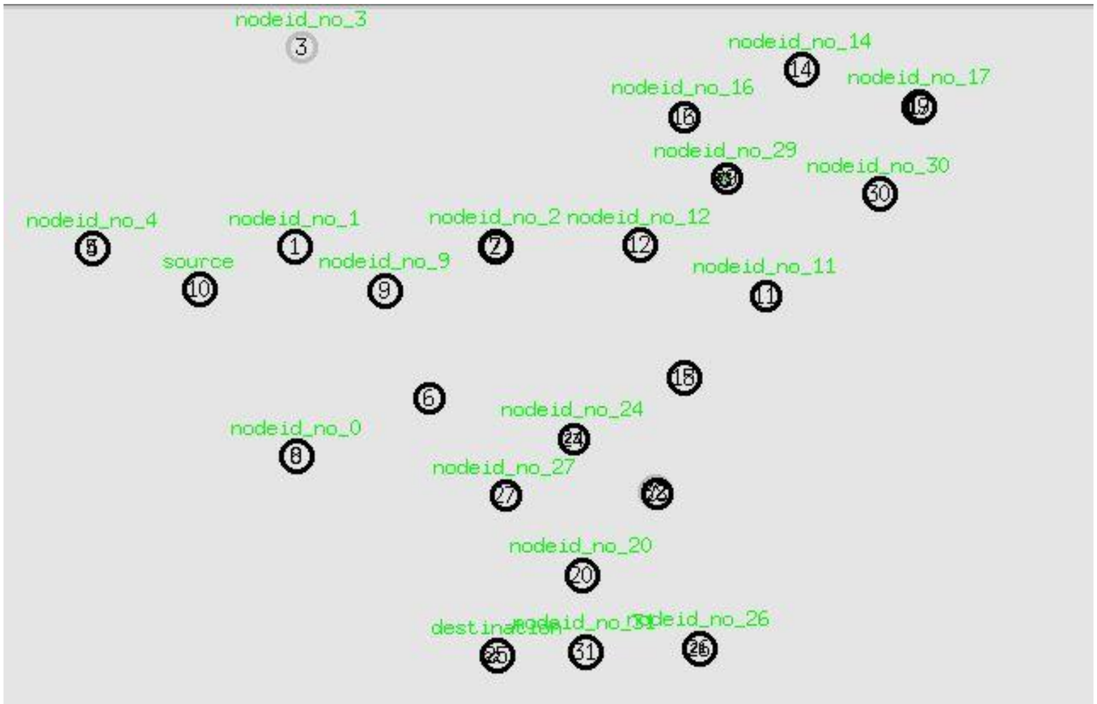

Figure 12: Source and destination nodes identified

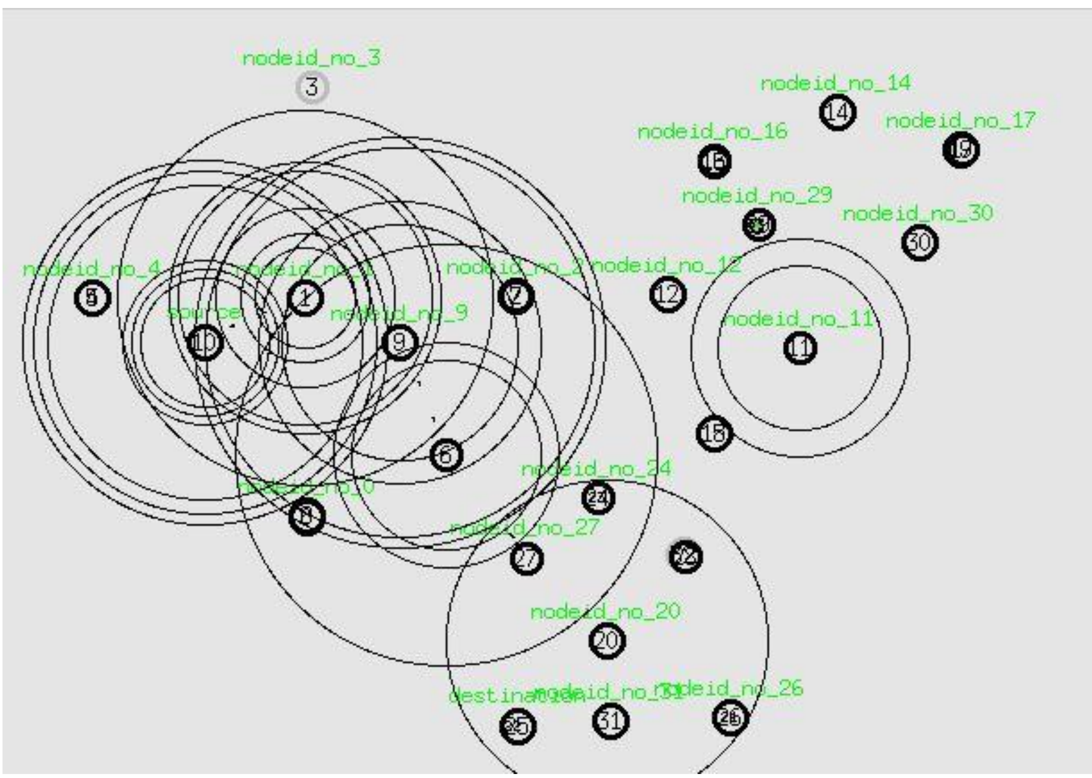

Figure 13: Transmission of the packet from source to destination.

The below screenshot shows the trace file of proposed work in NS-2

```
s -t 0.106360794 -Hs 16 -Hd -2 -Ni 16 -Nx 901.81 -Ny 499.31 -Nz 0.00 -Ne 149.940897 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 13 -Mt 800 -Is
16.255 -Id -1.255 -It IPAOMDV -Il 68 -If 0 -Ii 0 -Iv 29 -P ipaomdv -Pt 0x2 -Ph 1 -Pb 1 -Pd 13 -Pds 0 -Ps 19 -Pss 4 -Pc REQUEST
r -t 0.106380057 -Hs 5 -Hd -2 -Ni 5 -Nx 293.81 -Ny 495.99 -Nz 0.00 -Ne 149.943886 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 4 -Mt 800 -Is 4.255 -
Id -1.255 -It IPAOMDV -Il 68 -If 0 -Ii 0 -Iv 29 -P ipaomdv -Pt 0x2 -Ph 1 -Pb 1 -Pd 2 -Pds 0 -Ps 7 -Pss 4 -Pc REQUEST
r -t 0.106380065 -Hs 7 -Hd -2 -Ni 7 -Nx 296.19 -Ny 494.05 -Nz 0.00 -Ne 149.942878 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 4 -Mt 800 -Is 4.255 -
Id -1.255 -It IPAOMDV -Il 68 -If 0 -Ii 0 -Iv 29 -P ipaomdv -Pt 0x2 -Ph 1 -Pb 1 -Pd 2 -Pds 0 -Ps 7 -Pss 4 -Pc REQUEST
r -t 0.106380066 -Hs 1 -Hd -2 -Ni 1 -Nx 297.00 -Ny 496.00 -Nz 0.00 -Ne 149.943886 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 4 -Mt 800 -Is 4.255 -
Id -1.255 -It IPAOMDV -Il 68 -If 0 -Ii 0 -Iv 29 -P ipaomdv -Pt 0x2 -Ph 1 -Pb 1 -Pd 2 -Pds 0 -Ps 7 -Pss 4 -Pc REQUEST
r -t 0.106380068 -Hs 10 -Hd -2 -Ni 10 -Nx 297.07 -Ny 494.74 -Nz 0.00 -Ne 149.943886 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 4 -Mt 800 -Is 4.255
-Id -1.255 -It IPAOMDV -Il 68 -If 0 -Ii 0 -Iv 29 -P ipaomdv -Pt 0x2 -Ph 1 -Pb 1 -Pd 2 -Pds 0 -Ps 7 -Pss 4 -Pc REQUEST
r -t 0.106380070 -Hs 3 -Hd -2 -Ni 3 -Nx 297.09 -Ny 499.19 -Nz 0.00 -Ne 149.942878 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 4 -Mt 800 -Is 4.255 -
Id -1.255 -It IPAOMDV -Il 68 -If 0 -Ii 0 -Iv 29 -P ipaomdv -Pt 0x2 -Ph 1 -Pb 1 -Pd 2 -Pds 0 -Ps 7 -Pss 4 -Pc REQUEST
r -t 0.106380072 -Hs 8 -Hd -2 -Ni 8 -Nx 297.03 -Ny 491.81 -Nz 0.00 -Ne 149.942878 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 4 -Mt 800 -Is 4.255 -
Id -1.255 -It IPAOMDV -Il 68 -If 0 -Ii 0 -Iv 29 -P ipaomdv -Pt 0x2 -Ph 1 -Pb 1 -Pd 2 -Pds 0 -Ps 7 -Pss 4 -Pc REQUEST
r -t 0.106380072 -Hs 6 -Hd -2 -Ni 6 -Nx 298.13 -Ny 492.63 -Nz 0.00 -Ne 149.943886 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 4 -Mt 800 -Is 4.255 -
Id -1.255 -It IPAOMDV -Il 68 -If 0 -Ii 0 -Iv 29 -P ipaomdv -Pt 0x2 -Ph 1 -Pb 1 -Pd 2 -Pds 0 -Ps 7 -Pss 4 -Pc REQUEST
r -t 0.106380075 -Hs 2 -Hd -2 -Ni 2 -Nx 300.19 -Ny 496.03 -Nz 0.00 -Ne 149.943886 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 4 -Mt 800 -Is 4.255 -
Id -1.255 -It IPAOMDV -Il 68 -If 0 -Ii 0 -Iv 29 -P ipaomdv -Pt 0x2 -Ph 1 -Pb 1 -Pd 2 -Pds 0 -Ps 7 -Pss 4 -Pc REQUEST
r -t 0.106380081 -Hs 9 -Hd -2 -Ni 9 -Nx 301.87 -Ny 494.61 -Nz 0.00 -Ne 149.942878 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 4 -Mt 800 -Is 4.255 -
Id -1.255 -It IPAOMDV -Il 68 -If 0 -Ii 0 -Iv 29 -P ipaomdv -Pt 0x2 -Ph 1 -Pb 1 -Pd 2 -Pds 0 -Ps 7 -Pss 4 -Pc REQUEST
s -t 0.106445065 -Hs 7 -Hd -2 -Ni 7 -Nx 296.22 -Ny 494.05 -Nz 0.00 -Ne 149.942878 -Nl MAC -Nw --- -Ma 0 -Md ffffffff -Ms 7 -Mt 800 -Is 7.255 -
Id -1.255 -It IPAOMDV -Il 126 -If 0 -Ii 0 -Iv 29 -P ipaomdv -Pt 0x2 -Ph 1 -Pb 1 -Pd 15 -Pds 0 -Ps 8 -Pss 4 -Pc REQUEST
```

Figure 14: Trace File in Ns-2 for IP-AOMDV protocol

mywork.tcl

```
set val(chan)   Channel/WirelessChannel    ;# channel type
set val(prop)   Propagation/TwoRayGround   ;# radio-propagation model
set val(netif)  Phy/WirelessPhy            ;# network interface type
set val(mac)    Mac/802_11                 ;# MAC type
set val(ifq)    Queue/DropTail/PriQueue    ;# interface queue type
set val(ll)     LL                         ;# link layer type
set val(ant)    Antenna/OmniAntenna        ;# antenna model
set val(ifqlen) 500                         ;# max packet in ifq
set val(nn)     100                        ;# number of mobilenodes
set val(rp)     IPAOMDV                    ;# routing protocol
set val(mobility) dynamic                  ;# mobility model
set val(maxSpeed) 20                        ;# movement maximum speed [m/s]
set val(x)      1000                       ;# X dimension of topography
set val(y)      1000                       ;# Y dimension of topography
set val(stop)   15.0                        ;# time of simulation end
Mac/802_11 set dataRate_ 11Mb              ;# 802.11 data transmission rate
Mac/802_11 set basicRate_ 1Mb              ;# 802.11 basic transmission rate
set val(energymodel) EnergyModel           ;#Energy set up
Mac/802_11 set aarf_ false                 ;# 802.11 Auto Rate Fallback


set ns [new Simulator]


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


set tracefile [open out.tr w]
```

Figure 15: A Sample TCL Script to Run the IP-AOMDV Protocol

Appendix B: Code Snippets

The below screenshots shows some of the code snippets in NS-2

A) Sample source code for energy threshold checking

```
// IPAOMDV
void
IPAOMDV::recvRequest(Packet *p) {
        struct hdr_ip *ih = HDR_IP(p);
        struct hdr_ipaomdv_request *rq = HDR_IPAOMDV_REQUEST(p);
        ipaomdv_rt_entry *rt;
        IPAOMDVBroadcastID* b = NULL;
        bool kill_request_propagation = false;
        IPAOMDV_Path* reverse_path = NULL;
        struct hdr_cmn *ch = HDR_CMN(p);
        u_int8_t Iface; //Multiple Interface

                      //Energy Threshold Added By Dave
                           double re_energy;
                           iNode = (MobileNode *) (Node::get_node_by_address(index));
                           re_energy=iNode->energy_model()->energy();
                           if(re_energy<Thres_energy){
                           Packet::free(p);
                           return;
                           }
```

Figure 16: Dropping RREQ packets based on energy threshold

B) Sample source code for finding the maximal-minimal nodal residual energy

```
//Find Minimal Nodal Residual Energy -- begin By Dave
double
ipaomdv_rt_entry::path_get_min_re_energy(void)
{
IPAOMDV_Path *path = rt_path_list.lh_first;
double min_re_energy=INFINITY2;

 for(; path; path = path->path_link.le_next) {
   if(path->re_energy < min_re_energy) {
      min_re_energy = path->re_energy;
   }
 }
 return min_re_energy;
}
//Find Minimal Nodal Residual Energy -- end By Dave

//Find Maximal Nodal Residual Energy -- begin By Dave
double
ipaomdv_rt_entry::path_get_max_re_energy(void)
{
IPAOMDV_Path *path = rt_path_list.lh_first;
double max_re_energy=0;

 for(; path; path = path->path_link.le_next) {
   if(path->re_energy > max_re_energy) {
      max_re_energy = path->re_energy;
   }
 }
 return max_re_energy;
}
```

Figure 17: Finding the maximal-minimal nodal residual energy

C) Sample source code for finding the sum of residual bandwidth and calculating average bandwidth

```
//Compute the sum of nodal Residual Bandwidth -- begin By Dave
double
ipaomdv_rt_entry::path_get_sum_re_bandwidth(void)
{
IPAOMDV_Path *path = rt_path_list.lh_first;
double sum_re_bandwidth=0;

 for(; path; path = path->path_link.le_next) {
   if(path->re_bandwidth > min_re_bandwidth) {
      sum_re_bandwidth = path->re_bandwidth_k + re_bandwidth_k+1;
   }
 }
 return sum_re_bandwidth;
}
//Compute the sum of nodal Residual Bandwidth -- end By Dave

//Find Nodal Average Bandwith Calculation -- begin By Dave
double
ipaomdv_rt_entry::path_get_nodal_Avg_bandwidth(int n, double avbw)
{
  double Avg_bandwidth;
  if(n<=m)
        Avg_bandwidth=avbw/n;
  else
        Avg_bandwidth=avbw/m;
  return Avg_bandwidth;
}
double
ipaomdv_rt_entry::path_get_max_Avg_bandwidth(double Avgbw)
{
IPAOMDV_Path *path = rt_path_list.lh_first;
double max_Avg_bandwidth = 0;

 for(; path; path = path->path_link.le_next) {
   if(path->Avgbw > max_Avg_bandwidth) {
      max_Avg_bandwidth = path->Avgbw;
   }
 }
 return max_Avg_bandwidth;
}
```

Figure 18: Finding the sum of residual bandwidth and calculating average bandwidth